4. SEDIMENT CONTAMINATION AND DISPOSAL

4.1 Introduction

Chapter 2 illustrated that approximately 2Mm^3 of sediment is likely to be dredged from Tai O Bay in order to facilitate the sheltered boat anchorage development. It has been necessary to determine the quality of this dredged sediment during this Assignment in order to allow the following:

- to determine applicable environmentally acceptable disposal options for excess dredged sediment;
- to determine potential sediment impacts upon water quality during the proposed dredging activities; and
- to determine sediment suitability as a substrate for the establishment of a mangrove planting habitat.

Definition of sediment quality characteristics has been undertaken through a combination of a review of previously obtained data, as well as sediment quality monitoring programmes.

4.2 Sediment Data Review

4.2.1 Previous Sediment Investigations

Prior to this Assignment, there was effectively no contemporary relevant sediment quality data for the Tai O Bay Study Area. Various site investigations have been carried out in Tai O Bay and Creek (i.e. October 1975, February 1976, July 1978, January - December 1983, August 1984 and July 1986 by Wilbur Smith (1987)), although all these investigations were made primarily to investigate the site's geological conditions. Geotechnical sediment testing programmes have also be conducted as part of the on-going sewer improvement programmes, although these have not involved sediment chemical testing (TDD 1998 pers. comm.).

Previous investigations indicate that the sub-surface conditions in Tai O Bay reflect the changes in sea level during the Quaternary Period, with layers of silt and clay sediment alluvial deposits being overlain by recent marine sediments. **Figure 4.1** illustrates a typical geological profile in Tai O Bay and show the presence of the volcanic bedrock (Repulse Bay formation) overlain by completely decomposed volcanics, followed by stratum of alluvium, marine clay, a further layer of alluvium and then the most recently deposited marine sediments. The upper and lower marine deposits are generally consolidated with low strength and high compressibility. The bedrock lies from 30m to 60m below the sediment surface. The marine clay is of medium plasticity which has a plasticity index varying from 25% to 40% and a high moisture content approaching or exceeding the liquid limit.

4.2.2 CED Geophysical Investigation

CED undertook a geophysical investigation of Tai O Bay to map the seabed and the underlying significant geological horizons - data generated were used to facilitate the preliminary sheltered boat anchorage design. The geophysical survey was carried out during the period 8 - 10 July 1998 and involved the use of a seismic profiler and echo sounder. The geophysical survey demonstrated that the base of the marine mud deposit varies from about -3.75mPD at the southern end of the breakwater to about -13.5mPD at the northern end. Elsewhere in Tai O Bay the base of the marine deposits varies typically between -8mPD and -14mPD (refer to **Figure 2.5** and **2.6** for details of site bathymetry and mud deposit levels).

4.3 Sediment Quality Investigations

4.3.1 CED Sediment Investigation

Given the scarcity of available sediment quality data, CED undertook a site investigation in October 1998 which involved the collection and analysis of vibrocore sediment samples as detailed in **Figure 4.2**.

Collected sediment samples were analysed for heavy metals (Cu, Cr, Cd, Pb, Ni, Zn, Hg) in accordance with Works Branch Technical Circular No 22/92. This analysis was undertaken principally to allow applicable sediment disposal options to the defined (refer to Section 4.5). In addition, selected sediment samples were analysed for the following key parameters:

- moisture content;
- particle size distribution;
- Atterburg limits (liquid and plastic limits);
- bulk density; and
- pH.

In addition to the above, a series of boreholes were sunk in March 1999 at key strategic locations around the proposed Tai O sheltered boat anchorage layout.

Appendix 2 presents the results obtained from the analysis of vibrocore sediment samples, whilst data are summarised in **Table 4.1** and illustrated in **Figure 4.3**.

Table 4.1: Summary of Vibrocore Sediment Contamination Testing Data.

	Cu	Cd	Cr	Pb	Ni	Zn	Hg
0.0 - 0.1m							
No of samples	22	22	22	22	22	22	22
Mean	23.5	< 0.5	30.7	31.6	14.9	77.9	< 0.4
SD	18.1	0	13.1	16.3	7.1	36.7	0
0.9 - 1.0m							
No of samples	39	39	39	39	39	39	39
Mean	13.4	< 0.5	24.8	21.3	12.0	55.5	< 0.4
SD	10.2	0	10.1	10.7	5.4	23.2	0
1.9 - 2.0m							
No of samples	40	40	40	40	40	40	40
Mean	12.0	< 0.5	27.5	21.4	14.4	62.2	< 0.4
SD	9.6	0	8.0	6.6	3.9	20.0	0
2.80 - 2.90m							
No of samples	41	41	41	41	41	41	41
Mean	10.7	< 0.5	32.0	24.5	15.1	71.3	< 0.4
SD	4.5	0	8.1	7.5	3.6	16.5	0
5.80 - 5.90m							
No of samples	33	33	33	33	33	33	33
Mean	10.6	< 0.5	30.8	27.4	15.6	64.6	< 0.4
SD	2.4	0	8.9	6.9	3.9	16.6	0
8.9 - 9.0m							
No of samples	11	11	11	11	11	11	11
Mean	10.0	< 0.5	30.9	22.4	21.8	61.9	< 0.4
SD	0	0	3.2	3.0	3.6	11.3	0
11.80 - 11.90m							
No of samples	11	11	11	11	11	11	11
Mean	12.3	< 0.5	26.4	27.0	14.3	44.1	< 0.4
SD	5.2	0	10.4	6.3	7.1	13.6	0
14.9 - 15.0m							
No of samples	6	6	6	6	6	6	6
Mean	12.3	< 0.5	20.3	23.0	12.3	49.5	< 0.4
SD	5.7	0	14.7	6.3	7.3	31.8	0
17.80 - 17.90m							
No of samples	3	3	3	3	3	3	3
Mean	19.0	< 0.5	31.0	27.7	22.3	68.3	< 0.4
SD	8.5	0	22.6	12.5	14.2	42.5	0
All depths							
No of samples	206	206	206	206	206	206	206
Mean	13.0	< 0.5	28.7	24.5	14.8	63.6	< 0.4
SD	9.7	0	9.9	9.5	5.5	23.2	0.1

Table 4.1 illustrates that none of the 206 sediment samples tested contained detectable concentrations of cadmium or mercury (< 0.5 and < 0.4 mg/kg respectively). Sediment copper concentrations ranged between < 3 - 75 mg/kg (mean 13.0 ± 9.7 mg/kg), chromium concentrations ranged from 5 - 58 mg/kg (28.7 ± 9.9 mg/kg), lead concentrations varied between 10 - 78 mg/kg (24.5 ± 9.5 mg/kg), nickel concentrations varied between 4 - 31 mg/kg (14.8 ± 5.5 mg/kg), whilst zinc concentrations varied between 15 - 180 mg/kg (63.6 ± 23.2 mg/kg). Sediment physical data collected during the CED site investigation are detailed in **Appendix 2**, whilst the

sediment texture data are summarised in **Table 4.2**.

Table 4.2: Texture of Sediments from Various Vibrocores Taken in Tai O Bay.

Sample	Depth (m)	Visual Description	Texture (%)		
			Stone (>2mm)	Sand (2-0.063mm)	Silt+clay (<0.063mm)
1 (V1)	1 - 1.9	Silt/clay + shell	1	2	97
2 (V1)	3 - 4	Silt/clay + shell	0	4	96
3 (V3)	1 - 1.9	Sandy silt/clay + shell	0	22	78
4 (V3)	3 - 4	Silt/clay + shell	1	3	96
5 (V5)	1 - 1.9	Silt/clay	0	2	98
6 (V5)	6 - 7	Silt/clay + shell	2	8	90
7 (V5)	15 - 16	Silt/clay	0	8	92
8 (V6)	1 - 1.9	Silt/clay + shell	0	8	92
9 (V6)	6 - 7	Silt/clay	0	3	97
10 (V8)	1 - 1.9	Silt/clayey sand + shell	7	55	38
11 (V8)	3 - 4	Silt/clay + shell	0	3	97
12 (V9)	1- 1.9	Silt/clay + shell	1	3	96
13 (V9)	2.9 - 3.9	Silt/clay + shell	1	4	95
14 (V10)	1 - 1.9	Silt/clay + shell	2	4	94
15 (V10)	2.9 - 3.9	Sandy silt/clay + shell	1	3	96
16 (V11)	1 - 1.9	Silt/clay + shell	1	71	28
17 (V11)	6.9 - 7.0	Silt/clay + shell	1	1	98
18 (V11)	14.9 - 15.7	Silt/clay	1	1	98
19 (V13)	1 - 1.9	Silt/clay + shell	4	31	65
20 (V13)	6.2 - 7.0	Silt/clayey, gravely sand	20	44	36
21 (V14)	1 - 1.9	Silt/clayey, sand +shell	2	54	44
22 (V14)	6 - 7	Silt/clay sand + shell	1	7	92
23 (V14)	15.0 - 15.4	Silt/clay	0	31	69
24 (V15)	1 - 1.9	Sandy silt/clay + shell	2	14	84
25 (V15)	6 - 7	Sandy silt/clay + shell	1	8	91
26 (V15)	15 - 16	Silt/clay + shell	1	4	95
27 (V17)	1 - 1.9	Silt/clay + shell	2	14	84
28 (V17)	3 - 4	Silt/clay + shell	1	9	90
29 (V20)	1 - 1.9	Silt/clayey sand + shell	1	23	76
30 (V20)	2.9 - 3.9	Silt/clay + shell	2	6	92
31 (V23)	1 - 1.9	Silt/clay + shell	2	10	88
32 (V23)	3 - 4	Silt/clay + shell	3	4	93
33 (V26)	1 - 1.9	Silt/clayey, sand +shell	1	24	75
34 (V26)	2.9 - 3.9	Silt/clay + shell	1	3	96
35 (V28)	1 - 1.9	Silt/clay + shell	3	12	85
36 (V28)	6 - 7	Silt/clay + shell	1	3	96
37 (V35)	1 - 1.9	Silt/clayey, sand + shell	2	20	78
38 (V35)	15.0 - 15.9	Silt/clay	0	21	79
39 (V37)	1 - 1.9	Silt/clayey, sand + shell	1	21	78
40 (V37)	6.35 - 7.0	Silt/clay + shell	3	3	94
41 (V37)	14.9 - 15.9	Gravely sand	2	85	13
42 (V38)	1 - 1.9	Silt/clay + shell	1	27	72
43 (V38)	6.3 - 6.9	Silt/clay + shell	0	2	98
44 (V39)	1 - 1.9	Silt/clay + shell	2	60	38
45 (V39)	6.7 - 6.9	Silt/clay + shell	3	5	92
46 (V40)	1 - 1.9	Silt/clay + shell	2	4	94
47 (V40)	2.9 - 3.9	Silt/clay + shell	1	2	97

The observed variations in sediment texture do not appear to be related to either location within Tai O Bay or the sampling depth. Most sediment samples had a high percentage of silt/clay (> 90%), while some samples had around 10-30% sand. The average silt/clay content was 82%, with a range of 13-98%.

4.3.2 Consultants Sediment Investigation

In addition to the above, a focused sediment quality investigation was undertaken by the Consultants in February 1999. Surface sediment samples were collected from four locations (Stations 2, 3, 4 and 6 - refer to **Figure 4.4)** using a Van Veen grab sampler. Sampling locations were positioned using an approved Global Positioning System (GPS) accurate to within 1m. Sediment samples collected were submitted for chemical testing, the results of which are illustrated in **Table 4.3**.

Table 4.3: Sediment Testing Data (mg/kg dry weight unless specified)[1].

Parameter	Detection Limit	Station 2	Station 3	Station 4	Station 6
Moisture content (%)	0.1%	58.4	50.0	32.7	29.7
Ammonia nitrogen	0.4	36.1	22.0	4.2	4.1
Total Kjeldahl nitrogen	2.0	1,154	940	550	341
Total nitrogen	2.0	1,154	940	550	341
Total phosphorus	1.0	553	440	371	313
Total silica	0.01	1,625	963	888	654
pH (pH units)	0.1	7.9	8.1	8.6	8.7
Total sulphides (%)	1%	0.15	0.16	0.14	0.07
Acid volatile sulphides	5.0	81	< 5	26	< 5
Total organic carbon (%)	0.5	1.3	1.2	0.7	0.5
Total inorganic carbon (%)	0.5	< 0.5	< 0.5	< 0.5	< 0.5

Notes:
1 refer to **Figure 4.4** for site locations

4.4 Sediment and Sediment Contaminant Sources

4.4.1 Sediment Sources

The sections above illustrate the presence of marine mud in Tai O Bay that extends to over 10m in depth in some locations. This marine sediment is considered to come from a variety of sources, including the following:

- Tai O Creek;
- effluent discharges;
- surface runoff;
- the Pearl River Estuary; and
- headland erosion.

Studies by Wilbur Smith (1987) concluded that the Tai O River was not carrying a significant amount of sediment - the principal reason being that the Shek Pik catchwater in the centre of the local watershed intercepts approximately 57% of the surface runoff and its associated sediment load. There are also numerous small dams in the upper watershed and weirs upstream of Tai O Road which serve as sediment traps.

Some of the sediments within Tai O Creek and Bay are considered to derive from Tai O village wastewater discharges. Using data presented in **Table 5.8** in Chapter 5, it can be estimated that approximately 25 tonnes of suspended solids are delivered to the Tai O Creek and Bay each year from unsewered Tai O village houses (approximately 68kg/day). Sediment from such wastewater discharges is expected to accumulate predominantly within the confines of the river system where water flows are generally restricted, although a proportion of sediment will be flushed into the bay during storm events, and during the ebb tide. Any sediment delivered into Tai O Bay is expected to accumulate given the prevailing quiescent conditions. Chapter 5 also illustrates that approximately 126 tonnes of suspended solids are delivered to Tai O Bay a year (i.e. 348 kg/day) from urban runoff (refer to data presented in **Table 5.11**). In addition, surface runoff from the surrounding hillsides is also likely to deliver sandy deposits into the bay.

Sediment is also delivered into Tai O Bay by local and regional water currents. Inputs from the Pearl River Estuary may be significant except as may local sediment inputs resulting from the erosion of the headland.

4.4.2 Sedimentation Rates and Maintenance Dredging

Following construction of the Tai O Sheltered Boat Anchorage there will a requirement for periodic maintenance dredging in order to maintain a sufficient water depth to allow boat access.

An accurate prediction of the sedimentation rate in Tai O Bay is not possible given the lack of historic bathymetric data and the number of interacting factors. As indicated in Section 5.9.3, Tai O Bay is not anticipated to receive large volumes of sediment from Tai O village - only about 440 tonnes of sediment are likely to be delivered into Tai O Bay from identified pollution sources each year. This sediment input is equivalent to <1mm per year over the entire Tai O Bay (assuming a dry density of 500kg/m^3), but the sediment is likely to be deposited unevenly leading to a greater rate of sedimentation in areas close to Tai O village.

According to the Port Works Manual - Design, Construction and Maintenance (2nd Edition - December 1996), past records and studies indicate that siltation rates in the general harbour area (including fairways, but remote from outfalls) are in the order of 50mm to 100mm per year. A siltation rate of 50mm per year has also recently been used for the assessment of maintenance dredging requirements in the Tang Lung Chau Dangerous Goods Anchorage (Maunsells, 1999).

We would expect that average siltation rates in Tai O Bay will tend more towards 50mm per year than 100mm per year, but the sediment will inevitably tend to settle preferentially in the dredged channels and anchorage areas. Taking into account the above, it is considered that future maintenance requirements should be tentatively based on a siltation rate of 100mm per year in the dredged areas. This sedimentation rate is equivalent to up to 23,250 m^3 of sediment accumulation a year. Assuming that 0.5m of sedimentation can be tolerated between maintenance campaigns, this suggests that maintenance dredging will be required approximately once every five years and may entail the removal of approximately 120,000m^3 of material.

It is recommended that sedimentation in the dredged areas is carefully monitored during the first few years of sheltered boat anchorage operation in order to establish the requirements for maintenance and, particularly, to identify areas where sedimentation may be taking place at an above-average rate.

4.4.3 Sediment Contaminant Sources

The sections above identify that sediment is delivered to Tai O Bay from a variety of sources, including Tai O Creek, surface runoff and effluent discharges. Of these sediment sources, only the wastewater discharges/surface runoff from Tai O village are anticipated to result in the delivery and accumulation of contaminants. Section 4.5 below illustrates that the sediments within Tai O Bay are uncontaminated, and as such the effect of effluent discharges on sediment quality is limited, although it is noted that in locations closest to Tai O there are elevated contaminant levels in the sediment surface layer (0 - 0.1 m).

In the future, some of the identified sediment contaminant sources will change. Whilst inputs from surface runoff, the Pearl River and headland erosion are unlikely to change significantly, inputs from effluent discharges will change over the next few years due to sewer connection programmes and sheltered boat anchorage development. Whilst the sewerage connection programmes detailed in Section 5.9.2 will reduce the potential for pollutants to accumulate in sediments, discharges from vessels using the anchorage have the potential to increase the surface sediment contamination within the sheltered boat anchorage itself. Whilst it is not possible to state the exact effect of such boat effluent discharges upon sediment quality. Future sediment contamination data are also required in order to allow applicable disposal options to be identified for sediment removed during maintenance dredging events.

4.5 Sediment Disposal Options

4.5.1 Disposal of Excess Dredged Materials

It is expected that approximately 2Mm^3 of dredged materials will be generated by the dredging works and that the vast majority of material will need to be disposed off-site. The materials comprise predominantly marine mud, whilst a small proportion is likely to comprise alluvial deposits. It is currently estimated that approximately 20,000m^3 of material may be placed in the salt pans in order to facilitate the creation of the mangrove habitat (refer to Section 2.8).

In Hong Kong the offshore disposal of sediment is controlled by the Dumping at Sea Ordinance (1995). All works which involve the marine disposal of dredged mud must follow the procedures set out under the Works Branch Technical Circular No 22/92. All aspects of marine disposal are controlled by means of permits issued by the Director of Environmental Protection (DEP).

EPD Technical Circular TC-1-1-92 Classification of Dredged Sediments for Marine Disposal sets out the criteria used to establish whether or not dredged sediment is considered to be contaminated for the purposes of backfilling or placement within designated Marine Borrow Areas. EPD Technical Circular TC-1-1-92 defines three classes of dredged sediments based on the analysis of seven heavy metals as follows (refer to **Table 4.4**):

Class A: Uncontaminated material for which no special dredging, transport or disposal methods are required beyond those which would normally be applied for the purpose of ensuring compliance with EPD's Water Quality Objectives, or for protection of sensitive receptors near the dredging or disposal areas.

Class B: Moderately contaminated material, which requires special care during dredging and transport and which must be disposed of in a manner which minimises the loss of pollutants either into solution or by resuspension.

Class C: Seriously contaminated material which must be dredged and transported with great care and which cannot be dumped in the gazetted disposal grounds and which must be effectively isolated from the environment upon final disposal.

Table 4.4: Sediment Contamination Criteria for Marine Disposal Purposes (mg/kg dry weight).

	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Class A	< 1	< 50	< 55	< 0.8	< 35	< 65	< 150
Class B	1.0 - 1.4	50 - 79	55 - 64	0.8 - 0.9	35 - 39	65 - 74	150 - 190
Class C	> 1.5	> 80	> 65	> 1.0	> 40	> 75	> 200

The Fill Management Committee (FMC) of CED is responsible for the management and allocation of disposal facilities for the disposal of contaminated and uncontaminated sediments. FMC have indicated (meeting 21.10.98) that disposal of uncontaminated dredged material dredged from Tai O can be assumed to be at the North of Lantau Marine Borrow Area (MBA) where the present disposal capacity around 7 - 10 Mm^3. If the capacity of this area, at the time of anchorage construction, is insufficient, any surplus would be directed to the South of Tsing Yi MBA, South of Cheung Chau MBA or other available exhausted marine borrow pits. It is noted that the South of Tsing Yi MBA has been allocated for the development of Container Terminal No. 9 (CT9) - thus the availability of this MBA for the disposal of uncontaminated mud generated during development of the Tai O sheltered boat anchorage can only be considered upon the completion of CT9 reclamation works. The exact location of the sediment disposal ground will need to be discussed with FMC closer to the time of dredging taking into account space availability. Any contaminated sediments need to be disposed of in Pit IV of the contaminated mud disposal facility at East Sha Chau. The locations of potential sediment disposal sites are shown in **Figure 4.5**.

Monitoring of the dredged material disposal will not be required as part of this project since the impacts of disposal operations at the proposed dumping sites (East Sha Chau CMP IV and the North of Lantau/South of Tsing Yi MBAs) have been thoroughly assessed under separate EIAs and monitoring will be implemented as described in their respective EM&A Manuals. Disposal of excess dredged materials is, therefore, not an issue with respect to this Study. However, in view of the limited disposal capacity, it is desirable that the overall design of the project should minimise the volumes of material requiring off-site disposal.

It is noted that the Tai O dredging programme is due to be initiated prior to 31 December 2001. Therefore, the proposed new sediment classification scheme currently being drafted by EPD is not considered to be applicable to the classification of the Tai O dredged sediment arisings.

4.5.2 Disposal of Tai O Dredged Materials

According to the existing sediment disposal criteria as defined in EPD Technical Circular TC-1-1-92 Classification of Dredged Sediments for Marine Disposal, all the material defined as Class A is suitable for open marine disposal. As indicated in Section 4.5.1 FMC have indicated that such material may be directed to the North of Lantau MBA, South of Tsing Yi MBA, South of Cheung Chau MBA or other available exhausted marine borrow pits, although the final decision will be made by FMC closer to the time of dredging.

As illustrated in **Appendix 2,** only three of the 206 Tai O Bay sediment samples tested during this Assignment contained contaminant concentrations in excess of the Class A criteria as presented in **Table 4.4**. Surface sediment samples (0 - 0.1 m) taken from locations V6 and V28 (refer to **Figure 4.2**) contained lead and copper concentrations 3mg/kg and 10mg/kg in excess of the defined Class C criteria, respectively. All the remaining sediment samples tested were of Class A, except one surface sediment sample from V8 which is defined as Class B on the basis of its copper content.

Whilst the sediment data from V6 and V28 are for the very surface sediments, for the purposes of dredging it must be assumed that the contamination extends to a depth of 0.9m below seabed level in both areas. Assuming an allowance of 0.3m for over-dredging, the volume of contaminated sediment to be dredged is estimated to be 22,225m^3 (approximately 1.1% of total dredged sediment volume). This small volume of material should be disposed of to the contaminated mud pits at East Sha Chau - it is estimated that the very low volume of contaminated material can be dredged and disposed of within 1 week.

As indicated in Section 4.4.2, in future sediment contamination sources will change which may have knock-on effects with respect to future sediment quality. Prior to any maintenance dredging of the anchorage and approaches, a focused sediment testing programme should be carried out in order to define applicable sediment disposal methods.

4.6 Sediment Suitability for Mangrove Establishment

It is of key importance that the sediments placed in the salt pans are suitable for mangrove development. It is already known that sediments in the salt pans are suitable for mangrove growth given the occurrence of mangrove stands. In order to determine whether the dredged sediments are of a suitable quality, information regarding the physico-chemical properties of sediments at existing Hong Kong mangrove stands has been investigated and compared to the sediments found at the proposed sheltered boat anchorage site. Relevant studies from outside Hong Kong, particularly within the South China region, have also been reviewed. The sections below consider the suitability of dredged sediment for mangrove habitat creation in terms of texture and chemical characteristics.

4.6.1 Sediment Texture

Mangroves in Hong Kong grow on a wide range of substrate types, from very fine silt/clay mudflats to rocky shores. The silt-clay content of mangrove sediments in important mangrove habitats in Hong Kong (locations and depths of sample collection not specified) has been reported to range from 2.6% to 40.1%, with an average of about 17% (Tam and Wong 1997). However, most other studies both within and outside Hong Kong report a considerably higher level of silt/clay in mangrove sediments. The silt-clay content (particle size <0.01mm) of mangrove sediments along the China coastline has been found to range from 30-85% (Lin 1997). Lee (1988) documented an average of 85% silt-clay content of sediments at a *gei wai* pond dominated by *Kandelia candel* at Mai Po, Inner Deep Bay. Mangroves growing on the mudflats of Inner Deep Bay are among the tallest in Hong Kong, reaching up to 5m, and silt/clay content of those mudflats averages 95.8% (McChesney 1997).

The average percentage of silt/clay content in samples from the proposed anchorage site (82%) is lower than the 85% documented by Lee (1988) at a Mai Po Marshes *gei wai*. It is also lower than the average (95.8%) and range (83.2-99.4%) of the silt/clay content (<0.050mm) found by McChesney (1997) for the Inner Deep Bay mudflats which support Hong Kong's largest stands of *Kandelia candel*, *Avicennia marina*, and *Aegiceras corniculatum*. Finally, it is within the range of silt/clay contents of mangrove substrates examined by Lin (1997) along the China coast (30-85%). Hence, Tai O sediments have silt/clay content well within the range of substrate types demonstrated to be suitable for mangrove colonisation in Hong Kong, particularly western Hong Kong, and thus should be fully suitable for use as a mangrove planting substrate.

The proposed layout plan for the mangrove planting area (refer to **Figure 2.2**) involves breaking some of the former fish pond bunds within the salt pans to improve tidal flushing. About 70% of the internal bunds will be reworked. These bund materials, which are of a sand/gravel texture, will be mixed with sediments dredged from the anchorage site to increase the sand content of the fill material. It was suggested during the early stages of the Study that it might be necessary to mix the dredged material with fine sand to enhance substrate diversity and avoid cracking of clayey mud upon drying. Breaking down parts of the internal bunds and mixing them with the dredged sediments during placement in the salt pans will achieve this objective, whilst reducing the relative proportion of the silt/clay component in the planting substrate and risks of instability.

4.6.2 Chemical Suitability

Some of Hong Kong's most valuable mangrove habitats grow in what may be deemed to be contaminated sediment. In a recent study by Prof. Tam (1998 pers. comm.) sediment samples from 18 mangrove swamps in Hong Kong were analysed for their heavy metal content. Sediments from the ecologically important Mai Po, Lut Chau and Tsim Bei Tsui mangrove areas were found to contain heavy metal concentrations as follows: 80mg/kg Cu, 240mg/kg Zn, 40mg/kg Cr, 30mg/kg Ni, 3mg/kg Cd, 80mg/kg Pb (refer to **Table 4.5**). Such sediments are of Class C contamination according to EPD Technical Circular TC-1-1-92 (refer to Section 4.5.1). Therefore, many of Hong Kong's most ecologically important mangrove habitats are growing on what is deemed to be contaminated material without apparent adverse effects.

Table 4.5: Mean Cu, Zn, Mn and Fe Concentrations in < 63μm Fraction of Hong Kong Mangrove Sediments (mg/kg unless indicated) (Tam and Wong 1998 pers. comm.).

Location	Site	Total Cu	Total Zn	Total Mn	Total Fe (%)
Northeast NT	Sha Tau Kok (STK)	44.3 ± 18.9	94 ± 16	88 ± 9	1.75 ± 0.19
	Lai Chi Wo (LCW)	58.1 ± 68.6	67 ± 22	164 ± 106	2.11 ± 0.33
Tolo Harbour	Sam Mun Tsui (SMT)	58.1 ± 24.4	45 ± 19	53 ± 17	1.83 ± 0.73
	Ting Kok (TK)	25.4 ± 18.2	49 ± 18	86 ± 42	1.20 ± 0.30
	Tolo Pond (TP)	28.3 ± 15.9	118 ± 23	147 ± 40	1.88 ± 0.19
Sai Kung	Nai Chung (NC)	68.5 ± 37.7	212 ± 125	64 ± 11	1.89 ± 0.25
	Sai Keng (SK)	26.8 ± 21.6	49 ± 17	70 ± 33	1.28 ± 0.49
	Kei Ling Ha (KLH)	18.9 ± 16.1	59 ± 9	116 ± 32	1.98 ± 0.22
	Hoi Hai Wan (HHW)	1.1 ± 1.4	71 ± 37	52 ± 9	1.05 ± 0.25
	Ta Tan (TT)	11.3 ± 10.9	76 ± 48	72 ± 16	1.41 ± 0.25
	Chek Keng (CK)	11.2 ± 9.1	79 ± 20	105 ± 93	1.62 ± 0.43
	Tai Wan (TW)	23.3 ± 14.6	68 ± 19	72 ± 16	1.84 ± 0.33
	Ho Chung (HC)	37.8 ± 6.9	153 ± 33	113 ± 32	1.68 ± 0.42
Deep Bay	Mai Po (MP)	82.1 ± 19.5	233 ± 41	273 ± 34	3.62 ± 0.62
	Lut Chau (LC)	69.3 ± 19.3	214 ± 42	197 ± 29	3.19 ± 0.43
	Tsim Bei Tsui (TBT)	46.0 ± 13.5	218 ± 44	416 ± 75	3.58 ± 1.31
Lantau Island	Tai Ho Wan (THW)	29.8 ± 7.1	76 ± 9	192 ± 22	2.59 ± 0.39
	Yi O (YO)	26.0 ± 24.0	72 ± 18	170 ± 54	3.31 ± 0.21

Measured levels of metals within sediment at the sheltered boat anchorage site fall comfortably within the range in which mangroves are documented to grow in Hong Kong. Sediment quality data presented in Section 4.3 and **Appendix 2** thus illustrate that the metal content of the sediment to be dredged from Tai O Bay does not represent a constraint on the mangrove habitat creation scheme.

4.6.3 pH, Nutrients and Organic Matter

Tam and Wong (1997) did not measure the pH of substrate soils in their study of Hong Kong mangroves. They did, however, measure pH levels of pore water in 16 Hong Kong mangrove stands. Measured pH values varied from 6.10 to 8.54, with mean levels of 6.46 to 8.12. The sediment samples taken from the sheltered boat anchorage site had pH values somewhat higher than this, ranging from 7.9 to 8.7 (**Table 4.3**). Lin (1997) reported that the pH of major mangroves stands in China varies from 3.0 to 8.0. Moreover, mangroves tend to acidify soils over time through decomposition, which releases sulphate compounds (Lin 1997). The pH of the sediments at the anchorage site are thus not considered to be a constraint to mangrove growth; while the pH of sediments used in the mangrove planting area will in any case gradually decrease over time as the mangrove community becomes established.

Nutrient levels (total N and total P) of the sediment samples (**Table 4.3**) fall within the range of values recorded in major mangrove stands in China (Lin 1997). Total organic carbon concentrations in the Tai O sediment samples were lower than levels recorded in Inner Deep Bay (Lee 1988, McChesney 1997). The review of the available literature does not indicate that nutrient or organic matter levels of the substrate are essential factors for mangrove establishment. In fact, the clay content of mangrove sediments has been found to be positively correlated with nutrient levels due to nutrients binding by the clay (Lin 1997). This is one reason why mangroves function as nutrient sinks, removing organic matter and pollutants from the water. The relatively high clay content reported for the Tai O sediment samples will help to bind nutrients in the mangrove planting area and increase nutrient levels in the sediment.

4.6.4 Overview

The texture of the sediment to be dredged from the Tai O sheltered boat anchorage site has been compared to that of existing mangroves in Hong Kong and China and found to be wholly suitable in terms of particle size distribution for the growth of mangroves. Similarly, sediment metal content, pH, nutrient and organic matter content have been found to be within the acceptable range for mangrove growth. In summary, the sediments are considered to be entirely suitable for use in creating a mangrove planting substrate in the salt pan area.

4.7 Conclusions

The sections above have illustrated the following key conclusions with respect to sediment quality:

- the sediment testing programme has illustrated that the vast majority of the $2Mm^3$ of material that may be dredged to facilitate the development of the Tai O sheltered boat anchorage are of Class A and thus suitable for open marine disposal. FMC have indicated that such material may be directed to the North of Lantau MBA, South of Tsing Yi MBA, South of Cheung Chau MBA or other available exhausted marine borrow pits, although the final decision will be made by FMC closer to the time of dredging;

- surface sediment samples (0 - 0.1 m) taken from two locations contained lead and copper concentrations slightly in excess of the defined Class C criteria. The total volume of contaminated sediment is estimated to be $24,500m^3$ (1.2% of total dredged sediment volume), assuming that contamination extends to a depth of 0.9m below seabed level and an allowance of 0.3m for over-dredging. This small volume of contaminated surface sediments should be disposed of to East Sha Chau Pit IV;

- the physico-chemical characteristics of the sediment to be dredged from the Tai O sheltered boat anchorage site have been compared to sediments at existing mangroves in Hong Kong and China. This comparison illustrate that the Tai O sediments are wholly suitable for the creation of a mangrove habitat.