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ADVISORY COUNCIL ON THE ENVIRONMENT
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(for information)

Territory-wide Measurement of the Physical and Ecological Effects of Dredging and Dumping

PURPOSE

To update Members on the progress of studies into the overall effects of dredging and dumping activities in Hong Kong waters, and to present some background information on the fundamental physical and ecological processes taking place.

BACKGROUND

2. At the EPCOM meeting of 22 February 1993, members were briefed by the Geotechnical Engineering Office (GEO) of the Civil Engineering Department (CED) on the various sand dredging activities in Hong Kong waters. Members inquired whether any studies of the overall cumulative impacts of these works had been carried out. It was explained to Members that predictive computer modelling techniques could not be applied to the whole of Hong Kong, but that the Territory-wide situation was being monitored. Members asked to be regularly updated on the progress of these studies. The last update was in March 1994, when ACE Paper 8/94 was considered.

PHYSICAL STUDIES

3. The physical studies are providing information on the levels of suspended sediment throughout the water column, and on sea bed conditions and processes. A variety of survey methods are being used to gauge the effects that dredging and dumping are having on suspended solids levels and on the sea bed. In order to assess the possible impacts of human activities on the physical processes taking place it is also necessary to study the natural water circulation and sedimentation patterns.

Natural water circulation and sedimentation patterns

4. The effects of dredging and dumping should be viewed in the context of the natural processes which are operating in the region. Water circulation patterns, natural sediment flux and storm impacts, inter alia, have to be considered.

Water circulation patterns

4.1 The waters adjacent to Hong Kong can be divided into three general regions: the oceanic waters in the offshore region, the seasonal fluvial and tidal current dominated Pearl estuary and the tidal current dominated coastal waters. The oceanic currents are driven mainly by the monsoon winds, with currents from the ENE in the winter dry season (October through April/May) and from the WSW in the summer wet season (May/June through September). The boundary between oceanic and coastal tidal flow is probably transitional and locally variable, but has been defined in the Hong Kong South area as lying between 1 and 3.3km south of Lamma Island.

4.2 Tidal currents in Hong Kong waters are generally relatively weak, with strong flows restricted to a few narrow channels such as Kap Shui Mun/Ma Wan and Lei Yue Mun. There appears to be a net westerly component to the tidal flow in the coastal waters, inducing a flushing effect through Hong Kong from East to West. The river discharge from the Pearl estuary rises rapidly in May and peaks from June to August before dropping equally rapidly in September-October. The majority of the Pearl discharge takes place in the western half of the estuary (adjacent to Macau and Zhuhai), but flows of brackish, highly turbid water are also discharged eastward in the immediate coastal and oceanic zone as a buoyant upper layer (fresh and brackish water being less dense than oceanic water), particularly during the summer wet season, and these surface flows affect Hong Kong. Modelling predicts that, in Hong Kong, the basal layer of saline, low turbidity oceanic water continues to flow to the west during the summer, with a boundary between the two layers at perhaps 6-10m depth in 30m of water. Thus, during the summer, a two-layer situation complicates the tidal and oceanic water circulation patterns in the Hong Kong region.

4.3 Water circulation within the Pearl estuary itself appears to be in the form of an anti-clockwise rotation, with inflow on the eastern (Hong Kong) side and outflow on the western (Macau) side. This anti-clockwise circulation pattern may result from a number of overlapping oceanographic factors, including the geography of the estuary (most of the river inputs are on the western side), the dominant winter ocean current (which tends to induce flow through Hong Kong from east to west) and the Coriolis effect (a force induced by the rotation of the earth which acts - in the northern hemisphere - to push any moving object to the right).

4.4 Saline oceanic water moves in and out of the estuary with the tide as a saline wedge beneath the fresh/brackish river outflow. The zone of tidal movement of the wedge, and the mixing associated with this zone, moves up and down the estuary with the seasons. In the winter, when the Pearl outflow is at a minimum, the mixing zone moves up the estuary, away from Hong Kong, while in the summer the zone moves seawards and closer to Hong Kong. The factors influencing water movements in the Hong Kong area are summarised in Figure 1.

Natural sediment flux

4.5 The offshore oceanic zone is characterised by very low suspended solids concentrations (often less than 5mg/l). The tidal coastal region typically has suspended solids levels in the range 5-20mg/l. These two zones contrast markedly with the Pearl estuary, which is a highly dynamic region dominated by very high levels of suspended solids, and which is strongly seasonal with marked variations in water and sediment transport between the wet and dry seasons. Chinese sources quote suspended sediment values of 3,000mg/l from the Pearl at unspecified localities, while mean water column values of 1,004 and 1,410mg/l have been reported from the Macau region.

4.6 The interaction between the saline, low turbidity oceanic and coastal water and the turbid, brackish Pearl estuary water is a very important factor in the regional sediment regime. Dispersed silt entering the Pearl estuary in the north flocculates progressively as it moves south and the salinity of the water increases. The toe of the saline wedge moves up and down the estuary about 15km on an average tide, forming a broad mixing zone in which very high levels of suspended solids occur. Peak concentrations of about 2,000mg/l are expected to occur at the toe of the saline wedge (a phenomenon common to all stratified estuaries). As described in Section 4.4, the mixing zone moves closer to Hong Kong during the summer, when the increased flow of the Pearl pushes the saline wedge to the south and east. These phenomena are illustrated in Figure 1.

4.7 While the waters to the north and west of Lantau may be directly affected by the very high silt concentrations associated with the toe of the salt wedge, a larger area of Hong Kong waters is periodically influenced (usually during the summer) by brackish Pearl water which flows out of the estuary above the salt wedge, forming a distinctive stratification in the water column. This brackish water penetrates Hong Kong during the ebb tide and flows around Lantau via the Lantau Channel and Kap Shui Mun. Figure 2 shows the boundary between turbid Pearl and relatively clean coastal water positioned to the north and west of Lantau at the top of a flood tide, while Figure 3 shows the same boundary in the vicinity of the Ma Wan Channel near the bottom of an ebb tide.

4.8 The Territory-wide ADCP survey carried out in August 1993 detected high suspended solids Pearl water (over 100mg/l) reaching as far as the Soko Islands and Lamma at the bottom of the ebb tide. Salinity measurements have detected brackish water extending as far to the east as the Po Toi islands and Fury Rocks. Suspended solids levels in this surface layer of brackish water are variable but can be high, and sedimentation can be expected when water velocities are low. The actual topography of the seabed in Hong Kong is generally very stable, which tends to support the hypothesis that any sedimentation which occurs at periods of low current flow is later removed. The sediment profiling camera survey undertaken in October 1993 suggested that cycles of erosion and deposition were fairly common in most of Hong Kong, tending to support the "dynamic equilibrium" model in which it is proposed that while seabed levels remain relatively constant in the absence of external changes, deposition and subsequent erosion is constantly taking place.

4.9 An alternative approach to the sedimentary regime in the Hong Kong region is to examine the existing sedimentological environments as inferred by geological investigations. Figure 4 shows the locations of these zones and can be compared with Figure 1. The continental shelf roughly coincides with the oceanic zone and is characterised by relic sandy deposits and by reworked muds from closer inshore, ie. there is little modern sedimentation. The front slope, or prodelta, comprises fine grained sediment, usually silty clay, and probably reflects past sedimentation associated with the outflow of brackish Pearl water over the saline wedge, with additional local sediment input from streams and rivers. This sediment has been deposited as sea levels have risen over the last 10,000 years. The dynamic equilibrium model suggests that, within most of Hong Kong, net sedimentation in this zone is relatively minor at present. The dynamic environment of the mixing zone within the Pearl estuary is reflected in the sedimentological zone known as the delta front, within which rapid net sedimentation is occurring.

Storm impacts

4.10 Hong Kong is periodically affected by the passage of tropical storms and typhoons which may generate storm sea waves of 10m or more in height. The eastern and

southeastern parts of the Territory are exposed to these storm waves, while even within the more sheltered southern waters and Western Harbour waves of 5m or 6m may occur during severe weather. These large storm waves have the potential to resuspend significant amounts of seabed sediment. The reduction in atmospheric pressure and the onshore winds associated with the passage of typhoons also causes an increase in tidal height over normal levels. This phenomenon is known as a typhoon surge, and associated with it are increases in the velocity of tidal current flows which may also cause sediment resuspension. Anecdotal evidence suggests that suspended solids levels throughout much of Hong Kong remain elevated for a number of days following the passage of a severe storm. The heavy rain which is often associated with tropical storms can lead to a short-lived influx of sediment from local rivers and streams. Again, anecdotal evidence suggests that high, if temporary, levels of suspended solids occur adjacent to river, stream and drainage discharges following rainstorms.

Remote sensing

5. Satellite imagery and high quality air photography are continuing to be used to investigate that patterns of surface water turbidity in Hong Kong. The possibility of undertaking air surveys using multi-spectral scanners is also being investigated.

Satellite imagery

5.1 A satellite image taken in December 1993 by the French SPOT satellite is reproduced as Figure 5. The image shows dramatically the differentiation between the high turbidity water in the Pearl to the north and west of Lantau and the relatively clean water of the coastal and oceanic zones to the south and east. These images are stored digitally and have a resolution of 20m, which permits individual ships and barges to be seen when areas of interest are enlarged. One restriction of satellite imagery which is becoming apparent is that it is very difficult to obtain images during the spring and summer due to the widespread cloud cover over Hong Kong at these times. Good "seeing" conditions tend to be restricted to autumn and winter.

Colour photography air surveys

5.2 The Air Survey unit of the Lands Department has now carried out vertical colour air photography of Hong Kong waters in August and December 1993 and in March 1994. Continuing surveys are planned at a frequency of three/four times per year, with the next survey scheduled for August 1994. The resolution of the air photographs is such that both small and large scale phenomena can be observed. Figures 6 to 10 are copies of a selection of these pictures which illustrate some of the processes which are being observed.

Figure 6 shows typically turbid water in the Pearl estuary to the west of Chek Lap Kok during a wet season ebb tide. This picture also illustrates the effects of ship's wakes, which can cause additional entrainment and mixing of sediment.

Figure 7 shows the situation north of Lantau 1.5 hours before low water on a wet season spring tide. The picture illustrates how the turbulence in the current induced by rocks and small islands is entraining large amounts of sediment.

Figure 8 shows the same location north of Lantau half an hour later, when the background

turbidity of the water has increased dramatically. This illustrates how the dynamic sediment regime of the Pearl can extend into Hong Kong waters.

Figure 9, at the same scale as the previous photographs, shows the Po Toi - Fury Rocks - Sung Kong area one hour before high water during the dry season. This area lies within the coastal waters zone, and the contrast between the clean water here and the turbid water in the Pearl estuary is marked. This picture also shows how natural sediment is entrained downstream from outcrops such as Sung Kong and Fury Rocks. The plume of sediment from a dredger overflow can also be seen, and can be compared with the natural sediment entrainment taking place in the area.

Figure 10 shows a dredging plume produced near the Ninepins Islands half an hour before high water during the dry season. Again, this region lies in the coastal zone where relatively low background levels of suspended solids can be expected. The picture is shown here for comparison with Figure 12, which is a computer prediction of surface dredging plume movement in the area under similar conditions. This is an example of how direct observation can be used to validate and enhance mathematical modelling.

Water column suspended solids measurements

6. Suspended solids levels can be measured directly or indirectly. Direct measurement of suspended solids in terms of mg/l involves the collection of water samples with subsequent laboratory analysis. Direct measurement is time consuming and expensive and does not permit collection of large amounts of data. For this reason the number of direct measurements in a survey is usually restricted and most data is obtained from indirect methods of measurement. Measurement of turbidity (the capacity of water to obstruct the passage of light) is carried out using optical or infra-red light siltmeters which are calibrated in terms of Formazine Turbidity Units (FTUs). The relationship between FTU and mg/l for a particular siltmeter at a particular time can then be calculated by comparison with water sample direct measurements taken in the same location. Hence siltmeter measurements may be reported either as FTUs or reduced to mg/l if the correlation has been established.

Acoustic Doppler Current Profilers

6.1 The GEO has been involved in the development of a more sophisticated method of indirect suspended solids measurement. This technique uses acoustic backscatter intensity as measured by the Acoustic Doppler Current Profiler (ADCP), and surveys using this technique have been reported in previous Papers to ACE. GEO consultants DRL have recently produced a report on the theory and techniques involved. Extracts from this report are reproduced in Appendix I. Data from ADCP surveys of the East Ninepins marine disposal area and from the West Po Toi sand borrow area have now been processed and interpreted, and extracts from the DRL reports are also presented in Appendix I.

6.2 The East Ninepins active marine disposal site was surveyed in June 1993. Disposal activity was light, with about six barges dumping on the day of the survey. Depth-averaged suspended solids concentrations averaged only 2-3mg/l, which accords with the expected natural background in this area. Localised concentrations of 5-25mg/l, related to the dumping operations, were detected.

6.3 The West Po Toi active sand dredging area was surveyed over two days in December 1994. The survey was curtailed due to bad weather. Depth-averaged suspended

solids concentrations over the area were typically about 10mg/l, with localised plumes of up to 50mg/l. Very high concentrations of over 100mg/l were noted but were restricted to the immediate vicinity of working dredgers.

6.4 A further focused survey of dredging plumes has been carried out at Fury Rocks (late June 1994), and the ADCP has also been used at this site to produce background suspended solids data as a by-product of an intensive programme of current monitoring (see Section 14). Preliminary results from the background suspended solids processing at this site have been obtained and full analysis of the ADCP data is in progress. For further information on work carried out in the Fury Rocks area refer to Section 14. A further focused survey of an active dredging or dumping site will be carried out in August 1994, although the location has yet to be decided. Advance planning is also under way for a second Territory-wide survey, to be carried out in November 1994 (dry season), which may be extended to the south and west of Hong Kong waters to gain more understanding of the processes operating at the boundary of the coastal and estuarine zones..

Organic content

6.5 Suspended solids can comprise both inorganic material (silt) and organic material (mainly algae). When investigating the effects of dredging and dumping-induced turbidity only silt has to be considered. The next stage in the GEO investigations is therefore to examine the effects of organic suspended solids on the measurements being made. Chlorophyll is conventionally taken to be the most convenient parameter to measure this algal component in sea water, which may be particularly high when algal blooms occur. Three approaches are being pursued at present:

- The use of fluorimeters to measure chlorophyll levels during ADCP/siltmeter/conventional water sampling surveys.

- The use of a boat-mounted laser backscattering device which has the potential to measure total suspended solids and to distinguish silt from organic matter. This device has been developed in the Peoples Republic of China and the GEO, in collaboration with HKUST, are supporting a trial in Hong Kong waters which is planned for August 1994. Further information is contained in Appendix II.

- Laboratory analyses of water samples to determine chlorophyll levels.

Dredging plume surveys

7. The large amount of data obtained from the second dredger plume trial (February 1994) is still being processed, and an interim report is in preparation. One of the main objectives of the final report will be to check the assumptions made for hydraulic modelling ie: rate of plume decay and proportions of material which remain in suspension.

Near-bed dense suspensions

8. High concentrations of silt derived from natural processes or from activities such as dredging and dumping have the potential to form dense suspensions just above the seabed. The evolution and behaviour of these suspensions is complex and difficult to analyse as their physical properties often fall into a range where they cannot be categorised as solid or liquid, but belong to a transitional

phase between these two more normal types of behaviour. These dense suspensions are often referred to as "fluid" or "liquid" muds, but it must be appreciated that this is a simplification. Dense suspensions are of interest because they have the potential, under certain circumstances, to cause adverse environmental impacts directly related to their physical properties. Potential problems arise where a dense suspension has a concentration sufficiently high to "smother" existing benthic fauna, but a density which is not sufficiently high to permit recolonisation, ie: recolonising organisms will tend to sink into the suspension. If the dense suspension consolidates to a firmer material this situation will be essentially temporary and recolonisation will occur after a suitable time interval. A further complication is that dense suspensions may be mobile, ie: they have the potential to move laterally, usually under the influence of gravity (ie: they can flow downhill). The generation and physical properties of dense suspensions are therefore of direct interest, and are being investigated by the GEO.

Rapid drop profiling siltmeter

8.1 Ravensrodd Consultants Ltd have developed for the GEO an advanced profiling siltmeter, which has the potential to measure very high silt concentrations. The device uses a pulsed infra-red signal and can generate many measurements per second. Field trials of this device have demonstrated its potential. Significant thicknesses of dense suspensions have been found in seabed pits which are being used for the disposal of mud, while, in contrast, preliminary investigations at the South Cheung Chau marine disposal area have shown that dense suspensions are not tending to form at this open seabed disposal site. This work will be reported in more detail in the next ACE Paper in this series.

High resolution acoustic profiling

8.2 Geophysical techniques can also be used to detect dense suspensions. The GEO has been experimenting with the use of a high resolution acoustic profiler which has been used at various sites to distinguish veneers and ponds of very weak, low density mud. This development work is continuing.

Other techniques

8.3 The possibility of combining a siltmeter and a nuclear density probe in a single instrument is being investigated. Such a device would be able to measure near bed silt concentration and density over a wide range. In addition, the sediment profiling camera operated by Science Applications International Corporation (SAIC) also has the potential to provide information on dense suspensions, both by direct imaging and by interpretation of the camera penetration depth.

ECOLOGICAL STUDIES

9. Surveys and investigations of the various habitats within Hong Kong waters are designed to provide data on existing conditions and to detect any changes which may indicate potential problem areas. These studies complement the physical investigations by monitoring the general health of the ecosystem and the ways in which it responds to physical processes. By documenting the locations of sensitive and high diversity ecological communities in Hong Kong waters, Government will be able to take account of their value at an early stage in project planning. For the purposes of these studies it has proved convenient to subdivide the sea bottom ecosystem into

coastal (nearshore, hard substrate) and sea bed (offshore, soft substrate), as these areas are quite distinct and require different survey methods. The reaction of marine organisms to the physical conditions which may be induced or exacerbated by dredging, dumping and extreme natural processes in Hong Kong is of fundamental importance to any assessment of environmental impacts.

Effects of Suspended Sediment and Sedimentation on Aquatic Organisms

10. Sedimentation and turbidity are natural phenomena, and there are many organisms that live in turbid water, some actually preferring such conditions. The natural level of suspended solids in a body of water may be called the "background" or "baseline" suspended load, and in a relatively complex coastal/estuarine environment such as Hong Kong wide variations in background levels can occur (see Section 4). Marine organisms living in a given area can be expected to be tolerant of the background levels of suspended solids and sedimentation and of the normal natural fluctuations in these levels. Additional suspended solids loads and increased sedimentation rates caused by human activities (including dredging and dumping) may be classified as a form of pollution when the combination of background and anthropogenic levels exceeds the tolerance thresholds of organisms and injures or kills them, or when human activities such as fishing and recreational diving are disrupted. GEO consultants Binnie Consultants Ltd (BCL) have recently summarised the known effects of suspended solids on a range of marine organisms.

Effects of Excess Sediment

10.1 Excess sediment can harm aquatic organisms either directly or indirectly. Direct effects include abrasion, gill clogging, light reduction, visibility reduction and burial. Indirect effects include reduction in food sources, extent of habitat and number of settlement sites for larvae. Large mobile organisms such as fish can avoid suspended sediment by swimming to cleaner water and can clear their gills by flushing. Plankton and slow-moving benthic and sessile organisms rely on body motion and movement of appendages to rid themselves of unwanted sediment. If the rate of sediment deposition or the concentration of suspended solids reach a level that is greater than can be handled by these clearance mechanisms, the organism will suffer injury. These levels are called tolerance thresholds, and differ between species and between different stages in the life cycle of an individual species. In general, susceptibility decreases as the organism ages, with the egg stage being the most vulnerable.

Fish

10.2 Specific data on the sediment tolerance of Hong Kong fish species are not available. However, tests carried out elsewhere and reported in the literature have shown that fish can survive very high levels of suspended solids - up to 50,000mg/l being reported. However, injuries and "stress" have been noted in juvenile fish at suspended solids levels of 1,000mg/l. The lowest concentration known to have reduced life expectancy is 90mg/l, and the lowest concentration known to have increased susceptibility to disease is 100mg/l. It should be noted that the AFD in Hong Kong defines a target level of 80mg/l for mariculture protection purposes. GEO consultants BCL suggest that action levels of 125mg/l for wild fish larvae stocks, and 250mg/l for one hour for wild adult fish stocks could be regarded as conservative estimates for wild marine fish in Hong Kong. It must also be noted that tolerance will vary between species and that Hong Kong fish species adapted to living in turbid waters on a soft seabed would be expected to have higher thresholds than fish adapted to living in clear water rock or coral reef habitats. Indirect adverse effects of excess

suspended solids levels on fish stocks can result from disruption of mating and territorial behaviour patterns, which are reported to be highly dependent on visual clues, and from reduction in food supplies. Coral reef fish are highly dependant on the maintenance of the coral reef community, and major shifts in fish diversity and abundance can be expected to result from changes in coral reef community structure. There are many pressures on the coral reefs of Hong Kong, including illegal dynamite fishing and recreational diving.

Hard (Reef) Corals

10.3 High suspended solids concentrations and high deposition rates may limit coral growth or cause coral mortality. The precise cause of coral death due to sediment load is not known. Many researchers have speculated that a variety of factors acting alone, or in concert, may be responsible. These factors include abrasion by silt-laden currents, light reduction, smothering by physical blocking of oxygenated water currents, microbial action and energy drain due to self-cleaning efforts. High suspended sediment loads increase turbidity and reduce light penetration, although the available data suggest that light limitation must be prolonged to kill corals. Periods of eighteen days to six weeks of light exclusion before mortality occurs are described in the literature. Complete burial of corals under several centimetres of sediment will cause mortality, especially if the sediment is fine and anoxic. At lesser rates of sedimentation, corals exhibit a wide range of responses varying from bleaching - defined as a loss of the algal cells which normally live within the coral tissue in a symbiotic relationship - to death. Coral form is important in determining resistance to sedimentation - most corals in Hong Kong are massive or encrusting, and these tend to be more resistant than plate-forming corals. Species of hard corals found in Hong Kong cover a wide range of sediment tolerance. GEO consultant BCL has arrived at a figure of 0.2kg/m^2/day as being potentially damaging to reef corals in Hong Kong for exposures of more than 24 hours.

Gorgonians, Soft Corals and Non-Reefbuilding Hard Corals

10.4 Little work has been done worldwide to study the effects of sedimentation on these organisms. Most species of soft corals and gorgonians found in Hong Kong appear to have a preference for areas of fast current, which would tend to prevent the settlement of sediment.

Other Organisms

10.5 There is a lack of data on the effects of sediment on tropical organisms other than coral. The following is a synthesis of what is known.

Crabs A study from California indicates a lethal concentration of 4,000mg/l over 25 days.

Polychaete worms Four species from Oregon, USA, were assessed. Two of the species were shown to be well-adapted to dynamic sediment conditions, while the other species were considered to be moderate bottom turnover and frequent disturbance, while being less tolerant of chronic sedimentation.

Oysters High levels of suspended solids have been shown to kill oysters. Concentrations of 125 to 188mg/l have been shown to impair oyster larvae shell formation, with mortality commencing at levels of 750mg/l.

Invertebrates Available data suggest that the lowest suspended sediment concentration causing chronic sub-lethal effects on invertebrate eggs and larvae is around 100mg/l. Acute lethal effects are generally found above several hundred mg/l.

Coastal ecology

11. Dive surveys of the coastal zone by marine biologists continue to be carried out by BCL. The work is currently concentrating on four main projects: continued monitoring at the Ninepins Islands, a baseline audit of the condition of the East Lamma Channel, continuing Territory-wide surveys for baseline information and a new programme of focused monitoring at a highly sensitive receiver, Fury Rocks, near Po Toi Island (this work is described further in Section 14). Since January 1994, 48 dive surveys have been completed at the locations shown in Table 1 and in Figure 12.

Ninepins Islands

11.1 Continued monitoring at the Ninepins Islands has revealed a minor amount (10% of the total population) of possibly dredging-related bleaching of corals at Tai Mei Chau, off the southern tip of South Ninepin. Some of the bleached corals will eventually die, but it is not possible to predict how many. Given the low percentage of affected corals, this is not considered a major impact. No other coral damage at Ninepins has been recorded.

East Lamma Channel

11.2 Sensitive marine receivers in and around the East Lamma Channel were surveyed as part of a baseline study prior to the proposed pilot dredging scheme in this area. Special care was taken to note the location of indicator species of hard and soft corals. This work will be reported in more detail in the next ACE Paper in this series.

Territory-wide Baseline Surveys

11.3 Ten stations have been studied since January 1994. A portable underwater video camera has been purchased and has proved invaluable in quickly documenting large areas of reef in a short period. Video locations are indicated in Table I. Due to vandalism of permanent steel transect lines, a new technique focusing on the status of indicator species has been used to survey coral populations in shallow water.

Sea bed ecology

12. Surveys of the soft seabed ecology are continuing, using both conventional benthic grab sampling/organism identification techniques and the REMOTS sediment profiling camera system. The pilot grab-sampling study, carried out by BCL in association with the First Institute of Oceanography in Quingdao, Peoples Republic of China, was completed in July 1994. Grab sampling has now been carried out at the Ninepins Islands, the South Cheung Chau marine disposal area and in Sulphur Channel (Green Island). In addition, more than 25 stations were sampled in June 1994 as part of a ground truthing exercise for the REMOTS system (see below). Analysis of the data from Ninepins is complete, while preliminary analysis of the results of the South Cheung Chau and Sulphur Channel surveys has also been carried out. The sampling locations at Ninepins were shown in Paper ACE 8/94. The sampling locations at South Cheung Chau and Sulphur

Channel are shown in Figure 13. The second REMOTS survey was completed in June 1994. Continuing REMOTS and grab surveys are planned.

Grab Sampling

12.1 Analysis and interpretation of the data obtained by the grab survey carried out in the South Ninepins area during December 1993 and January 1994 is now complete. Sampling was carried out at a total of eleven stations, two within an active borrow area and seven outside the proposed South Ninepins Borrow Area, as described in Paper ACE 8/94. Two control stations were located approximately 9km to the north, outside the expected zone of influence of dredging activities. Organisms were identified to species level with the exception of polychaete worms, where identification was limited to family level. Biomass was also recorded. The marine macrobenthic fauna collected were diverse and almost entirely comprised of invertebrates. Polychaetes, crustaceans and molluscs were the dominant groups. The biomass was higher than measured in a study performed 20 years ago. The study has established the current baseline condition of the benthos in the area of the Ninepin Islands, and will allow statistical comparison with results obtained from any future surveys.

12.2 Preliminary results from the grab survey at South Cheung Chau reveal a low diversity, low biomass community outside the dumping area. Within the dumping area few organisms and a low diversity were recorded. At one station within the dump site where dumping had ended two months prior to the survey, a slow recovery of population density was recorded.

12.3 A similar low diversity, low biomass community was recorded from two stations in Sulphur Channel. More details of the results of these surveys will be provided in the next ACE Paper in this series.

REMOTS survey

12.4 The second REMOTS sediment profiling camera survey (REMOTS II) was completed in June 1994. Figure 14 is a plan of the stations sampled during this survey. The objectives of REMOTS II were to address a number of site-specific questions and to provide more background information on Hong Kong waters. In addition, a programme of seabed grab sampling was combined with REMOTS II to allow "ground-truthing" of the camera images by comparison with conventional (if time-consuming) taxonomic identification. Analysis of the data obtained is being progressed by SAIC. Specific topics to be addressed in the reporting are as follows:

- Recolonisation of spoil disposal areas.
- Extent of any impacts arising from the spoil disposal areas.
- Effects of spoil disposal areas on the biota of the surrounding seabed.
- Recolonisation of worked-out sand borrow pits.
- Baseline ecology of areas of future proposed dredging.
- "Ground-truthing" of sediment profiling camera data.

12.5 In addition some sites, not related to dredging and dumping, were surveyed at the request the Environmental Protection Department (EPD). These sites included the Waglan sewage sludge dump site, the Urmston Road sewage outfall, and parts of Tolo Harbour. The results of REMOTS II will be reported in the next ACE Paper.

Fishery surveys

13. Analysis and reporting of the data obtained by the trawl survey carried out in the South Ninepins area during December 1993 and January 1994 is now complete.

Ninepins

13.1 This survey was designed to assess existing conditions in an area where sand dredging is proposed. The area cannot, however, be regarded as completely undisturbed, as dredging has taken place at other locations in the vicinity. Trawls were conducted at two sites, one inside the proposed borrow area and one outside. Trawling was the method of choice as this method catches demersal (bottom-dwelling) species which are most likely to be affected by dredging works, and a Hong Kong shrimp trawler deploying twin beam trawls was used. Beam trawling is a relatively quick and simple technique which can be used for comparative studies between areas, or to evaluate changes in a given area with time. Beam trawl catches are not, however, strictly analogous to commercial catches, which are more likely to be by gill-netting or otter trawling.

13.2 Catches were sorted into fish and invertebrates and identified to species level. The total trawl catch was dominated by invertebrates as measured by numbers of individuals and total weight. The fish catch was dominated by a few non-commercial species such as cardinal fish and gobies. Only small numbers of commercial species such as croaker, flounder and sole were caught. The invertebrate catch was dominated by commercial species of crab and shrimp. Fish catch rates inside and outside the proposed borrow area averaged 1.6kg/hr and 1.2kg/hr, while average invertebrate catch rates were 1.8kg/hr and 2.1kg/hr respectively.

13.3 Much of the commercial fishing in the Ninepins area uses the gill-netting method, and a survey in the South Ninepins area using this technique is planned for July/August 1994.

Fisheries Sensitive Receivers

13.4 GEO consultants BCL have submitted a proposal for a study to identify fisheries sensitive receivers such as spawning grounds and nursery areas. This proposal is currently being assessed in liaison with Agriculture and Fisheries Department (AFD).

Fury Rocks dredging monitoring

14. Fury Rocks are located to the south of Hong Kong Island, adjacent to Po Toi and Sung Kong. The site is known to have a rich marine ecosystem and is a popular location for recreational diving. A sand resource adjacent to Fury Rocks has been allocated to the Central Reclamation project. Concern has been expressed as to the possible impact of the sand dredging which is now taking place in the area. The GEO has put in place a comprehensive programme of environmental and operational monitoring to ensure that any adverse impacts are detected and corrected during the works.

Baseline monitoring

14.1 Comprehensive current data were gathered at the site over complete spring and neap tidal cycles using an Acoustic Doppler Current Profiler (ADCP) (date). An example of the type of data produced is shown in Appendix III. Sidescan sonar was used to determine the extent of the rock/coral outcrop. Three days of dive surveying were carried out by GEO consultants BCL to determine the condition of the Fury Rocks site prior to the start of dredging. Ten REMOTS stations were located in the area as part of the REMOTS II survey, to determine the nature of the soft seabed benthic conditions in the dredging area. The REMOTS data is currently being processed and analysed. Air photographs of the site are available from August and December 1993 and from March 1994, showing the surface water conditions before dredging began.

14.2 Suspended solids levels were processed from the ADCP backscatter records obtained during the current monitoring on 23/24 and 26/27 April 1994. Examples of the processed ADCP data are given in Appendix III. Depth-averaged background levels were as follows:

Neap tides, southern part of area; average 1.4 - 3.0 mg/l
Neap tides, northern part of area; average 4.0 - 10.8 mg/l
Spring tides, southern part of area; average 2.8 - 7.5 mg/l
Spring tides, northern part of area; average 4.4 - 17.2 mg/l

These figures are as would be expected for a site within the transition zone between oceanic and coastal regimes. Figure 9 shows the site in December 1993 and illustrates how the low turbidity background is locally affected by natural sediment entrainment downstream from the various islands in the area.

14.3 A pre-dredging dive survey was carried out by BCL and confirmed the rich marine ecology of the site. The preliminary report of this survey is reproduced in Appendix III.

Dredging operations

14.4 The current data and details of the extent of the rock/coral were supplied to the dredging contractor before dredging began. The contractor proposed a dredging plan which was designed to minimise any impacts on Fury Rocks by working different areas of the site at different states of the tide. Shortly after dredging began on 25 May 1994 the contractor proposed a change in his method statement to allow working at all states of the tide by preventing overflow of silt while working in the northern part of the site (adjacent to Fury Rocks), and this modified dredging method continues to be used. For more information on the technical details and progress of the dredging refer to Appendix V.

Operational monitoring

14.5 Three continuously-recording infra-red siltmeters have been installed on the seabed at Fury Rocks. These instruments, which also record temperature and salinity, are retrieved by divers and the data is processed. A focused ADCP backscatter survey was carried out at the site in late June 1994 to assess the migration and concentration of dredging plumes being generated at the site. The data from this survey are being processed and analysed and will be reported in the next ACE paper in this series. Monitoring of the dredging operation is being carried out by DEMAS, dredging consultants to the GEO. Trackplots and dredging data are regularly supplied by the dredging contractor and DEMAS maintain a regular site

presence on board the dredger. Weekly dive surveys to assess the condition of the ecosystem at Fury Rocks are being performed by BCL. Examples of the data obtained during the monitoring are included in Appendix VI.

Monitoring results to date

14.6 The seabed siltmeters experienced some initial problems with algal growth affecting the instruments and giving falsely high readings. Thus there was initial concern that the water quality in the area was deteriorating. The frequency of servicing and retrieval visits to the siltmeters was increased from once a week to approximately twice per week and the instruments are now giving reliable data, albeit with a slight increase in recorded levels between each servicing visit. Background silt levels at Fury Rocks during the dredging operation, as measured by the siltmeters, are in the range 5-20mg/l (essentially the natural background before dredging began) with occasional peaks of up to 100mg/l. These peaks are of short duration (rising from and returning to background levels in one hour or less) and are probably caused by the dredging operation.

14.7 The main finding of the regular dive surveys at the site has been that the dredging operation has caused no silting of, and no damage to, the rich coral life at the site. At the start of the dredging some concern was caused when the divers observed temporary increases in turbidity resulting from the dredging (as also shown by the siltmeters). However, continued dive surveys (see Appendix VI) have shown that the currents at the site are preventing any sedimentation from taking place.

DATA MANAGEMENT

15. Environmental data continues to be entered into the Information Management System operated by the GEO. A summary of the environmental data now held in the system is given in Table 2.

CONCLUSIONS

16. The results of the work described in this Paper may be summarised as follows, and should be reviewed together with the initial findings reported in Paper ACE 8/94.

(a) Natural water circulation and sedimentation patterns are sufficiently well known to allow assessment of probable natural variations in background suspended solids levels and approximate sedimentation rates in different parts of Hong Kong.

(b) The impacts of storms on natural levels of suspended sediment is not well documented and further work on this subject is planned.

(c) Remote sensing is confirming the broad patterns of natural suspended solids and is also providing valuable information on the fine detail of suspended solids movement.

(d) Focused ADCP surveys of suspended solids at dredging sites are continuing and are showing that elevated levels of suspended solids (over 25mg/l above natural background) are restricted in both duration and extent. Measured levels of suspended solids may be exaggerated by organic material in the water column and further work is planned to investigate this.

(e) The extent, nature, derivation and possible impacts of dense seabed mud suspensions are being investigated. This subject will be more fully reported in the next Paper in this series.

(f) Specific data on the tolerance to suspended solids of organisms found in Hong Kong waters are sparse. However, by analogy with research performed overseas it is possible to determine levels of suspended solids above which organisms may be expected to suffer damage. These levels are generally in the region of 100mg/l or higher.

(g) Dive surveys of coastal sites are continuing. A minor amount of dredging-related coral bleaching has been noted at the Ninepins Islands. No other damage has been documented since the coral deaths at Ninepins reported in Paper ACE 8/94.

(h) Grab and trawl surveys have been undertaken in the South Ninepins area to establish the existing condition of the demersal and benthic fauna, prior to sand dredging works proposed for this site. It is intended that future such surveys at this, and other locations, will enable any impacts caused by dredging and dumping to be monitored.

(i) Dredging in the vicinity of Fury Rocks - an environmentally sensitive site due to its diverse coral and fish communities - is now in progress and intensive monitoring of the dredging operation and the sensitive receiver is being carried out. The dredging contractor has adopted a work method designed to minimise potential adverse impacts. To date, no impacts on the marine ecosystem have been detected.

NEXT REPORT

17. The next report to ACE is expected to be in January 1995.

LIST OF TABLES

LIST OF FIGURES

LIST OF ATTACHMENTS

Geotechnical Engineering Office
Civil Engineering Department
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