STRATEGIC RE-ASSESSMENT OF DISPOSAL SITE SELECTION AND MANAGEMENT OF CONTAMINATED MUD

GEO REPORT No. 87

EVS Environment Consultants

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING DEPARTMENT
THE GOVERNMENT OF THE HONG KONG
SPECIAL ADMINISTRATIVE REGION

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PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. A charge is made to cover the cost of printing.

The Geotechnical Engineering Office also publishes guidance documents as GEO Publications. These publications and the GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
April 1999

FOREWORD

This report was edited from a chapter of the study "Review of contaminated mud disposal strategy and status report on contaminated mud disposal facility at East Sha Chau" by Dr. K.C. Ng of the Geotechnical Engineering Office (GEO). It summarises the assessment of disposal site selection and management of contaminated mud in Hong Kong.

The study was undertaken by EVS Environment Consultants of Canada for GEO of the Civil Engineering Department under Agreement No. CE 68/94. Mr. P.G.D. Whiteside and Dr K.C. Ng of GEO coordinated the study and reviewed the report.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 Background

As with most urban coastlines, requirements for marine disposal of dredged material has increased on a regular basis in Hong Kong in concert with extensive coastal developments, particularly with the increase in reclamation projects in Victoria Harbour. In 1991, the Contaminated Spoil Management Study (CSMS; Mott MacDonald, 1991) identified a major requirement for disposal of dredged material over the next decade, and recommended the use of exhausted marine borrow pits as a short-term disposal option. Subsequently, an exhausted marine borrow pit in Urmston Road was considered to be unsuitable due to high sediment re-suspension (Binnie et al., 1992). After a number of additional marine disposal sites were evaluated, agreement was reached in May 1992 among the relevant government departments, including the Environmental Protection Department (EPD), that contaminated mud should be disposed of in purpose-dredged pits excavated in the seabed at East Sha Chau (ESC) (Figure 1). The site was chosen principally because of the shallow water depth (5 - 6 m) and the relatively low current velocities in the area, as revealed by results obtained from computer modelling (FMC, 1995). The first pit started receiving contaminated mud in December 1992. This decision of site selection was supported by two studies conducted at ESC in early 1993 (CES and Binnie, 1993; Premchitt and Evans, 1993), which were presented to the Legislative Council and the Environmental Pollution Committee (since renamed Advisory Council on the Environment).

A number of pits have been filled but the requirements for disposal of contaminated dredged material continues. Before commitments are made to accommodate future dredged material at ESC, a re-evaluation of the ESC site was deemed necessary to ensure it continues to be the most suitable and environmentally acceptable disposal strategy in light of the London Convention (LC) and the Dredged Material Assessment Framework (DMAF), which was agreed internationally in 1995 and was to be included as a proposed amendment to the LC (IMO, 1995).

The present re-assessment of disposal site selection and management was therefore commissioned to review key elements of the current confined marine disposal program at ESC. A re-assessment of the need for marine disposal and the suitability of the ESC site as the preferred disposal site was desired to ensure that future disposal activities would be continued using the most suitable option.

1.2 Purpose and Objectives of the Review

The purpose of this review was to re-evaluate the present focus on confined marine disposal as a disposal option for dredged material in Hong Kong, to re-evaluate the site selected for the disposal facility, and to evaluate the management structures in place for the disposal program. Specifically, the objectives were to:

- Review the need for marine disposal in Hong Kong.
- Re-evaluate the suitability of ESC as a confined disposal site, identifying the advantages and disadvantages of this site compared to other notional sites.

- Review current decision-making and management strategies at ESC and assess their acceptability in light of new international policies.
- Identify any technical information gaps at ESC that would improve existing environmental management programs currently in place.

1.3 Approach

The CSMS compared predicted volumes of dredged material to available alternatives for disposal as a primary basis for recommending marine disposal. In assessing the need for marine disposal in Hong Kong, the CSMS considered the current needs of dredging and reclamation projects, the potential alternatives to marine disposal, and international criteria and guidelines for marine disposal. A review of the requirements for marine disposal is provided in Section 2.

A review of the suitability of ESC as a confined marine disposal site is provided in Section 3. The review consisted of two stages. In the initial stage, data characterizing notional disposal sites were collected from available literature and through correspondence with the Civil Engineering Department (CED). Data collection was based on the LC (IMO, 1991), an international accord to which Hong Kong is a signatory through the United Kingdom and post-1997 China. By applying this framework, the review ensured that consistent data were obtained for each site, and helped identify important data gaps. In the subsequent stage, a semi-quantitative evaluation of each site was performed based on available data. The evaluation considered the main advantages and disadvantages of each location as possible contaminated mud disposal site(s). Both the environmental impacts observed and the potential human health and ecological risks predicted for ESC have direct bearing on its suitability as a disposal site.

A comparison was also made between the current management program at ESC and the requirements of the DMAF. The steps under the DMAF were compared to management actions in place at ESC. From this comparison and from information on the operations of ESC as a disposal site, technical information gaps were identified.

2 OVERVIEW OF THE NEED FOR MARINE DISPOSAL IN HONG KONG

2.1 Volume of Dredged Material

An essential criterion for determining marine disposal requirements is an estimation of the capacity of existing disposal options versus the predicted volume of dredged material. Figure 2 compares predictions made for total volumes of dredged material in 1991 (Mott MacDonald, 1991) with predictions made in 1995 (FMC Secretariat, 1995).

In 1991, the CSMS predicted the total volume of dredged material in Hong Kong from 1991 to 2006 equalled 381,230,000 m^3. Approximately 6%, or 23,480,000 m^3, of this volume was estimated to be contaminated (i.e., Class C under the sediment classification strategy presented in the CSMS). Peak volumes of material would occur from 1991 to approximately 1995.

As of December 1995, the total volume of dredged material estimated to be produced within a comparable time frame (1991 to 2006) was 426,570,000 m^3 (FMC Secretariat, 1995). Over 8% of this volume was estimated to be contaminated (35,960,000 m^3), to similar levels as Class C above. This is a substantial increase in predicted volumes since 1991, and identifies an even greater need for environmentally acceptable disposal option alternatives. This increase in predicted volumes reflects additional reclamation and other projects planned for the Hong Kong area over the next 10 years. According to Figure 3, the predicted volumes of contaminated material did not reach levels anticipated between 1991 and 1995, and are now predicted to peak at the turn of the century.

In some cases, efforts are being made to reduce the need for marine disposal. The Hong Kong Government's policy to discourage mud dredging (FMC, 1989) is considered an appropriate approach under international requirements of the LC's DMAF which identifies the first question to be "is dredging necessary".

2.2 Land Disposal Options

The land disposal and reclamation options identified in the CSMS included:

- Landfill: The CSMS identified a potential for small volumes of contaminated material to be disposed in the WENT, SENT and Pillar Point landfills. Limitations to this alternative at the time were identified as limited capacity, potential leachate concerns, and higher costs.

  The limitations identified in 1991 by the CSMS remain at issue. Western New Territories (WENT), South Eastern New Territories (SENT) and Northern New Territories (NENT) landfills have been developed as strategic landfills for Hong Kong's solid waste needs and are operated by EPD (EPD, 1995b). The CED-operated Pillar Point Valley landfill identified as a possible disposal site in the CSMS is no longer an available landfill option as it is scheduled to be closed near the end of 1996 (EPD, pers. comm. 1996a). WENT has the greatest capacity and longest operational timeframe of these three landfills. Its capacity is presently estimated as 61,000,000 m^3 (58,800,000 m^3 remaining) with an operational time frame of 25 years (EPD, 1995b, 1996b). The limited capacity of this disposal option is apparent given that the amount of contaminated dredged material over the next 10 years (i.e., 1996 - 2006) is estimated at about 24.5 Mm^3 (FMC Secretariat, 1995).

  The volume of dredged material anticipated in Hong Kong over the next decade cannot be solely handled by landfill sites currently available in the region. The strategic landfill sites in Hong Kong are dedicated to solid waste management, and acceptance of significant volumes of dredged material would rapidly consume capacity dedicated to solid waste management priorities. In principle, only uncontaminated mud is accepted at WENT, SENT, and NENT. Dewatered dredged material (<70% moisture content) may be disposed at these landfills under special approval; however, if moisture content exceeds 70% the waste is classified as "unpermitted" (EPD, 1996b). This moisture content limitation is currently under review by the Hong Kong Government. Waste producers are responsible for assessing the potential environmental and operational impacts associated with the disposal of potentially contaminated waste at strategic landfills. Final approval is based on the recommendations of the landfill management group in EPD. It may be possible that small amounts of highly contaminated material would be assimilated at these landfill sites.

Both WENT and SENT are lined with "state of the art" liners to protect against leachate exfiltration (EPD, 1995b). Landfill gas and leachate are being or will be collected and treated before discharge from the sites. Data are available on the quantity and quality of leachate discharged from the strategic landfills (EPD, 1996b). The higher water content of dredged material may not be treatable under these current engineering designs (e.g., the >70% moisture content limitation), and could raise serious technical concerns related to the volume of dredged material for disposal in the landfill. The impact of contaminated mud disposal on landfill leachate management and treatment systems in use at strategic landfill sites in Hong Kong needs further consideration before this option can be accepted as viable.

Costs of capping (i.e., marine disposal) were estimated to be $18 - 28 per m^3 of dredged material in the CSMS (Mott MacDonald, 1991). Comparatively, there is presently no charge for the disposal of solid waste at Hong Kong landfills but the Government has considered introducing a charging scheme (proposed 1994/95 rate was $43 per tonne [EPD, 1995b]). Current operating costs are $94.37 per tonne (EPD, 1996b). Both of these estimates are above the costs of dredging, transport, and potentially dewatering and more extensive leachate treatment.

- Treatment: Incineration of dredged material contaminated by pathogens (e.g. bacteria) was identified as a potential option in the CSMS. Limitations to this option were the very limited capacity and availability of incineration facilities. Incineration was identified as the only option for sediments highly contaminated with polychlorinated biphenyls (PCB).

  The Chemical Waste Treatment Centre (CWTC) at Tsing Yi has been in operation since 1993, and is equipped with a high temperature incinerator for disposal of chemical waste. Chemical wastes presently collected at CWTC include toxic metals, waste oil, pesticides, spent degreasing solutions and etchants, acids, alkalis and solvents (EPD, 1995b). The capacity of this facility for dredged material is limited as it is designed to treat 100,000 tonnes of chemical waste per year. The facility is intended primarily for chemical waste producers to divert highly contaminated chemical wastes away from landfills (EPD, 1995b). The civic incinerator which has a treatment capacity of only 15,000 tonnes per year may be a possible treatment alternative for dredged material highly contaminated with PCB or other highly toxic organics. Costs of incineration at the CWTC begin at a basic charge of $1,589 per tonne. Costs of physical or chemical treatment of chemical waste begin at a basic charge $573 per tonne (EPD, 1996b). This method has not been used for contaminated mud in Hong Kong (EPD, 1996b). Residual material (e.g., ash) would need to be disposed in a landfill, but quantities would be much smaller.

- Land Reclamation: The CSMS identified land reclamation as a potential long-term disposal alternative for contaminated dredged material. Technical limitations to this 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 quality from leachate and dewatering. Various reports have considered land formation, or poldering, to be a potential long-term disposal option for dredged material (CSMS; FMC, 1989; Whiteside et al., 1990) and potential sites include the southeastern shore of Deep Bay; however, marine disposal at ESC has been more feasible and less problematic for management of operations than land reclamation.

Long-term options for disposal of dredged material or for disposal of highly contaminated material may have to re-examine landfill, treatment and land reclamation options for possible field testing. For example, if poldering warrants serious consideration, currently available information lacks field investigations to assess the potential impacts associated with this option (e.g., contaminant mobility, site stability, dewatering issues). Such investigations could provide a better understanding of these impacts, including locations for land formation projects, sensitive marine resources and human settlements in close proximity (see Table 1).

The CSMS recommended the use of marine borrow pits for confined marine disposal as a short-term solution to accommodate the volumes of contaminated dredged material predicted to peak by 1995. According to recent predictions (see Section 2.1), peak volumes of contaminated material will now occur over the next five years. The FMC (1995) states that technical and environmental studies have been initiated to assess the feasibility of using an exhausted marine borrow pit, located immediately east of the existing contaminated mud pits, for disposal beyond 1997. With an appropriate management program involving such steps as a more intensive site investigation before dredging (to identify more precisely the location of contaminated dredged material and reduce disposal volumes), appropriate sediment quality criteria, and an appropriate sediment classification strategy for highly contaminated material, confined marine disposal may be the most appropriate long-term disposal alternative for moderately polluted dredged material.

Specific details of other disposal options, particularly with respect to highly contaminated material, will be reviewed as part of a separate study to be completed by EVS Environment Consultants.

2.3 International Requirements

The 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 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.

The LC identifies that dredged material can be disposed at sea if:

- The LC Annex I contaminants (e.g., mercury, cadmium) are present as trace contaminants, or can be rapidly rendered harmless by physical, chemical or biological processes of the sea without affecting palatability, or taste, of edible organisms or impacting human health and the marine environment.

- Less than significant amounts of the LC Annex II contaminants (e.g., chromium, lead, zinc, etc.) are present. This condition can be waived if Annex I conditions are met; in such cases, special care measures should be described in the permit.

Disposal management techniques identified in the LC to meet rapidly rendered harmless requirements include:

- Burial on or in the sea floor followed by capping.

- Utilization of geochemical interactions and transformation of substances in dredged material when combined with seawater or bottom sediment.

- Selection of special sites such as abiotic zones.

- Methods of containment such as artificial islands.

According to the above international requirements, confined marine disposal at ESC is appropriate in principle. Post-disposal monitoring is identified as imperative in the LC for any of these options, and is being undertaken at ESC.

3 SUITABILITY OF THE EAST SHA CHAU DISPOSAL SITE

3.1 Review Strategy

The suitability of ESC for continued use as a contaminated mud disposal site was evaluated in relation to other notional sites within Hong Kong's Territorial waters (Figure 1). Sites outside Hong Kong Territorial waters were not considered to be within the scope of this evaluation. Six sites were considered and are listed from east to west:

- Urmston Road

- Deep Bay

- South Tsing Yi

- East Tung Lung Chau and South Tathong Channel

- Tolo Harbour

- Ngau Mei Hoi (Port Shelter)

Although the Urmston Road site is currently unavailable for mud disposal because the borrow pits have been filled with uncontaminated mud, it was included for historical comparative purposes. East Tung Lung Chau and South Tathong Channel were considered a single site in this investigation because of their close proximity to one another and since they will likely have similar site characteristics. Selection of the notional sites was based on a consideration of site characteristics such as location, general features, water depth, proximity to areas of ecological or cultural importance, and water, sediment, and biological characteristics.

3.2 Site Selection Criteria and Evaluation Process

The criteria used to evaluate the potential contaminated mud disposal sites were taken from Annex III to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (IMO, 1991). The LC recommends that the following data be collected as part of an initial site characterization:

1. Location (depth, distance from coast, proximity to important areas, etc.)
2. Rate of disposal
3. Methods of packaging and containment, if any
4. Initial dilution achieved by proposed method of release
5. Dispersal characteristics (e.g., effects of currents, wind and tides)
6. Water column characteristics (e.g., water quality)
7. Bottom characteristics (e.g., topography, sediment quality)
8. Existence and effects of other dumpings

The site evaluation did not consider (2), (3) or (4) above for the following reasons:

- It was assumed that all the sites had adequate capacity to accommodate the anticipated flow of contaminated mud. It was also assumed that the volume of mud dredging is minimized, so the rate of disposal is fixed.

- The form of packaging or containment used during transportation or disposal of the contaminated materials was assumed to be similar and consistent for all sites.

- The initial dilution is dependent on the disposal method used (i.e., equipment, speed and size of vessel; IMCO, 1982). Since a similar disposal method would be used at all potential sites, it was assumed that the initial dilution would be equivalent at all sites apart from the effect of water depth which is considered separately.

The site evaluation process was two-tiered. First, available information in site characteristics was collated and provided in a data matrix (Table 1). The organization of the data matrix was consistent with the site selection criteria derived from the LC. The advantages and disadvantages of each notional site characteristic being evaluated (Section 3.3). Second, a semi-quantitative evaluation was conducted in which characteristics of the notional sites were ranked according to high, moderate, and poor suitability for contaminated mud disposal (Table 2). The evaluation process also considered that unsurmountable disadvantages related to some specific site characteristics (e.g., site inaccessibility during certain seasons) render a site completely unsuitable for disposal of contaminated mud (Section 3.4).

3.3 Site Characteristics

Site characterization data collected during the initial stage of the site evaluation are presented in Table 1.

3.3.1 Location

Contaminated mud disposal sites should be located in an area that will minimize environmental and social impact of the waste, and minimize interference with other current and potential future uses of the sea. Ecologically and socially sensitive areas may include fish nursery areas, bird habitat, amenity areas, historic sites, animal migration routes, fishing areas, and areas of scientific or biological importance. Other potentially conflicting uses of the sea may include reclamations, sand extraction, undersea cables, transportation, and national defence.

General Features

East Sha Chau and the six notional disposal sites are shown in Figure 1:

- The ESC site is located north of Lantau Island, about 1 km north of the Chek Lap Kok Airport reclamation.
- The Urmston Road site is located between Black Point and Lung Kwu Chau. The site was formerly a marine borrow area used as a source of sand for the Tin Shui Wai Land Formation between 1988 and 1990. The site is currently unavailable for use as a contaminated mud disposal site because the marine borrows have since been filled with clean sediments.
- The Deep Bay site is located in a large bay bordering Guangdong Sheng and the New Territories and it opens to the Pearl River Estuary.
- The South Tsing Yi site is located south of the south-eastern tip of Tsing Yi Island. The site is a marine borrow area that has been excavated for a variety of projects including the North Lantau Expressway.
- The East Tung Lung Chau and South Tathong sites are marine borrow pits located east of Hong Kong Island in proximity to Tung Lung Chau.
- The Tolo Harbour site is located in a large embayment which opens to Mirs Bay.
- The Port Shelter site is situated in a partially enclosed water body on the east coast in the vicinity of Sai Kung.

The ESC, South Tsing Yi and East Tung Lung Chau/South Tathong sites are marine borrow areas that have previously been excavated. This is advantageous because limited dredging and mud disposal would be required during pit formation whereas other sites would require extensive dredging in order to excavate pits for confined disposal operations.

Since all of the sites are within a few kilometres of the coastline, they will be influenced by tides, longshore currents, storm surges and variable water salinity due to freshwater runoff. However, the magnitude of the effects will be very site specific, and dependent on a complex of conditions. Further details on the hydrography of the region are provided in Section 3.3.2.

Water Depth

All sites are located in shallow to moderately shallow water (generally less than 40 metres depth; see Figure 4). Shallow water is preferable because it facilitates sample collection, site construction, and disposal operations, and minimizes sediment losses during disposal. The ESC, Deep Bay and Port Shelter sites are located in shallow water (< 10 meters) which makes them preferable to other sites in this regard.

Proximity to Areas of Ecological or Cultural Importance

All sites are in close proximity to areas that are environmentally and/or culturally sensitive. Potential impacts on these areas could occur during transportation and disposal of contaminated spoil, and through resuspension of contaminated mud deposits during and after disposal operations. Impacts may include physical alteration of the seabed resulting in changes in current regime and benthic habitat, ecotoxicological impacts, objectionable odour, visible effects, effects caused by increased sedimentation (e.g., smothering of benthic organisms), noise impacts, and public health concerns (e.g., bacteria, consumption of contaminated seafood) (IMCO, 1982).

The ESC and Urmston Road sites are located within the habitat range of the Chinese white dolphin (*Sousa chinensis*), and important fishing grounds and nursery areas (EPD, 1995a). Both sites are also within reasonable distance to the fish culture facility at Ma Wan and bird roosting grounds at Lung Kwu Chau (EPD, 1995a). The Chinese white dolphin is currently protected under Chinese State Law and Hong Kong Law (Wild Animal Protection Ordinance, Chapter 170, 1976; revised 1992), and under Appendix 1 of the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), and the Hong Kong Government is considering a 1200 ha marine park in the vicinity of ESC and Lung Kwu Chau.

In the vicinity of South Tsing Yi, there are a number of beaches (e.g. Anglers, Genini, Hoi Mei Wan, Casam, and Lido), a fish culture facility on Ma Wan (Ma Wan Fish Culture Zone), and a fish nursery/spawning area situated between Peng Chau and Lantau Island (ERM, 1995; EPD, 1995a).

The Deep Bay area contains important sensitive ecological habitats and cultural amenities including: roosting grounds for many seabirds, intertidal mudflats, oyster farms at Lau Fau Shan, a large mangrove reserve located at the head of the Bay, and recreational facilities (EPD, 1995a). Because of its ecological, scientific, and educational value, several coastal Sites of Special Scientific Interests (SSSIs) (Mai Po Egretry, Mai Po Marshes, Tsiem Bei Tsui, and Pak Nai) and a nature reserve have been designated in Deep Bay (ERL, 1988). Many species of migrating waterfowl use the bay as a stopover during migration, and the intertidal mudflats of the inner bay are an important source of food. Deep Bay is the only area where oyster farms exist in Hong Kong, and in 1987 oyster production was estimated at 200 tonnes per year. The dwarf mangrove communities found in Deep Bay represent the last remnants of communities that were once widely indigenous to southern China. The approximately 600 ha of mangroves in the inner bay provide important habitat for invertebrates, reptiles, fish, amphibians, birds, and mammals, including some rare species (ERL, 1988). The entire bay is also considered a fish nursery by residents; fishermen are forbidden from fishing the area except near Shekou. Shenzhen Special Economic Zone regulations forbid shrimp trawling in the bay. This does not, however, prevent fishermen from operating nets and traps, and some trawling activity does take place (ERL, 1988).

Of the remaining sites, the following ecological and cultural values are recognized:

- The Port Shelter site is located very close to a large recreation area which includes Sai Kung, a number of gazetted beaches, and two marinas. As well, there are a number of small mangroves on Dua Sai Chau (EPD, 1995a).

- The Tolo Harbour site is located close to two fish culture farms, mangrove habitat, and sea bird roosting grounds (EPD, 1995a).

- The East Tung Lung Chau/South Tathong Channel sites are in the vicinity of several gazetted beaches on Hong Kong Island, Cape D'Aguilar marine reserve, Swire Institute of Marine Science (SWIMS), fish culture facilities on Tung Lung Chau and Hong Kong Island, fishing grounds, a marina on the mainland, bird nesting grounds at the Ninepins Group and coral reefs along much of the coastline (EPD, 1995a; Whiteside, pers. comm. 1996). Corals are ecologically important because they provide habitat and food for many organisms. The eastern waters of Hong Kong are also nursery grounds for many species of fish (e.g., scad, golden sardine, grunts, and other species) (Binnie, 1992).

Shipping Lanes

The Urmston Road area receives moderate marine traffic, including high speed ferries that transit North Lantau waters between Sha Chau, Lung Kwu Chau and the mainland enroute to and from China via the Pearl River (Hoffmann, 1995). The ESC site is outside the high speed ferry lane as the northern limit of the ESC facility is the marine traffic limit.

In Deep Bay, a main navigational channel runs through the middle of the bay providing marine access to Shenzhen City. In addition, a dredged channel branches off the main navigational channel towards Shekou (ERL, 1988).

The South Tsing Yi site is located within a very busy shipping channel, surrounded by anchorage buoys and a designated anchorage area (Figure 5), making on-site management of disposal operations impractical.

Other Uses of the Seafloor

A large number of dredging and/or infrastructure projects are in progress around ESC, Urmston Road, and South Tsing Yi sites (Figure 1). These projects may conflict with a contaminated mud disposal site because insufficient seabed may be available. Use of a disposal site, or the excavation and filling associated with these projects, could affect water and sediment quality, or cause changes in the hydrodynamics of the area. If the area is used as an anchorage, the integrity of the constructed cap could be compromised by dragging anchors (Mott MacDonald, 1991). No conflicts are anticipated for Deep Bay, Tolo Harbour, Port Shelter, and East Tung Lung Chau/South Tathong Channel.

Suitability for Transportation

The ease of transport to a site is an important consideration even though it is not a specified factor in the LC (Whiteside et al., 1990). This was included as a site selection criterion for Hong Kong because in Territorial waters, certain sites are of limited utility due to sea state or storm conditions which greatly compromise the safe transport of dredged material from source to disposal site.

In terms of suitability for transportation, the Urmston Road, ESC, South Tsing Yi and Deep Bay sites are all located in relatively protected waters of the western regions, and easily accessible. On the other hand, rough sea conditions occur in eastern waters between September and March when the northeast monsoon prevails (Evans, 1995). These conditions make transport of loaded barges to navigate eastern waters hazardous during the northeast monsoon season (Ng, pers. comm. 1995). In order to reach the Port Shelter, Tolo Harbour, and possibly East Tung Lung Chau/South Tathong sites, barges would have to travel through unprotected waters. Consequently, the Port Shelter, Tolo Harbour, and East Tung Lung Chau/South Tathong sites are fundamentally unable to be secure sites for year-round operation, and therefore are unsuitable sites for contaminated mud disposal. In addition, Tolo Harbour is distant from most dredging activities, resulting in increased transportation costs for disposal.

3.3.2 Water Characteristics

General Features

All of the sites are located in waters which are dynamic and to varying degrees influenced by freshwater runoff. Sites located in western Territorial waters are controlled by discharges from the Pearl River, while sites located in more eastern waters are less influenced by the Pearl River but may still exhibit marked seasonal variations in salinity (e.g., Port Shelter and Tolo Harbour). The East Tung Lung Channel site is influenced predominantly by oceanic waters of the South China Sea, and the hydrography is generally more uniform and stable.

Discharge from the Pearl River has considerable freshwater influence on conditions at sites located in the Pearl River Estuary (i.e., ESC, Urmston Road, South Tsing Yi and Deep Bay). The Pearl River discharges 310 billion m^3 of water and 15 million m^3 of sediment and organic material annually. Approximately 80% of the flow occurs during the summer months. The highly variable flows from the Pearl River cause large fluctuations in salinity, temperature, and suspended solids in the water column at these sites. In the summer, a marked halocline occurs with waters of reduced salinities over denser marine waters. In some shallow areas with poor exchange rates (i.e., Deep Bay), the oxygen levels in the bottom waters can become depleted, resulting in kills of benthic fauna. During the winter, turbulent mixing caused by the strong northeast monsoon breaks down the stratification of the water column.

Water Quality

All the sites are influenced by freshwater runoff, though to different degrees. Large seasonal variations may occur in the salinity, pH, temperature, dissolved oxygen (DO), and suspended solids levels. In addition, waters may become highly stratified when freshwater flows are high. These fluctuations in salinity, pH, temperature, DO, and suspended solids may cause changes in the bioavailability and toxicity of metals. Many metals are more soluble in low salinity water, and thus, sediment-bound metals may be released from the spoil and enter the water column and be accumulated by aquatic plants and animals. In addition, the development of a marked halocline may result in waters of lower oxygen content being trapped below the halocline in areas where bottom currents are weak. Locations which suffer from periodic episodes of low DO content may be more susceptible to negative effects from disposal activities. For example, the increased chemical and biological oxygen demand associated with the spoil could further reduce oxygen levels, and potentially contribute to kills of fish and benthos.

The LC recommended that data on the following water characteristics should be considered:

- Temperature
- pH
- Salinity and stratification
- Suspended solids concentration and composition (if necessary)
- Oxygen indices (biochemical oxygen demand [BOD], chemical oxygen demand [COD], DO)
- Nutrients (if necessary)
- Persistent organic chemicals and metals (if necessary)
- Microbial components (if necessary)
- Productivity

The water quality at ESC has been well characterized (Table 1). As part of the routine monitoring program (CES and Binnie, 1994; Binnie and CES, 1994, 1995), salinity, turbidity, temperature, DO, suspended solids concentration, and pH were measured on a continuing basis. The results indicated that conditions at ESC are seasonally variable, reflecting normal estuarine conditions. Salinity was highest during the winter and lowest during the summer. The water column became highly stratified during the summer months with differences in salinity as high as 20 ppt noted between bottom and surface waters. The water temperature ranged between 16°C and 28°C over a yearly cycle. The DO content of the water was generally between 5 and 8 mg/l, but was variable. Suspended solids concentrations at the seabed occasionally reached 1000 mg/l but exhibited no particular trends. The pH of the water typically varied between 8.1 and 8.4 (Lam, 1994). Biochemical oxygen demand (BOD) and nutrient levels in the North West Water Control Zone (including the ESC area) indicated only moderate levels of anthropogenic contamination (Lam, 1994).

Additional water quality data for ESC and the other notional sites were obtained from Lam (1994) (Table 1). In general terms, the data reflect the following:

- Stratification of the water column occurs at all the sites, but the water column at East Tung Lung Chau/South Tathong Channel is the most stable and uniform.

- The DO content of the surface waters is higher than bottom waters. Some locations (i.e., Tolo Harbour and Port Shelter) periodically suffer from low oxygen levels. If wastes with a high BOD are released into these waters, deoxygenation of the water and sediment may occur.

- The BOD of the water is highest at Deep Bay and Tolo Harbour while lower levels are found at the other locations.

- Nutrient levels are highest in Deep Bay; moderate levels are found at ESC, Urmston Road, Tolo Harbour and South Tsing Yi; and the lowest levels are found at Port Shelter and East Tung Lung Chau/South Tathong Channel.

- Primary productivity levels are generally highest in Tolo Harbour and Deep Bay.

In general ambient physical, chemical and biological water quality characteristics which are preferable for contaminated mud disposal include a stable water column with low seasonal variability in temperature, pH, DO and suspended solids. In addition, the level of suspended solids, biological oxygen demand, nutrients, metal and organic chemicals, and microbial components should be relatively low, and the DO content of the water should be high. Cumulative impacts are of concern at sites already exposed to anthropogenic pollution, or naturally elevated eutrophication levels. However, it is also desirable to offer a high standard of protection to waters which are relatively unexposed to anthropogenic pollution and support a high existing level of ecological or other amenity, such as coral reefs or fishery resources. Based on the potential trade-off of initiating contaminated mud disposal activities at sites with relatively good vs. poor water quality, none of the six notional sites can be considered unequivocally suitable for contaminated mud disposal. The six notional sites were therefore given a rank of moderate suitability for water quality. The ESC site, however, is already established as a successful contaminated mud disposal facility. Long-term and persistent contamination of the water column was not observed and elevations of suspended solids were only observed immediately after disposal events and were small relative to natural fluctuations. Therefore, continued contaminated mud disposal at ESC is not expected to impact water quality.

3.3.3 Dispersal Characteristics

The LC recommends that background data regarding currents, tides, winds, and the stratification of the water column at the potential site be considered because these factors influence the dispersal of contaminated sediments. The stratification of the water column has already been described above. In high energy areas, sediment dispersion will occur and resuspended sediments and associated pollutants may be transported substantial distances. The transport of contaminants away from the sediments is driven by the vertical mixing of the water column (physical transport) and the partitioning of the contaminant between aqueous phases and suspended matter (IMCO, 1982).

Water Currents

An important consideration for site selection is current velocity. Currents should not exceed velocities that cause loss of significant quantities of contaminated material to surrounding areas during disposal, that sediment is not eroded substantially prior to capping, and that cap material will stabilize in place. The site should, therefore, be located in a depositional environment where near-bottom currents are predominantly below the critical speed required to move fine-grained sediment.

The ESC site is located within such an area, characterized by low to moderate current velocities. Current velocity were routinely monitored by CES and Binnie (1994). Sixty-seven percent of current measurements were less than 0.4 m/s; 85% were less than 0.6 m/s; and, about 3% were in excess of 1.0 m/s. These occasionally high currents may cause some resuspension and transport of sediments from the site. The strongest currents occur during the latter part of the spring ebb tides. The ebb tide is generally a southerly flow, whereas the flood flows were generally northerly.

Water currents at the Urmston Road marine borrows pits were fairly strong, particularly during the ebb tide (Binnie et al., 1992). It appears that the area is hydrodynamically complex and very dynamic, and both erosion and accretion occur at different times and locations within the site. During the tidal cycle, considerable quantities of sediment pass into and out of the abandoned borrow pits, but the source of these sediments was uncertain. The eastern regions were particularly susceptible to erosion from strong bottom currents (Binnie et al., 1992).

Current data for the other notional sites were more limited or were unavailable. Current speeds at South Tsing Yi are relatively high. During the dry season, peak surface water velocities (during the spring tide) are about 1 m/s and during dry season are 0.3-0.7 m/s (ERM, 1995). Tidal currents in the vicinity of East Tung Lung Chau/South Tathong Channel are usually less than 0.5 m/s during the dry season spring tide and less than 0.25 m/s during the wet season spring tide (Evans, 1995). Tolo Harbour is characterized by very low current velocities and flushing rates because the narrow channel (Tolo Channel) separating Tolo Harbour from Mirs Bay restricts the movement of water in and out of the Harbour (Oakley and Cripps, 1972; Preston, 1975 [cited in Morton, 1989]). Because of limited flushing, Tolo Harbour may be prone to accumulation of anthropogenic pollutants. Tidal currents in inner Deep Bay reach approximately 0.65 m/s during the spring tide (Peking University et al., 1995).

3.3.4 Sediment Losses During Disposal

Disposal experiments have been performed at both ESC and Urmston Road to estimate sediment losses during the disposal procedure. The amount of loss may be dependent on the physical structure of the spoil and the type of disposal method (barge size, disposal or suction pipe discharge, employment of silt curtains), but site conditions represent more significant major variables, and logically, losses are reduced at sites with shallow water depths and minimal current velocities.

The disposal experiments at ESC and Urmston Road differed in that different equipment and spoil were used. The estimated losses at ESC for a variety of site conditions (current speeds, pit depth), disposal volumes, and particle composition varied between 1.2 and 3.1% of total dry solids dumped for six disposal events (Dredging Research Ltd., 1995). The results of an earlier study carried out in August 1993 in which suspended solids concentrations were measured during a disposal event indicated that under low current conditions, there was little dispersion of silt from the dump site and no sediment plume was visible at the surface (CES and Binnie, 1994). Losses at Urmston Road were significantly higher, being about 6% over a distance of 600 metres from the discharge point, and about 3% over a distance of 300 metres (Binnie et al., 1992). The results were comparable for both bottom disposal and suction pipe discharge. Higher losses at Urmston Road would be expected because of the higher current speeds and the greater water depths associated with the location. Because of the high losses, Binnie et al. (1992) concluded that Urmston Road was unsuitable as a disposal site for contaminated materials.

Potential losses of sediment during backfilling operations at South Tsing Yi were assessed as part of an Environmental Impact Assessment (ERM, 1995). Based on the study results, it was concluded that the sediment plumes associated with disposal of uncontaminated mud were environmentally acceptable. Concerns, however, remain due to potentially unacceptable losses of contaminated sediment (CED and Hydraulics and Water Research [Asia] Ltd., 1993).

3.3.5 Sediment Characteristics

General Features

None of the seabeds in the vicinity of the notional sites contained any notable natural topographic features (Figure 4). Topographical features such as marine channels and shelves in the vicinity of the disposal sites are important because they may affect the waste dispersal pattern. Irregular depressions or unusual sediment composition may also affect the current regime and sediment mobility.

In general, the sediment structure and composition (i.e., particle size, organic carbon content, electrochemical potential, and pH) of the source material for disposal should be as similar as possible to the disposal site receiving environment. Sediment structure and composition can influence the stability of deposited sediments and the solubility of metals and organic pollutants at the site. For example, sediments with low organic carbon content have less capacity to sorb organic chemicals. The organic carbon content of the sediments is lowest at ESC, Urmston Road and Deep Bay.

The seabed at the ESC site is characterized as a 10-20 m layer of clay/silt ("mud") of the Hang Hau Formation overlying alluvial sands and clays of the Chek Lap Kok Formation. At Urmston Road, the sediment composition is highly variable, and includes *in situ* sands and clays, soft trailer-dredged mud, and mixtures of trailer-dredged and grab-dredged alluvial clays and muds (Binnie et al., 1992).

Electrochemical potential (Eh) is a measure of the reduction-oxidation status of bottom sediments. High Eh values indicate generally aerobic conditions, whereas negative values indicate anaerobic conditions. Most marine sediments like much of those in Hong Kong waters are anaerobic with an upper bioturbated and oxygenated surface. However, moderately anaerobic conditions are found in the North Western Water Control Zone (ESC, Urmston Road and South Tsing Yi), Port Shelter, and Outer Deep Bay, while extensive anaerobic conditions are found in Inner Deep Bay and Tolo Harbour (Lam, 1994).

Sediment Quality

Available data on contaminant concentrations, as well as existence of previous disposal and other contaminant sources were reviewed. Metal concentrations measured in bottom sediments from ESC and in the vicinity of the other notional sites suggest that Tolo Harbour and Deep Bay locations are relatively more contaminated (Phillips, 1989; Lam, 1994). In many instances the concentrations exceed targets for Class A sediments based on criteria taken from the CSMS and EPD (1992). For instance, exceedances in Deep Bay were noted for chromium, copper, lead, nickel and zinc (Lam, 1994). CES (1995) also found elevated tri-butyl tin (TBT) levels in sediments from shipyards and marinas at Tsing Yi, Port Shelter (e.g. Marina Cove Marina, Hebe Haven Marina) and Tolo Harbour (Tai Po shipyard) compared to a control station. It should be noted that these samples were taken very close to shore and within shipyards and marinas which are unlikely sites for mud disposal. The level of TBT contamination further from shore is likely to be lower. The sites with generally low to moderate heavy metal contamination include ESC, Urmston Road, South Tsing Yi and East Tung Lung Chau/South Tathong Channel (Lam, 1994; Binnie et al., 1993).

The ESC site has been used as a marine disposal site for contaminated mud since December 1992. Based on data obtained during the baseline investigations, prior to disposal operations, concentrations of trace metals in the sediments at the ESC site were consistently low and usually close to background concentrations or classified as Class A (inert) (CES and Binnie, 1993). The LC recommends that data be collected on existing impacts to biological communities before new or additional disposal operations are considered. Data for ESC are available from ongoing cumulative and compliance monitoring programs (e.g., Binnie and CES, 1994, 1995).

The remaining sites have not been used previously as disposal areas and more extensive sampling and analysis would be required to determine the extent of contamination and associated effects at these sites.

Consideration of sediment quality is important because contaminants already present at the site could interact with new substances introduced in the area (additive/synergistic effects), biological communities may already be stressed and may be less resistant to additional inputs of contaminants, and contaminated sediments may be disturbed during site preparation (i.e., pit formation). Furthermore, the ability to measure effects related to disposal activities may be confounded by contaminant "noise" and potential effects that may already be present at the site. Alternatively, as with water quality, it could also be argued that it is undesirable to introduce new risk to areas which are currently clean. Therefore, none of the six notional sites can be considered unequivocally suitable for contaminated mud disposal based on the trade-off of initiating disposal activities at sites with relatively good vs. poor sediment quality. The six notional sites were thus given a rank of moderate suitability for sediment quality. Continued disposal of contaminated mud of ESC, however, is not expected to impact sediment quality. The ESC site is already established as a successful contaminated mud disposal facility. Metal contaminant concentrations were lower nearest to the ESC disposal pits and were not dispersed from the disposal area. In addition, there is currently strong evidence for limited exposure to contaminants of concern (e.g., metals) from the ESC facility.

Sediment Mobility

The stability of bottom sediments is a function of the sediment composition and the wave and current regime in the area. The contaminated mud pits may remain uncapped for several months, and public concerns have been expressed that water disturbances may be sufficient to remobilize contaminated spoil. Monitoring data at ESC have not supported these concerns. At ESC, the seabed is in a state of long-term equilibrium, with episodes of deposition alternating with periods of erosion. The sediments are relatively stable and are not eroded by tidal currents, but they may erode due to the combined action of waves and currents, or during extreme events such as typhoons (Premchitt and Evans, 1993). As described above, the Urmston Road site is much more dynamic than ESC, with substantial erosion occurring at certain areas. Concerns that these higher current velocities could transport contaminated material a significant distance negated the choice of this location for contaminated mud disposal in 1991 when ESC was selected in preference. A hydraulic modelling study was undertaken in 1993 to assess the stability and losses of dumped spoil at South Tsing Yi (CED and Hydraulics and Water Research [Asia] Ltd., 1993). The study concluded that water flows at the site are complex and significant losses of mud would occur during placement of the mud.

3.3.6 Biological Characteristics

Fisheries Characteristics

Annual fisheries production per ha for 1990 has been estimated by the Hong Kong Agriculture and Fisheries Department for areas adjacent to each of the notional sites using data on annual fish catch and distribution of fishing effort (Leung, pers. comm. 1996) (Table 1). This data was collected through interviews with Hong Kong fishermen using small craft (i.e., less than 15 m in length) during 1989 - 1991. The fisheries production estimates suggest that productivity was relatively low at Deep Bay, Urmston Road and ESC. A moderate level of productivity was estimated for South Tsing Yi, East Tung Lung Chau/South Thang Channel and Port Shelter, and a relatively high productivity was estimated for Tolo Harbour. Note that these production estimates refer to a period before South Tsing Yi became a major sand dredging and subsequently uncontaminated mud disposal area. Smaller craft considered sea conditions generally unsuitable for fishing in the ESC area which is predominantly fished by medium and large vessels, however, no concerns have been expressed by fishermen working in the area.

Benthic Communities Characteristics

Shin and Thompson (1982) examined the benthic community structure at 200 sampling stations in Hong Kong waters during 1976-1977. A comprehensive study was also undertaken for the Lantau Port and Western Harbour Development in December 1991 and June 1992 (Furano, 1992). The benthic community structure at ESC (CES and Binnie, 1993; Binnie and CES, 1994, 1995) and Tolo harbour have also been well characterised (Shin, 1980; Thompson et al., 1980). The results of these investigations suggest that in Hong Kong waters species diversity is generally high and abundance and biomass is low.

3.3.7 Adequate Scientific Basis for Assessing the Consequences of Disposal

The LC specifies that before a disposal permit is issued, the Contracting Parties should consider whether the consequences of disposal operations can be assessed with reasonable certainty. Based on available data regarding site characteristics of the seven sites, the only site which has sufficient data to predict the effects of contaminated mud disposal reliably is ESC. Comprehensive pre- and post-disposal monitoring of the physical characteristics of the ESC site have been undertaken since late 1992 and biological characteristics since mid 1993. This extensive monitoring program now characterizes sediment and water quality, aquatic biota, and ecotoxicology. On-going evaluation and refinement of the ESC program ensure that the most powerful designs have been applied that will detect any potential environmental impacts. The availability of such a significant amount of environmental data for the ESC facility is a considerable advantage compared to any of the notional sites. Achieving a similar level of environmental knowledge and degree of certainty in assessing impacts at these sites would not only require a substantial amount of financial commitments, but also substantial time and effort. Note, however, that for the purpose of conducting the site re-assessment, sufficient qualitative and quantitative information were available for all six notional sites to make final conclusions regarding overall site suitability for contaminated mud disposal.

3.4 Final Assessment and Recommendations

Based on the site characterization data obtained to date, a number of conclusions can be made regarding the relative suitability of the six notional sites and ESC for disposal of contaminated mud. These conclusions are based on both a review and assessment of available site characteristics data (Table 2-1) and a semi-quantitative evaluation of site suitability (Table 2-2). The main conclusions of this study are as follows:

- ESC is ranked as the most suitable location for contaminated mud disposal because: (1) bottom currents are relatively low, (2) anticipated sediment losses during disposal are low, (3) year-round safety of transportation, (4) trade-offs between initiating contaminated mud disposal at new sites with relatively good vs. poor water and/or sediment quality favour continued disposal operations at ESC which have not impacted water and sediment quality, and (5) substantial data are available for site characterization. The disadvantages of the site are its location within the habitat of the Chinese white dolphin and its proximity to fish and prawn nursery areas and inshore fishing grounds. However, there are clear indications that the current contaminated mud disposal facility at ESC is successful. Indicators include the absence of localized ecological impacts and the absence of site-specific risks to humans, dolphins, and fisheries.

- Advantages of the Urmston Road site include its suitability for transportation. However, disadvantages of the site include location within Chinese white dolphin habitat, and high bottom currents which could result in high sediment losses during mud disposal and erosion of the cap material. Field trials determined that because of the strong currents, this site was not likely to be suitable for contaminated mud disposal. In any event, because of its subsequent use to accommodate disposal of uncontaminated mud, the site is now filled.

- Deep Bay is relatively unsuitable for disposal of contaminated mud because of the ecological sensitivity of the Inner Bay, the proximity to inshore oyster farms, and the travel distance for barges loaded with contaminated sediments.

- Advantages of South Tsing Yi include suitability for transportation and the existence of marine borrow pits. However, disadvantages of the site are high levels of transportation traffic which renders it impractical to establish a full-time on-site management office, relatively strong bottom currents and water depth which could cause unacceptable losses of contaminated sediments.

- Advantages of the East Tung Lung Chau/South Tathong Channel site include the existence of marine borrow pits, and a relatively stable water column. The site is fundamentally unsuitable because it is inaccessible for part of the year due to rough sea conditions during the northeast monsoon season. The site is also located in deeper water, and is close to public beaches and bird nesting grounds.

- Tolo Harbour is fundamentally unsuitable because access to the site would not be possible during rough sea conditions which are typical during the northeast monsoon season from September to March. This would increase the risk of accidents for barges loaded with contaminated mud.

- Port Shelter site is fundamentally unsuitable for contaminated mud disposal because it is inaccessible during the northeast monsoon season. Other disadvantages include high recreational value, and transportation difficulties (distance).

Based on the results of this investigation, three of the six notional sites were considered fundamentally unsuitable for contaminated mud disposal: Tolo Harbour, Port Shelter, and East Tung Lung Chau and South Tathong Channel. The other three notional sites (Urmston Road, Deep Bay, and South Tsing Yi) were moderately to poorly suitable and therefore would not be recommended for future consideration, unless updated data from further site assessments were to indicate otherwise. At the present stage of knowledge, the conclusion from this review is that ESC is clearly the most suitable site and is the preferred area for continued disposal of contaminated mud in Hong Kong.

4. East Sha Chau Disposal Management Program

4.1 Acceptability of the Current Management Framework

The current management framework at ESC was reviewed with respect to its acceptability as compared to the newly developed DMAF (Table 3). Although some requirements of the DMAF need only be considered once for a disposal site (e.g., disposal site impact assessment), other requirements may need to be considered on a routine basis (e.g., site monitoring, chemical characterization). Those aspects of the DMAF (Figure 6) which are not incorporated into the ESC program are summarized below.

- Current guidelines for testing of dredged material (Figure 7; WBTC 22/92, 1992) do not require physical testing of sediments prior to dredging.

- Dredged material is not assessed with respect to biological effects prior to dredging and disposal. The DMAF emphasizes the importance of ascertaining whether an adequate basis exists on the characteristics and composition of the material to be disposed and on the potential impacts to marine life and human health. The DMAF suggests that assessments of acute and chronic toxicity, potential for bioaccumulation and potential for tainting be conducted.

- Comparisons to sediment quality criteria, or an "Action List" is limited to seven metal contaminants. Other metals and contaminants such as organics cannot be compared.

- Consideration of beneficial uses for uncontaminated material have not been delineated. This is a guideline of the LC and the DMAF.

- A complete impact assessment of the ESC disposal site was not completed prior to site use. Site information was collected for ESC before disposal, and more extensive studies were completed after initiation of disposal activities (CES and Binnie, 1993; Premchitt and Evans, 1993), serving as a retrospective impact assessment for ESC. Detailed environmental impact assessments are completed for gazetted marine disposal sites (The LC and DMAF require that all disposal sites be assessed for potential impacts).

- ESC permit requirements for compliance monitoring *during actual disposal activities* (e.g., water quality monitoring) are not evident. The DMAF does not explicitly require monitoring during disposal, but identifies that such monitoring is an option of the permitting process. The comprehensive monitoring program in place at ESC addresses the need for compliance monitoring, but does not monitor instantaneous impacts during disposal.

Based on this overview, there are some requirements of the DMAF that are not currently considered within the present disposal program at ESC. Some of these issues may simply require clarification while others may involve incorporating new steps into the management program to ensure that its operations conform to the international guidelines and conventions. Another important aspect of the disposal program at ESC is the operation of the site with respect to methods used in dredging, transport and disposal activities. Methods used in the ESC management program to date have included (FMC, 1995):

- Dredging - grab dredgers.

- Transport - barges (750 m^3 or 1,000 m^3 capacity).

- Disposal - bottom disposal.

- Capping - 1 m of sand following by 2 m of mud, both slowly released by a split hopper barge.

Use of mechanical dredgers and barge bottom disposal should minimize the physical impacts from sediment losses at ESC. These two methods are also compatible (U.S. ACOE and EPA, 1992). No actual assessments were done at ESC to identify appropriate capping procedure for this site prior to disposal. The cap design consolidates over time and additional mud is added to raise the surface level of the pit to the seabed (i.e., maintenance capping). Maintenance capping is also completed based on post-capping monitoring and vibrocore sampling at ESC. Tests done after cap placement showed that the caps had effectively isolated the contaminant from the marine environment (FMC, 1995). The final thickness of the cap may be 4 to 5 m (Whiteside, pers. comm. 1996). Cap integrity and the surrounding seabed is monitored annually for erosional effects from storms using Side Scan Sonar and high resolution Swath Bathymetry, and detailed seismic surveys are also conducted (Ng, pers. comm. 1996a).

4.2 Technical Information and Management Gaps

Most of the disposal site information required by the LC (IMO, 1991) and the DMAF (IMO, 1995) are available from the various government agencies in Hong Kong. No substantial technical information gaps remain for the pits currently in operation. However, some information is currently not available for the ESC site, including (see Table 1):

- Sorption/desorption processes in bottom sediment

- Persistent organic chemicals in bottom sediment (e.g., pesticides)

Although most of the information required by the LC is available for ESC, significant data gaps exist for other sites. It is recommended that establishment of any future disposal sites should consider all of the site information required by the LC prior to disposal of contaminated dredged material.

Section 4.1 identifies steps of the ESC management program which do not meet the new international requirements of the DMAF laid down in December 1995. Incorporation of these steps by CED, EPD or other appropriate agencies into the existing management framework would ensure more effective environmental management at ESC. Other desirable steps that would improve the current disposal program (but are not specifically required in the DMAF) include:

- Detailed sampling of source material (site investigation) to more closely delineate the amount of contaminated material and possibly reduce the amount of material requiring disposal at ESC. This issue will be addressed in a review of regulatory procedures, which is scheduled for completion in August 1996.

- Mixing zone modelling to identify settling rates and travel times for dredged spoil. Information from such a modelling exercise would facilitate estimations of potential and actual loss rates, disposal strategies, and timing for future disposal activities (recommended in EVS, 1994). This information was partially collected in 1995 during monitoring of short-term losses from disposal operations at ESC (DRL, 1995). This study recommended investigations of longer-term, low concentration losses, which will be included as a component of future impact assessments at ESC.

- Identification of ESC as a prohibited anchorage area (recommended in EVS, 1994). The Hong Kong Marine Department have not yet designated ESC as a prohibited anchorage area (Ng, pers. comm. 1996a). The shallow depth at the site would only permit small vessels of about 4 to 5 m draught to anchor at the ESC area. According to CED, anchors from these vessels would be unlikely to cause damage to the ESC caps (which are over 4 m thick); consequently, designation of ESC as a prohibited anchorage area is not a high priority.

- Timing of disposal with respect to water movement to minimize loss (recommended in EVS, 1994). Ensuring barges are properly positioned and at a full stop prior to disposal (recommended in EVS, 1994; DRL, 1995). According to the present on-site procedures, the disposal barge is tied to one of the marker barges as it disposes mud at ESC (Ng, pers. comm. 1996a). The overall disposal management procedures are being reviewed by the consultants currently undertaking the environmental monitoring and audit at ESC.

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TABLES

Table 1 - Summary matrix of available site characteristics data for notional marine disposal sites based on site selection criteria derived from the London Convention (Sheet 1 of 3)

Site Characteristics [a]	*East Sha Chau*	*Urmston Road*	*Deep Bay*	*South Tsing Yi*	*ETLC/STC* [a]	*Tolo Harbour*	*Port Shelter*	*Data Source*
LOCATION								
Water depths	5-6 m	18-22 m	< 5 m	20-42 m	20-30 m	< 20 m	0-10 m	See Figure 2-4
Distance to nearest coastline	< 5 km	< 5 km	< 5 km	< 5 km	< 5 km	< 5 km	< 5 km	
Proximity to areas of ecological, natural beauty, cultural, historical, and scientific importance	Fishing grounds Dolphin habitat Fish nursery Fish culture Seabird roosting Marine park	Fishing grounds Dolphin habitat Fish nursery Seabird roosting Marine park	Beaches Fish nursery Fishing grounds SSSIs Nature reserve Mangroves Seabird habitat Oyster culture	Beaches Fishing grounds Fish culture	Beaches Marina Bird nesting grounds Fish culture Fishing grounds/nursery Marine reserve Swire Insitute of Marine Sci. Coral habitat	Fishing grounds Mangroves Fish nursery Fish culture	Recreational area Beaches Marinas Fishing grounds Mangroves Fish culture Fish nursery	EPD, 1995; ERL, 1988; Binnie, 1992 Whiteside, pers. comm. 1996
Shipping lanes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	ERL, 1988; Hoffmann, 1995; VTPCS [b]
Military exclusion zones	NI	NI	NI	NI	NI	NI	NI	
Other uses of the sea area	Airport Aviation fuel facility Black Point Power Stn. Brothers sewerage Marine borrow areas Mud disposal sites Tuen Muen Area 38	Airport Tuen Muen Area 38 Tuen Muen Port Black Point Power Stn. Brothers sewerage Marine borrow areas Mud disposal sites		Lantau Port Tsing Yi Power Stn. Green Island West Kowloon Recl. Marine borrow areas Mud disposal sites				CED, 1995
Suitability for transportation [c,d]	Good	Good	Moderate	Good	Poor	Poor	Poor	
WATER CHARACTERISTICS [e]								
Stratification (including depth and seasonal variation in pycnocline)	Seasonally variable	Seasonally variable	Seasonally variable	Seasonally variable	Seasonally variable	Seasonally variable	Seasonally variable	CES and Binnie (1994); Lam (1994); Morton (1989)
Temperature (°C)								
Surface	24.2 (15.0-29.9)	24.4 (15.2-29.7)	24.2 (17.7-28.8)	23.0 (17.2-28.5)	23.4 (17.5-27.8)	23.3 (17.2-29.4)	23.7 (17.0-29.7)	Lam (1994)
Bottom	23.0 (14.9-28.5)	23.4 (15.0-28.6)	23.6 (18.3-27.9)	22.3 (17.2-27.2)	21.5 (17.4-26.9)	22.1 (15.6-28.0)	21.6 (16.9-27.3)	
pH	8.2 (8.1-8.4)	8.1 (8.1-8.4)	8.0 (7.4-8.4)	8.2 (8.0-8.4)	8.2 (8.0-8.4)	8.3 (8.0-8.5)	8.3 (8.1-8.4)	Lam (1994)
Salinity (ppt)								
Surface	22.3 (6.2-33.5)	22.7 (8.2-34.4)	20.9 (8.5-30.7)	30.3 (23.6-33.4)	32.9 (25.8-34.6)	30.3 (27.2-32.1)	31.4 (23.7-33.6)	Lam (1994)
Bottom	30.6 (27.6-33.6)	29.8 (24.0-33.4)	26.6 (20.0-32.6)	31.5 (19.4-33.3)	33.2 (27.1-46.8) [e]	32.2 (30.5-33.4)	33.4 (31.3-34.5)	
Dissolved oxygen (% saturation)								
Surface	102 (83-121)	95 (87-101)	94 (72-125)	83 (65-103)	99 (90-123)	105 (65-153)	98 (87-116)	Lam (1994)
Bottom	88 (64-103)	82 (70-92)	Not measured	79 (64-92)	79 (61-95)	53 (15-119)	75 (18-104)	
Biochemical oxygen demand (mg/L)	0.7 (0.4-1.0)	0.6 (0.4-0.9)	1.0 (0.6-2.0)	0.6 (0.2-1.7)	0.6	2.3 (1.0-3.6)	0.6 (0.3-1.5)	Lam (1994)

Table 1 - Summary matrix of available site characteristics data for notional marine disposal sites based on site selection criteria derived from the London Convention (Sheet 2 of 3)

Site Characteristics[a]	*East Sha Chau*	*Urmston Road*	*Deep Bay*	*South Tsing Yi*	*ETLC/STC*[b]	*Tolo Harbour*	*Port Shelter*	*Data Source*
Nutrients (mg/L)								
Total N	0.74 (0.22-1.18)	0.82 (0.57-1.10)	1.47 (0.97-2.46)	0.70 (0.44-1.03)	0.45 (0.38-0.82)	0.71 (0.37-0.99)	0.45 (0.18-1.16)	Lam (1994)
Total P	0.11 (0.05-0.17)	0.14 (0.06-0.25)	0.11 (0.06-0.21)	0.09 (0.04-0.18)	0.10 (0.03-0.27)	0.11 (0.07-0.19)	0.08 (0.04-0.17)	Lam (1994)
Productivity (Chorophyll-a [ug/l])	1.24 (0.43-4.35)	0.71 (0.30-1.70)	2.92 (0.30-16.00)	0.60 (0.33-0.97)	0.88 (0.23-2.43)	5.04 (0.27-22.43)	0.55 (0.27-1.17)	Lam (1994)
DISPERSAL CHARACTERISTICS								
Tidal period, orientation, velocities of minor and major axis	North/south orientation Usually <0.4 m/s	NI	<0.65 m/s during spring tides	1 m/s during dry season spring tides	<0.5 m/s during spring tides	NI	NI	CES and Binnie (1994); Evans (1995); Peking University et al. (1995); ERM (1995)
Mean surface/bottom drift (direction, velocity)	NI	NI	NI	NI	NI	NI	NI	
Storm wave induced bottom currents (velocities)	>1.0 m/s	NI	NI	NI	NI	NI	NI	CES and Binnie (1994)
Wind and wave characteristics	NI	NI	NI	Measured and predicted by model	NI	NI	NI	CED (1993)
Average number of storms per year	Similar for all sites	Similar for all sites	Similar for all sites	Similar for all sites	Similar for all sites	Similar for all sites	Similar for all sites	
Concentration of suspended solids (mg/L)	Generally <100 but may exceed 1000	17.1 (7.7-34.3)	10.6 (5.5-22.0)	12.4 (5-41.8)	2.4 (1.2-5.8)	2.8 (0.6-10.5)	1.6 (0.5-3.7)	CES and Binnie (1994); Lam (1994)
Composition of suspended solids	7 metals monitored	NI	NI	NI	NI	NI	NI	Binnie and CES (1994, 1995)
SEDIMENT CHARACTERISTICS[c,d]								
Major topographic features	None	None	None	None	None	None	None	
Possibility of seismic activity	Low	Low	Low	Low	Low	Low	Low	Ng, pers. comm. (1996c)
Sediment structure	Clay/silt over alluvial sands and clays	Highly variable	NI	NI	NI	NI	NI	Premchitt and Evans (1993); Binnie et al. (1992)
Electrochemical potential (-mV)	76.8-153.1	100-150	150-200	100-150	100-150	200-250	<100	CES and Binnie (1994); Lam (1994)
Mobility of sediments due to waves, tides or currents[e]	Low	Moderate to high	NI	Moderate to high	NI	NI	NI	CES and Binnie (1993); CED (1993) Binnie et al. (1992); ERM (1995)
Sorption/desorption processes	NI	NI	NI	NI	NI	NI	NI	
Trace metal concentrations (mg/kg)								
Chromium	18-26	<25	25-50	<25	25-50	<25	<25	CES and Binnie (1993); Lam (1994)
Copper	10-28	<20	20-65	<20	<20	20-65	<20	
Zinc	<100	75-80	75-80	<75	75-80	75-80	<75	
Nickel	13-22	<20	20-35	<20	20-35	<20	<20	
Lead	22-36	35-65	35-65	<35	<35	35-65	<35	
Mercury	0.05-0.11	0.05-0.08	0.05-0.08	0.05-0.08	-	0.05-0.08	0.05-0.08	

Table 1 - Summary matrix of available site characteristics data for notional marine disposal sites based on site selection criteria derived from the London Convention (Sheet 3 of 3)

Site Characteristics[a]	*East Sha Chau*	*Urmston Road*	*Deep Bay*	*South Tsing Yi*	*ETLC/STC*[h]	*Tolo Harbour*	*Port Shelter*	*Data Source*
Persistent organic chemicals	PAHs and PCBs generally below detection limit	measured[g]	measured[g]	measured[g]	measured[g]	measured[g]	measured[g]	Binnie and CES (1994, 1995); Lam (1994)
Total organic carbon (% wet weight)	<0.5	<0.5	<0.5	0.7-1.0	1.0-1.3	1.0-1.3	>1.3	Lam (1994)
BIOLOGICAL CHARACTERISTICS								
Benthic and epibenthic community characteristics	Adapted to estuarine cond.	Adapted to estuarine cond.	Adapted to estuarine cond.	Adapted to marine cond.	Adapted to marine cond.	Adapted to marine cond.	Adapted to marine cond.	CES and Binnie (1993); Furaro (1992); Shin and Thompson (1982); Shin (1980) etc.
Fisheries production (kg/ha)	35	24	12	102	109	561	208	Leung, pers. comm. (1996)
ADEQUATE SCIENTIFIC BASIS FOR ASSESSING CONSEQUENCES OF DISPOSAL	Yes	No	No	Moderate	No	No	No	

NI - No information available

[a] Adapted from Annex III to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (London Dumping Convention)

[b] Available from Vessel Traffic Port Centre Services, Marine Department

[c] Although the ease of transportation to the site was not included as a LDC criterion, it is an important consideration because certain sites are difficult to access during the monsoon season.

[d] Lam (1994) summarizes water and sediment quality for Hong Kong Terretorial waters. Data from sampling stations close to the potential contaminated mud disposal sites was used in this investigation.

[e] Values have not been verified.

[f] Metal concentrations in sediments at East Sha Chau represent baseline conditions.

[g] PCB and PAH were routinely monitored at various marine locations by the EPD, but these data were not reported by Lam (1994)

[h] Abbreviation denotes East Tung Lung Chau/South Tathong Channel

[i] The notional sites were compared on a relative basis using qualifiers.

Table 2 - Summary evaluation of site suitability based on characteristics of disposal site and site selection criteria derived from the London Convention

Site Characteristics	*East Sha Chau*	*Urmston Road*	*Deep Bay*	*South Tsing Yi*	*ETLC/STC*[1]	*Tolo Harbour*	*Port Shelter*
LOCATION							
Water depths	1	2	1	3	3	2	1
Proximity to areas of ecological or cultural importance	3	3	3	2	2	2	2
Shipping lanes	2	2	2	3	2	2	2
Other uses of the sea area	2	2	1	2	1	1	1
Suitability for transportation	1	1	2	1	X	X	X
WATER CHARACTERISTICS							
Water quality	1	2	2	2	2	2	2
DISPERSAL CHARACTERISTICS							
Water currents	2	3	2	3	2	1	NI
Sediment losses during disposal	2	3	NI	2	NI	NI	NI
SEDIMENT CHARACTERISTICS							
Sediment quality	1	2	2	2	2	2	2
Sediment mobility	2	3	NI	3	NI	NI	NI
BIOLOGICAL CHARACTERITICS							
Benthic community characteristics	1	1	1	1	1	1	1
Fisheries production	1	1	1	2	2	3	2
ADEQUATE SCIENTIFIC BASIS FOR ASSESSING CONSEQUENCES OF DISPOSAL	1	3	3	2	3	3	3
AVERAGE RANK	1.5	2.2	1.8	2.2	X	X	X

[1] Abbreviation denotes East Tung Lung Chau/South Tathong Channel

NI - No information available

Sites were ranked according to high (=1), moderate (=2), and poor (=3) suitability for contaminated mud disposal. A site marked by "X" (=unsuitable) in any of the site characteristics was also considered to be overall unsuitable due to insurmountable disadvantages for disposal of contaminated mud. Based on this process, lower average ranks indicate the most suitable sites.

Table 3 - Summary comparison between the Dredged Material Assessment Framework and the present management program for dredged material at East Sha Chau (Sheet 1 of 4)

Dredged Material Assessment Framework (IMO, 1995)		**East Sha Chau Management Program (from FMC, 1995; EVS, 1994; WBTC, 1992; FMC, 1989)**
Evaluation of Need for Dredging and Disposal		
• Is dredging necessary?	√	Hong Kong Government policy is to discourage mud dredging, and this is actively followed (FMC, 1989).
Dredged Material Characterization		
• Exemptions to characterization	√	No material can be exempted from characterization (WBTC, 1992).
• Physical characterization	X	"Guidelines for sampling and testing of mud to be dredged" (WBTC, 1992) does not explicitly require physical (e.g., amount of material, particle size distribution, specific gravity) testing of sediments prior to dredging.
• Vertical and horizontal chemical characterization	√	"Guidelines for sampling and testing of mud to be dredged" (WBTC, 1992) require chemical characterization of sediments horizontally and vertically, to the dredge depth.
• Biological characterization (if physical-chemical data are inadequate)	X	Dredged material is not routinely assessed with respect to biological effects (e.g., toxicity, bioaccumulation, tainting potential) (WBTC, 1992).
• Comparison to "Action List"	√/X	Characterization data are compared to EPD's sediment criteria; however, criteria are only available for metal contaminants (WBTC, 1992). Organic contaminants are not compared to an "Action List" at this time. The sediment classification strategy currently used in Hong Kong evolved over time, but has been consistently used in decision-making.
• Contaminant source evaluation and control	√	Various regulatory mechanisms and policies are in place to control pollution to Hong Kong's receiving environment (e.g., Water Pollution Control [Sewerage] Regulation, Water Pollution Control Ordinance, the Strategic Sewage Disposal Scheme, etc.) (EPD, 1995b). The effectiveness of source control measures should be continually evaluated.

Table 3 - Summary comparison between the Dredged Material Assessment Framework and the present management program for dredged material at East Sha Chau (Sheet 2 of 4)

Dredged Material Assessment Framework (IMO, 1995)	**East Sha Chau Management Program (from FMC, 1995; EVS, 1994; WBTC, 1992; FMC, 1989)**	
Evaluation of Disposal Options		
• Assess potential beneficial uses	√/X	No information is available to determine whether beneficial uses are assessed for uncontaminated dredged material. This activity should be encouraged, and is a stated requirement of the DMAF.
• For material unsuitable for marine disposal, evaluate alternative management options	√	In Hong Kong, alternative disposal options identified include *in situ* disposal, gazetted marine disposal sites, or confined disposal at ESC. Other options are not readily available for large volumes of low density, high moisture content mud.
Sea Disposal Site Selection		
• Information should be obtained on seabed characteristics, water column characteristics, and proximity to various resources and activities	√	A review of data available is provided in Section 2.3. The site was selected primarily because of its shallow depth and predicted low current velocities (FMC, 1995).
Impact Assessment		
• For a retentive site, impact assessment should delineate the zone of impact, predict severity of impact, estimate timescale for recovery, predict potential for impacts outside of the zone	√/X	Information was collected on site characteristics of ESC prior to disposal (see above). Predictions made included the risk of sediment remobilization from uncapped pits and from erosion of cap material; and modelling of low current velocities (FMC, 1995). More extensive data have been collected at the ESC disposal site since disposal operations began. This information (e.g., CES and Binnie, 1993; Premchitt and Evans, 1993) serves as a retrospective impact assessment for the ESC disposal site, and was accepted by the Hong Kong Advisory Council on the Environment (ACE) (Whiteside, pers. comm 1996).
• For a dispersive site, short and long-term impacts in the near and far-field zone should be considered, and the severity of impacts predicted	N/A	ESC is not a dispersive site. Environmental impact assessments are conducted for gazetted marine disposal sites (i.e., dispersive sites).

Table 3 - Summary comparison between the Dredged Material Assessment Framework and the present management program for dredged material at East Sha Chau (Sheet 3 of 4)

Dredged Material Assessment Framework (IMO, 1995)	East Sha Chau Management Program (from FMC, 1995; EVS, 1994; WBTC, 1992; FMC, 1989)	
Permit Issue		
• Permitting procedure must be in place	√	Licences for marine disposal in Hong Kong are valid for specific time period, dredged material, disposal site and management requirements (see Figure 2-7 for an outline of the permitting process) (WBTC, 1992).
• Surveillance to ensure compliance	√	A 24-h site management team provides close monitoring and control of disposal operations (FMC, 1995).
• Identification of necessary disposal management techniques	√	Disposal management techniques have included closing pits during typhoons [e.g., Typhoon Signal No. 3], adverse weather or other conditions (Ng, pers. comm. 1996a), using a silt curtain (although recent observations indicate this may not be essential [Dredging Research Ltd, 1995]). Other management techniques should be clearly documented.
• Identification of monitoring requirements	√/X	Disposal permits or licences are identified that include special requirements, but no information is provided on disposal monitoring requirements (WBTC, 1992) (see below).
Monitoring		
• Baseline conditions must be adequately understood so that changes can be evaluated	√	Some baseline data were collected prior to disposal of contaminated mud at ESC (CES and Binnie, 1993).
• Compliance monitoring with permit requirements	X/√	Compliance monitoring of environmental quality at the ESC site is done routinely. Compliance monitoring activities during disposal operations (e.g., monitoring suspended sediment concentrations within the silt plume) are not required under ESC disposal permits. Surveillance monitoring of disposal operations is done continuously to ensure operators meet specific operational conditions included in the permit, such as following disposal site coordinates for siting (WBTC, 1992).

Table 3 - Summary comparison between the Dredged Material Assessment Framework and the present management program for dredged material at East Sha Chau (Sheet 4 of 4)

Dredged Material Assessment Framework (IMO, 1995)	**East Sha Chau Management Program (from FMC, 1995; EVS, 1994; WBTC, 1992; FMC, 1989)**	
• Post operational monitoring to determine if the zone of impact differs from that predicted and if the extent of change outside of this zone is within the scale predicted	√	Cumulative monitoring is conducted for the entire ESC area, and pit-specific compliance monitoring is conducted as well. Monitoring program includes sediment, water, biota and ecotoxicology (FMC, 1995).
• Revision of monitoring plan as data become available	√	See Chapter 3

√ The ESC management framework meets the requirements of the DMAF (IMO, 1995).
X The ESC management framework may not fully meet the requirements of the DMAF (IMO, 1995).
N/A Not applicable

FIGURES

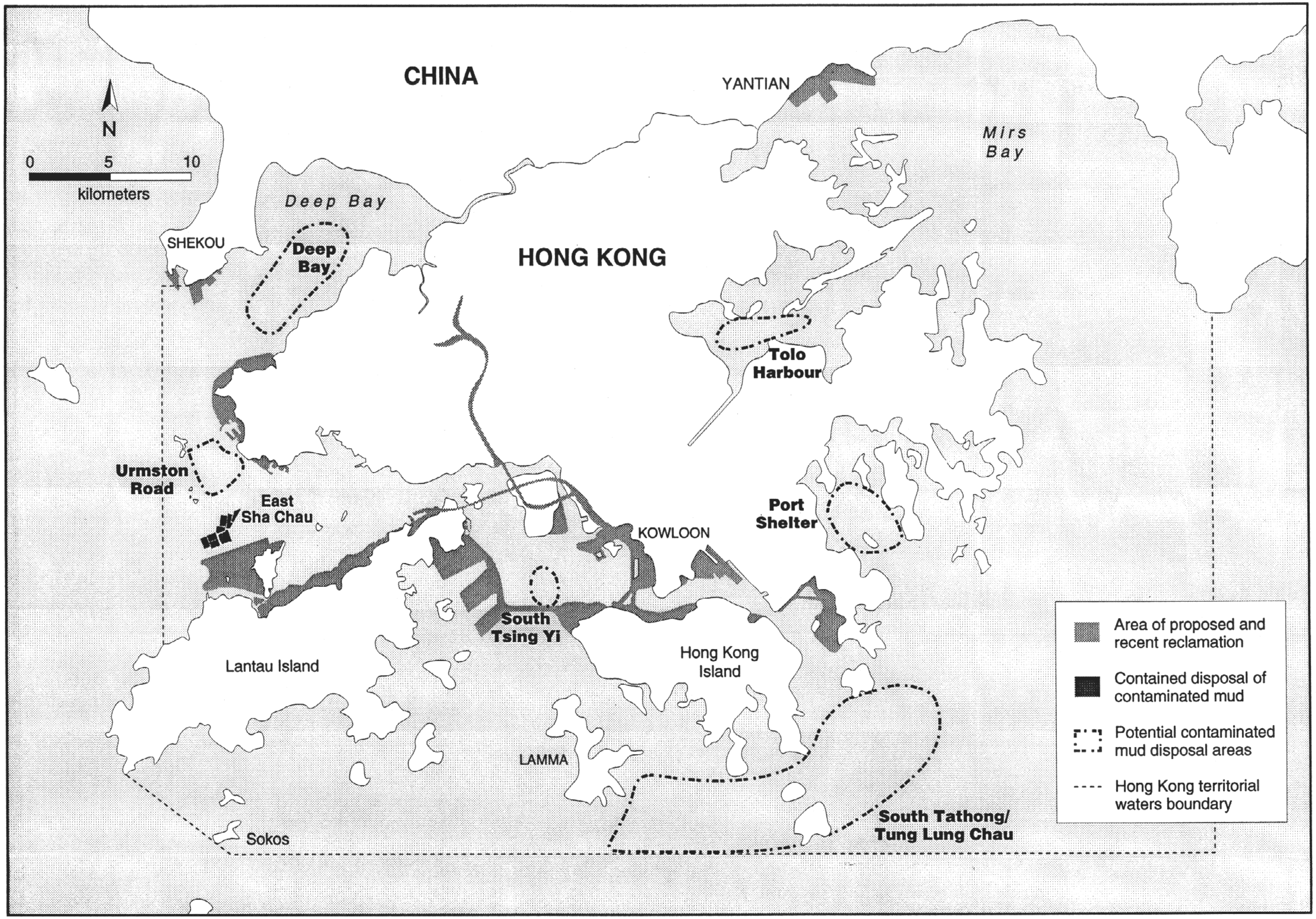

Figure 1. Map of notional marine disposal sites in Hong Kong.

Predicted volumes of dredged material in Hong Kong (1991 and 1995).

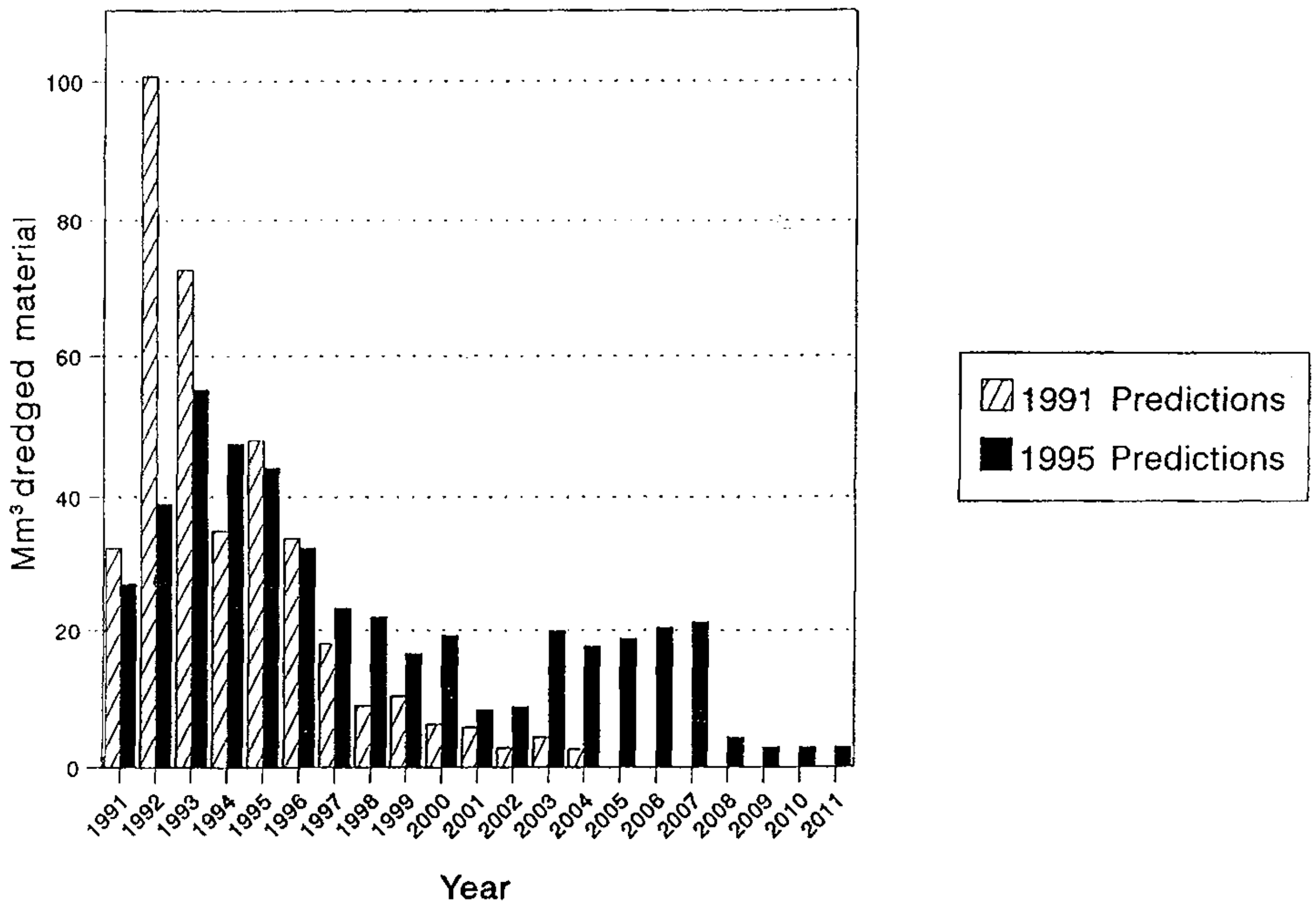

Figure 2. 1991 vs. 1995 predicted volumes of dredged material in Hong Kong. Note that for 1995 predictions, actual amounts are presented for previous years (before 1995).

Predicted volumes of contaminated dredged material in Hong Kong (1991 and 1995).

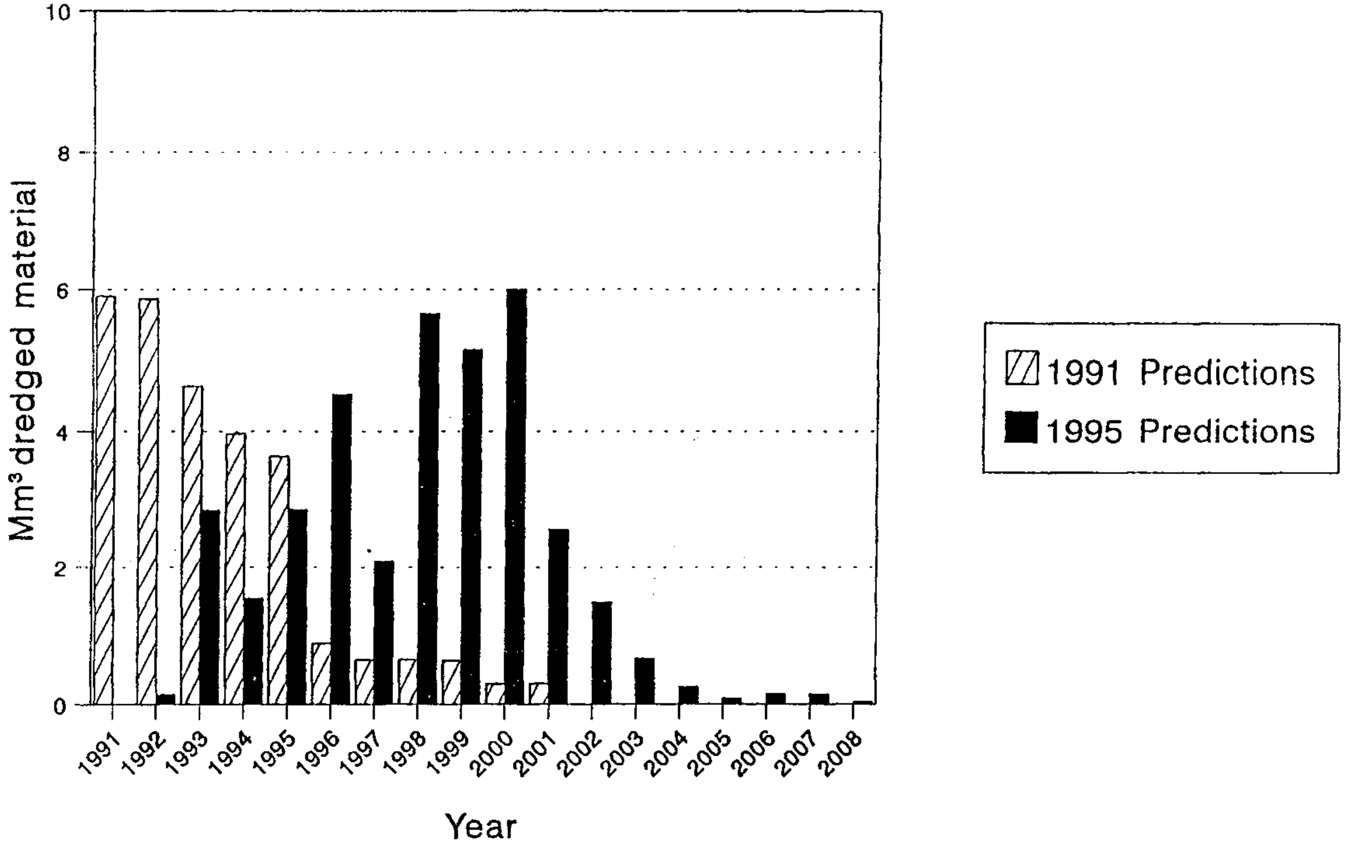

Figure 3. 1991 vs. 1995 predicted volumes of contaminated dredged material in Hong Kong.

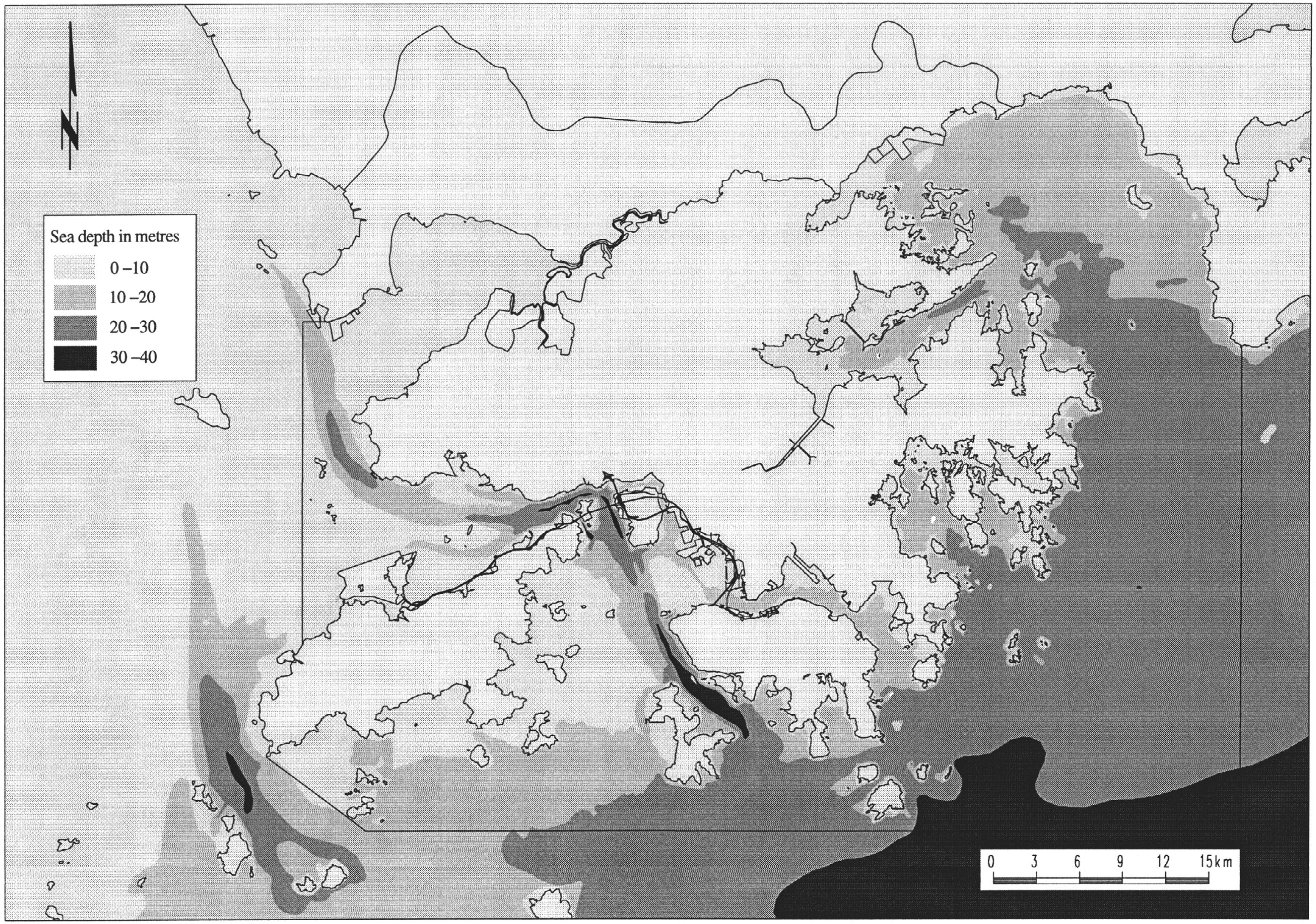

Figure 4. Map of sea depths in the Hong Kong study area.

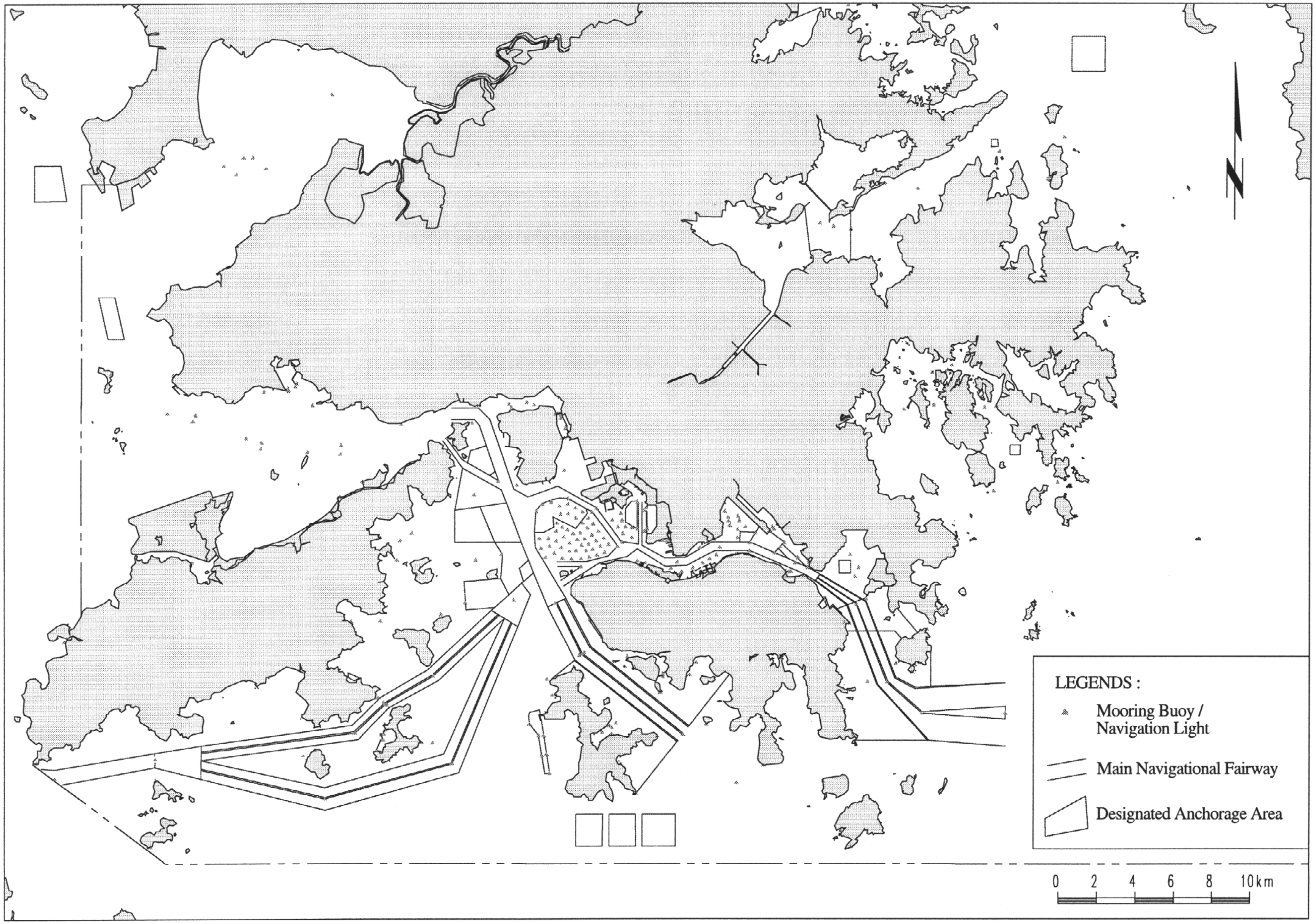

Figure 5. Map of main navigational route and anchorage area in Hong Kong.

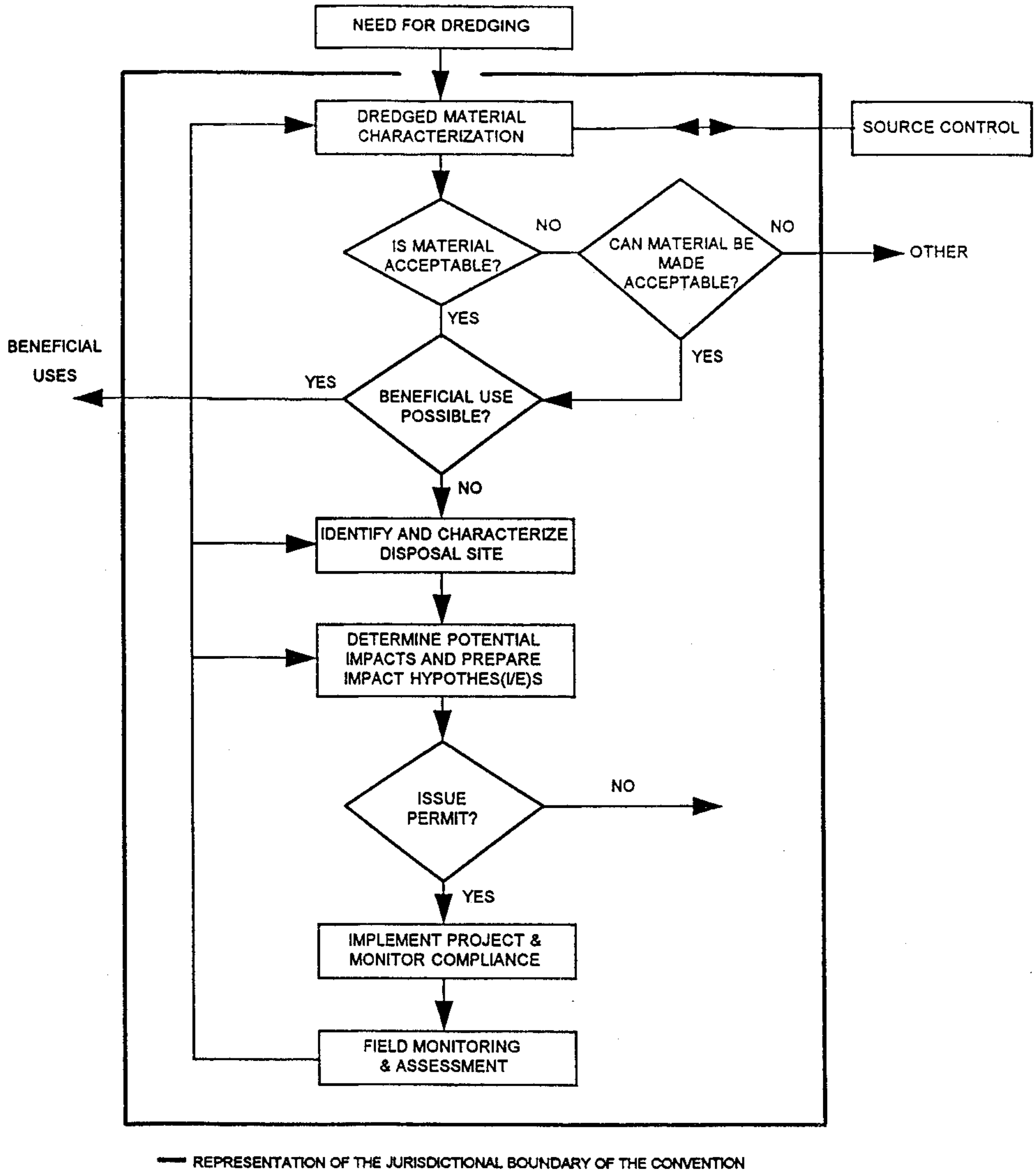

Figure 6. Dredged Material Assessment Framework (DMAF) (IMO, 1995).

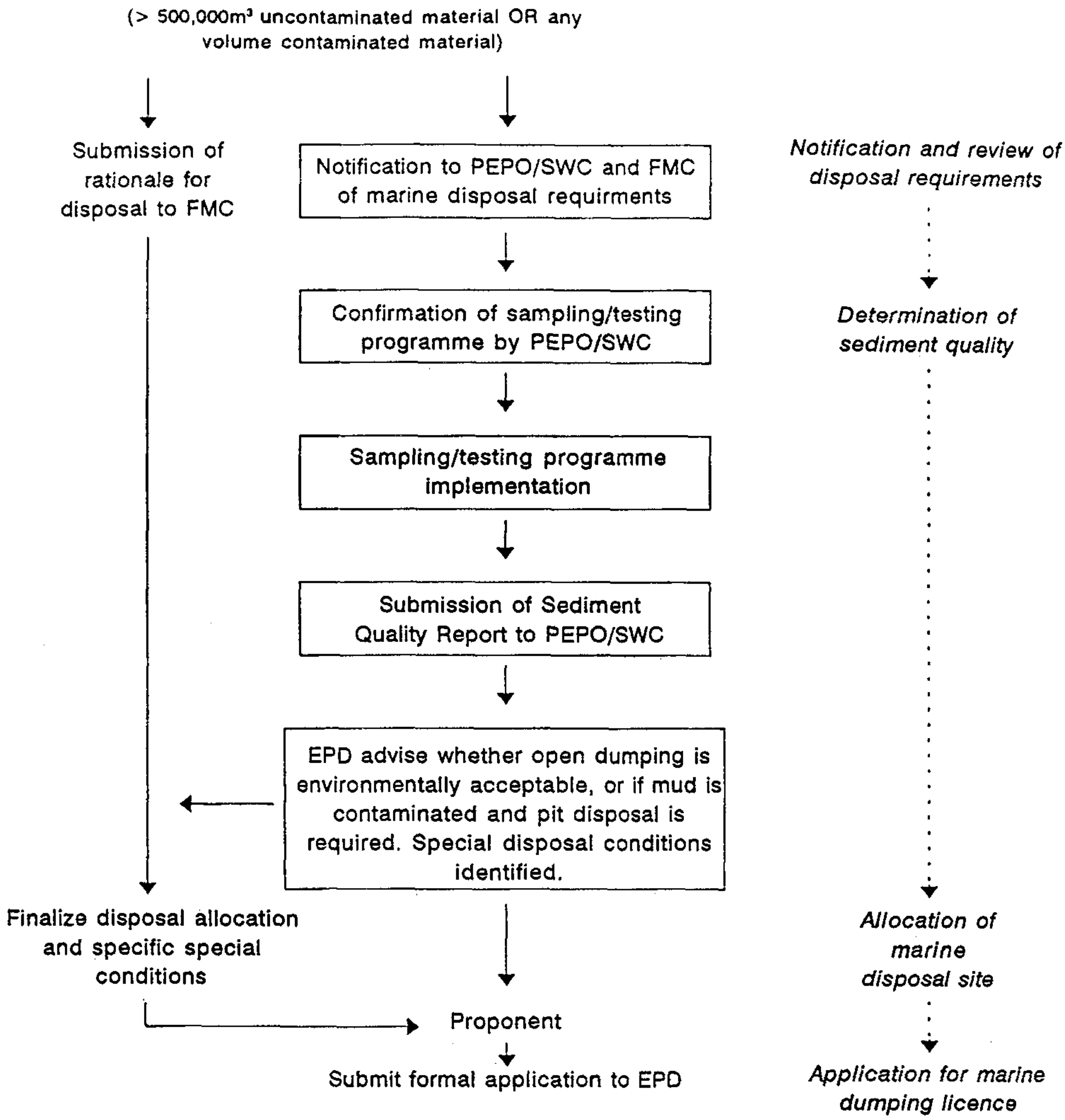

Figure 7. Procedures for works involving the marine disposal of dredged material (from WBTC, 1992).