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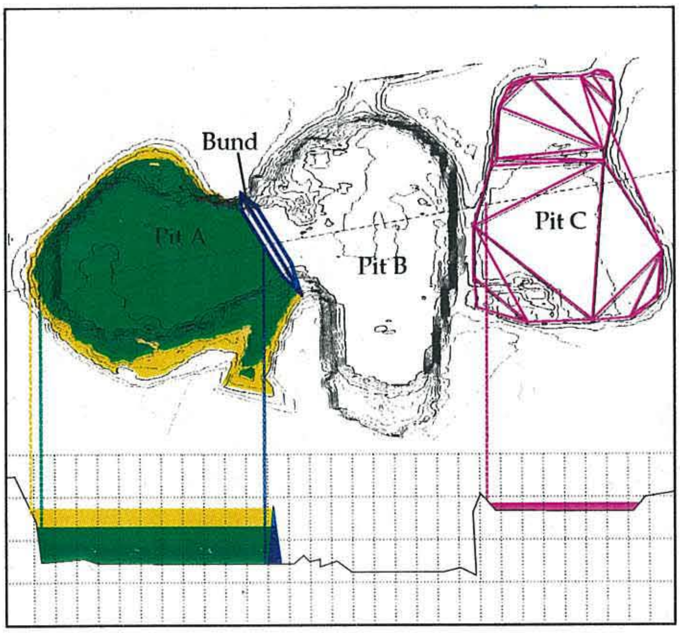
FINAL REPORT

CONSULTING SERVICES BY ENVIRONMENTAL RESOURCES MANAGEMENT

Civil Engineering Department



Environmental Impact Assessment Study for Disposal of Contaminated Mud in the East Sha Chau Marine Borrow Pit

27 January 1997

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Civil Engineering Department

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27 January 1997

Reference Agreement No: CE 81/95

For and on behalf of ERM-Hong Kong, Ltd

Approved by:

Position: MANAGING DIRECTOR

Date: 27 JANUARY 1997.

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1 INTRODUCTION

1.1 BACKGROUND TO THE STUDY

This Environmental Impact Assessment (EIA) evaluates the environmental acceptability of disposal of contaminated mud at the East Sha Chau marine borrow pits (the proposed CMP IV). The East Sha Chau marine borrow pits (CMP IV) were created by sand dredging undertaken by the Airport Authority (AA) and are located to the north of Chek Lap Kok Airport and Lantau Island (*Figure 1.1a*). The pits have the potential to accommodate more than 30Mm^3 of dredged material which will be sufficient to provide contaminated mud disposal capacity for the Territory until the year 2001.

At present, contaminated mud is deposited at the East Sha Chau Contaminated Mud Pit facilities (CMPs I-III), however the disposal capacity at this site is expected to be exhausted by mid-1997. Additional capacity is required to provide a disposal option for contaminated mud generated by continuing infrastructure development and maintenance dredging projects.

The proposed backfilling operations described in this Study represent a continuation of accepted disposal practices for contaminated dredged material in Hong Kong. A recent review of environmental monitoring data collected at the existing CMPs from 1992 to 1995 concluded that there was no evidence of contaminant impacts on biota due to disposal and that contamination from disposal activities has been successfully contained.(1) Furthermore, the study reviewed the suitability of a variety of potential sites for new CMPs and concluded that "contained marine disposal in the marine borrow pits (CMP IV) at East Sha Chau is clearly the most suitable site and is the preferred area for continued disposal of contaminated mud in Hong Kong"(2).

In order to investigate fully the feasibility of continuing disposal operations at the proposed CMP IV, this EIA was prepared to examine the nature and extent of potential environmental impacts. As the existing disposal operations have been found to be acceptable(3) this assessment focuses on those features which will differentiate disposal at CMP IV from previous disposal at CMPs I-III. These features include potentially stronger and more variable currents at the site, which may influence sediment transport and deposition, and the greater depth and area of the pits, which may influence erosional patterns and have implications for cap design and placement.

This EIA was prepared by ERM-Hong Kong Ltd (ERM) in association with Dredging Research Ltd (DRL), Hydraulics and Water Research Asia Ltd (HWR), Babtie BMT (BBMT), EVS Environment Consultants (EVS), and the U.S. Army Corps of Engineers Waterways Experiment Station (WES).

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(1) EVS 1996. Review of Contaminated Mud Disposal Strategy and Status Report on Contaminated Mud Disposal Facility at East Sha Chau. Prepared for the Civil Engineering Department, Hong Kong Government.

(2) Ibid.

(3) Ibid.

1.2 *OBJECTIVES OF THE EIA STUDY*

The objectives of this EIA Study are to provide information on the nature and extent of environmental impacts arising from the proposed disposal activities at CMP IV and to design an environmentally acceptable operations plan. Building on the information base established by the recent Government review(4) and extensive environmental monitoring and audit programmes, this study focuses on any changes in contaminated mud disposal operations due to use of the proposed CMP IV. Issues addressed include identification and evaluation of direct and indirect impacts to water quality, sensitive receivers, marine habitats, and human health from a variety of operational design elements. Cumulative impacts, as well as the potential benefits, of the proposed reinstatement of the seabed are also addressed.

The findings of this Study will contribute to decisions on the overall acceptability of environmental impacts likely to arise as a result of backfilling CMP IV with contaminated material. Mitigation measures in the form of design modifications and operational controls are recommended where appropriate. The Study also assesses the acceptability of any residual and cumulative impacts after the proposed mitigation measures are implemented.

1.3 *PURPOSE OF THE ENVIRONMENTAL IMPACT ASSESSMENT (EIA)*

The purpose of the EIA is provide a detailed assessment of key issues which have been addressed through further studies conducted subsequent to the Initial Assessment Report (IAR). In response to comments on the IAR, and in accordance with the Study programme, new and revised information has been presented in the EIA. Where necessary, practical and cost-effective mitigation measures to minimise adverse environmental impacts have been specified and incorporated into the project design. Any insurmountable residual environmental impacts associated with these operations after the implementation of mitigation measures have been identified. This EIA concludes with a finding on the environmental acceptability of the proposed operations.

Companion documents to this EIA will present details of various elements of the project in greater detail. The Operations Manual will provide specifications for engineering elements of the project which have been developed through environmental assessment of project impacts. The OM will thus provide a summary of environmentally-relevant design parameters which will comprise original, unaltered operational specifications (which have been found to be environmentally acceptable) and revised operational specifications (which have been identified as necessary mitigation measures). The Environmental Monitoring and Audit (EM&A) Manual, which will contain information and guidance for collecting and analysing environmental monitoring data and using these data to manage environmental impacts at the site, will also be presented as a separate document. Any issues highlighted in the Operations Manual, which have implications for the EM&A programme will also be presented in the EM&A Manual.

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(4) Ibid.

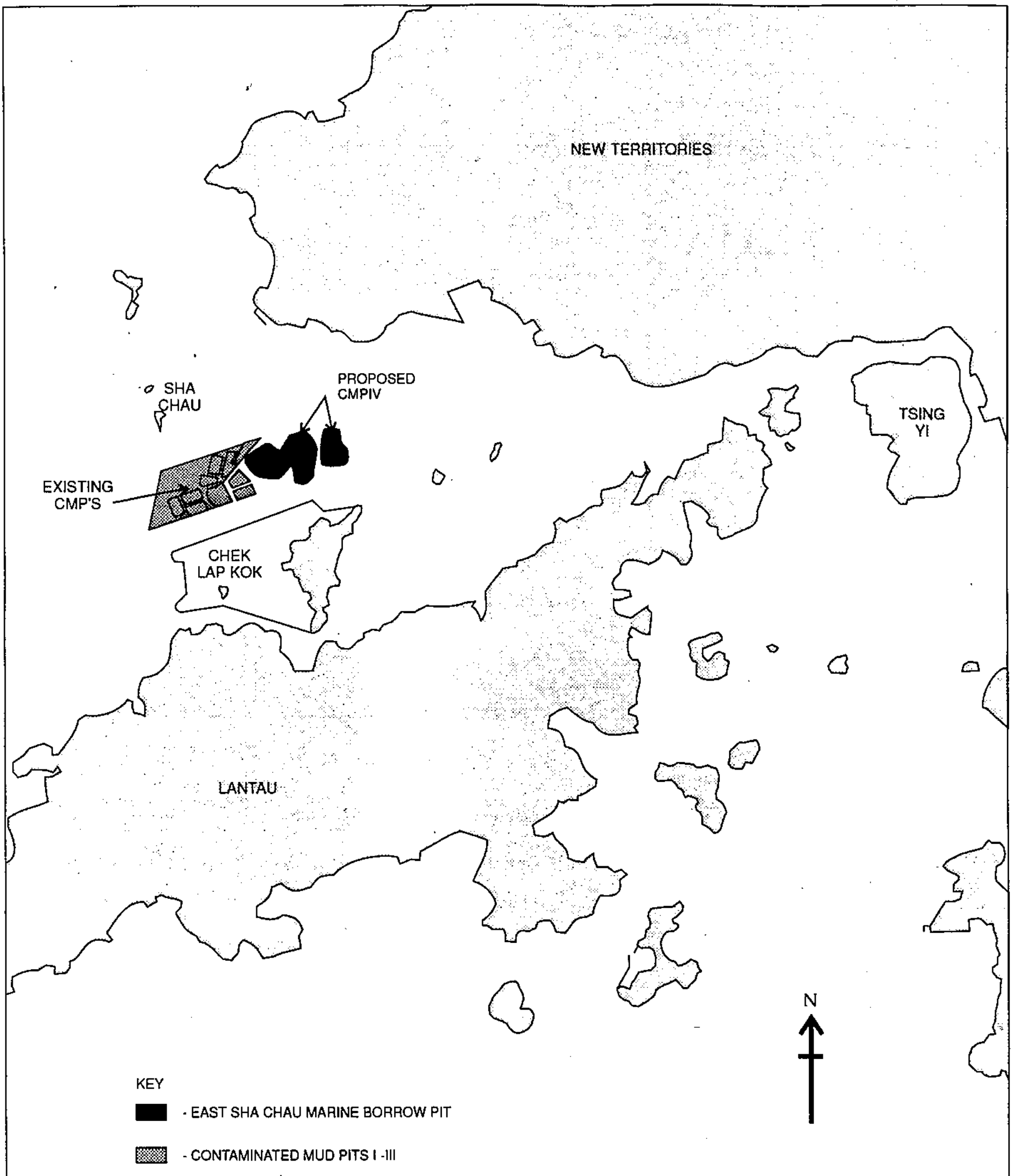

FIGURE 1.1a - LOCATION OF THE EAST SHA CHAU MARINE BORROW PIT (CMP IV)

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1.4 SCOPE OF THE ENVIRONMENTAL IMPACT ASSESSMENT

The EIA describes the existing environment within the study area, including background water and sediment quality, ecological, air and noise conditions. Where appropriate, it reviews the results of previous field studies and monitoring programmes in the East Sha Chau area for insight into the effects of contaminated mud disposal. The EIA identifies issues of key concern and provides findings on the nature and acceptability of potential environmental impacts. Where appropriate, practical and cost-effective mitigation measures are recommended to minimise potential adverse environmental impacts arising from the proposed contaminated mud disposal operations. These include operational controls in the form of design specifications and general working practices.

As previewed in the IAR and responses to comments on the IAR, the EIA contains further analysis of several key concerns identified earlier in the study. These new areas of detailed analysis include:

- additional water quality modelling scenarios covering disposal from alternative plant (ie trailer dredgers), other seasonal-tidal states and various disposal rates;
- erosion analyses to determine the level at which backfilled contaminated material will be stable, and the stability of the proposed cap design, under a variety of wave and storm conditions;
- modelling of contaminants, including metals, PAHs and PCBs;
- consolidation estimation and modelling of pore water release;
- an individual discussion of fisheries issues which incorporates recently-collected data to estimate impacts to fisheries resources;
- a comprehensive presentation of risk assessment results including a comparative risk assessment for the East Sha Chau area and a review of recent papers on the exposure of *Sousa chinensis* to contaminants;
- additional air and noise emissions assessments evaluating combined impacts of disposal in conjunction with dredging or capping.

This new information is incorporated into the discussion of existing information presented in the IAR and used to develop a conclusive finding on the environmental acceptability of the backfilling of CMP IV with contaminated dredged material.

1.5 STRUCTURE OF THE REPORT

Following this introductory section, the EIA is organised as follows:

- *Section* 2 describes the characteristics of CMP IV, and the proposed operational design, including engineering specifications, project programme, and marine traffic issues;

- *Sections 3, 4, 5, 6 and 7* predict and assess potential impacts which may arise during and after contaminated mud disposal with respect to water quality and sediment transport, fisheries, marine ecology and conservation, air quality, and noise, respectively. These sections also outline any required mitigation measures and suggest environmental monitoring and audit requirements where appropriate; and
- *Section 8* summarises the findings of the EIA, presenting a conclusive recommendation on the environmental feasibility of contaminated mud disposal at East Sha Chau.

2 PROJECT DESCRIPTION

2.1 INTRODUCTION

This Section describes an engineering design for the proposed CMP IV which is based on maximising disposal capacity, ensuring continuity in use of the site, and ensuring that environmental impacts are no greater than those associated with existing CMP operations. The design presented here is based on *Annex I* of the Study Brief which set out a Proposed Operational Scheme. The Scheme was divided into 15 stages, some of which can be executed simultaneously, and involves the sequential disposal of contaminated mud in Pits A, B and C. A glossary of terms used in the scheme is provided in *Annex A*.

This Scheme has been used to develop scenarios for sediment transport modelling, assess marine traffic issues and identify key environmental issues for water quality, ecology, fisheries, air and noise assessments. Several design components, which could be modified without any expected change in environmental impacts associated with the project, are presented as options in the text which follows.

2.2 SITE DESCRIPTION AND HISTORY

Investigations of potential sand sources for use in the formation of the platform for the new airport at Chek Lap Kok were conducted in 1991-1992 and revealed a south-westerly continuation of the sand resources of the Brothers Marine Borrow Area (MBA), extending almost to Sha Chau. Although the entire area was originally gazetted, as the East Sha Chau MBA, additional investigations showed that the sediments in the western part were of limited value as a sand resource. This part was therefore re-assigned for use as a confined disposal site for contaminated materials.

The disposal site had the advantages of shallow water (6 to 7 metres), relatively weak currents, and a position sheltered from southwesterly swell, all of which are conducive to minimising loss of material during placement. A series of eight pits have since been excavated in order to accommodate contaminated materials. The first pit (CMP I) began receiving mud in December 1992. The most recent (CMP IIIb) is presently being filled with contaminated sediments. Two further Pits, CMP IIIc and d, will be used to accommodate contaminated mud arising from projects in late 1996 and early 1997. Pit IIIc will start to receive mud in December 1996.

Prior to the land formation for the new airport, which was completed in 1995, the eastern part of the East Sha Chau Marine Borrow Area had a natural seabed level of approximately -6 to -8 mPD. During the airport land formation works, this area was extensively worked for sand and dredged to a level of approximately -35 mPD to form three contiguous pits (A, B and C) (see *Figure 1.1a*). To facilitate access by trailer dredgers to the pits, a northern access channel extending from the Urmston Road/Tuen Mun channel into Pit B was dredged (to approximately -12 mPD). A second access channel extends in a southerly direction towards the airport site from the point where Pits A and B meet.

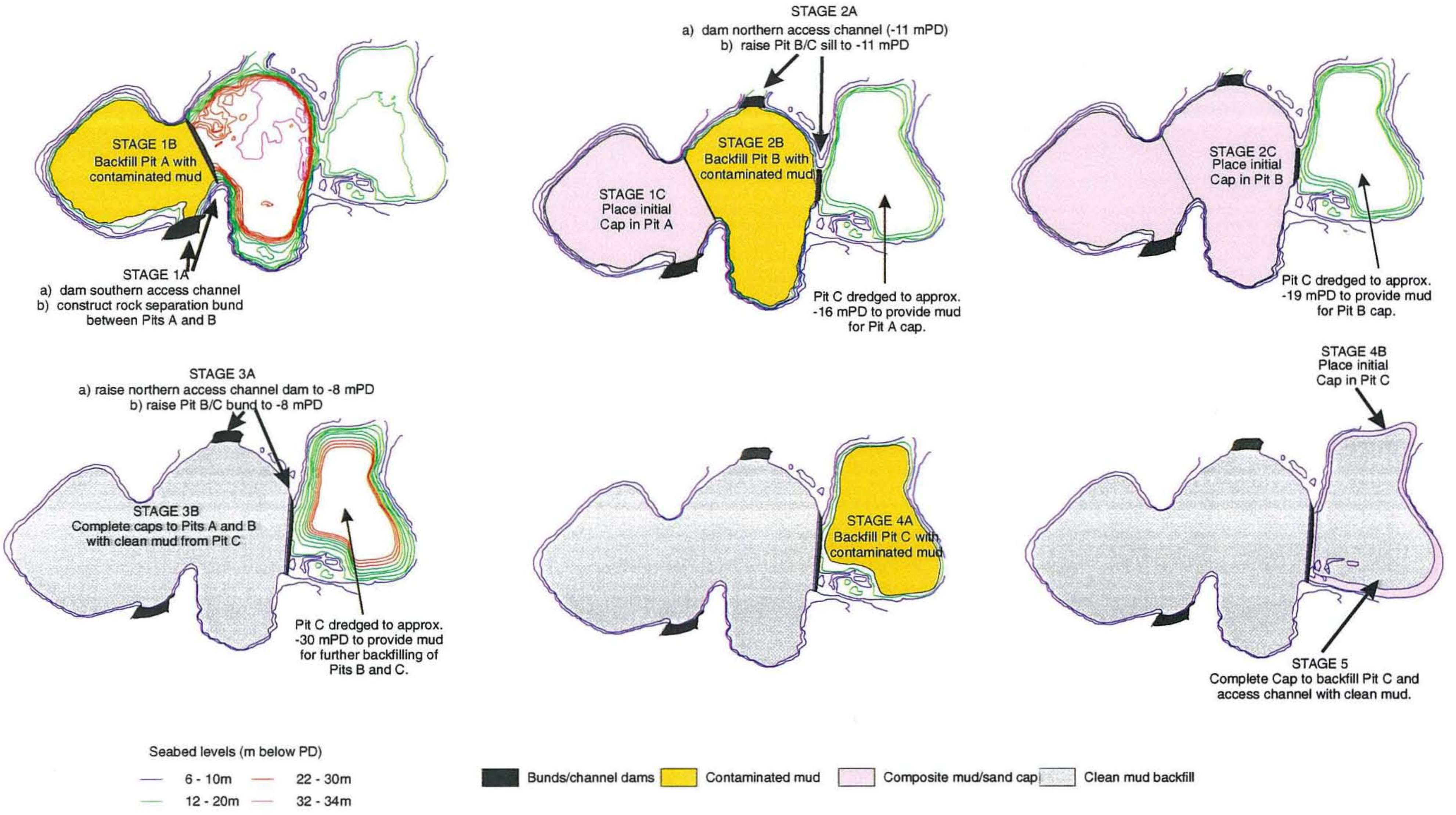
Dredging operations in Pit B ceased in February 1995. Pit C was partially backfilled with mud dredged from the airport site and with mud overburden removed from the adjacent Brothers MBA. Backfilling operations in Pit C ceased in May 1995, at which time the pit had been filled to a level of about -14 mPD with some 17 Mm^3 of dredged mud. The three borrow pits have subsequently been identified as having the potential to receive more than 30 Mm^3 of contaminated sediment, and will be designated as CMP IV, subject to the results of this EIA and the development of a suitable operations plan.

2.3 *DESIGN SCHEME*

The 15 stages of pit utilisation which were described in *Annex I* of the Brief, have been simplified and renumbered for the purposes of this description. They are summarised below and illustrated in *Figure 2.3a* and *Box 2.3a*.

The stages described in *Box 2.3a* are merely an example of the possible sequence of events which can be developed from the notional scheme described in the Brief. The key elements of the scheme, from an environmental perspective, are that Pit A will be filled with contaminated mud to a maximum level of -14 mPD following the construction of a bund to separate Pits A and B. When Pit A has been filled and disposal moves to Pit B, an initial cap of 3m thickness will be formed over the contaminated sediment in Pit A. Pit B will also be filled to -14 mPD before capping. The mud required to form the caps to Pits A and B will be sourced from Pit C. Additional disposal capacity could be formed in Pit C, if required, by raising the level of the Pits A and B caps to the level of the original seabed.

The length of the hiatus between completion of filling of Pit B and the start of filling of Pit C will depend on the length of time required to cap Pit B and the demand for disposal facilities at the time. If, for example, there was no demand for disposal, the cap to Pit B could comprise more than 2 metres of clean mud. Other minor works which form part of the overall scheme concern the backfilling of access channels to the pits which can be done using clean mud at any convenient stage of the works.



STAGE 1B
Backfill Pit A with contaminated mud

STAGE 1A
a) dam southern access channel
b) construct rock separation bund between Pits A and B

STAGE 2A
a) dam northern access channel (-11 mPD)
b) raise Pit B/C sill to -11 mPD

STAGE 1C
Place initial Cap in Pit A

STAGE 2B
Backfill Pit B with contaminated mud

Pit C dredged to approx. -16 mPD to provide mud for Pit A cap.

STAGE 2C
Place initial Cap in Pit B

Pit C dredged to approx. -19 mPD to provide mud for Pit B cap.

STAGE 3A
a) raise northern access channel dam to -8 mPD
b) raise Pit B/C bund to -8 mPD

STAGE 3B
Complete caps to Pits A and B with clean mud from Pit C

Pit C dredged to approx. -30 mPD to provide mud for further backfilling of Pits B and C.

STAGE 4A
Backfill Pit C with contaminated mud

STAGE 4B
Place initial Cap in Pit C

STAGE 5
Complete Cap to backfill Pit C and access channel with clean mud.

FIGURE 2.3a - PROPOSED DESIGN (BASED ON ANNEX I OF THE STUDY BRIEF)
STAGE 6 NOT SHOWN AS IT IS A LONG TERM ACTIVITY CARRIED OUT AS NECESSARY TO RESTORE THE SEABED

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Box 2.3a *Stages of Disposal of Contaminated Mud at the East Sha Chau CMP IV*

Stage 1
Preparatory Work and Backfilling of Pit A

Stage 1A
Preparatory works will be undertaken prior to the placement of contaminated muds in Pit A (ie a bund to separate Pit A from Pit B and the damming of the southern access channel to prevent migration of contaminated material). These tasks may be undertaken simultaneously. The bund will be constructed using approximately 260,000 m^3 of rock fill or construction waste up to a level of at least -11 mPD. The bund need not be raised to its full height before placement of contaminated mud can commence; it need only be maintained at a level of 3 metres or more higher than the level of contaminated mud. A section of the southern access channel to Pit A will be filled to a level of -6 mPD using clean grab-dredged mud or sand.

Stage 1B
On completion of the preparatory works, approximately 6.94Mm^3 of contaminated mud will be placed up to a level of -14 mPD in Pit A.

Stage 1C
On completion of backfilling, the contaminated mud will be initially capped to a level of -11 mPD. The mud for the cap may be obtained from Pit C which as a result will be deepened to approximately -16 mPD.

Stage 2
Preparatory Work and Backfilling of Pit B

Stage 2A
The northern access channel (to Pit B) will be backfilled with clean grab-dredged mud or sand to a level of -11 mPD, (permitting continued access by loaded trailer dredgers), and a bund will be formed to raise the divide between Pits B and C from the present -13 mPD to -11 mPD. These works must be completed before Pit B has been filled to a level of -16mPD.

Stage 2B
Pit B will be filled with approximately 12.73 Mm^3 of contaminated mud up to a level of -14 mPD.

Stage 2C
Pit B will then be initially capped to a level of -11 mPD. Mud may be dredged from Pit C to provide this capping material, further reducing the level of Pit C to approximately -19 mPD.

Stage 3
Complete Capping of Pits A and B and Preparatory Work for Pit C

Assuming that Pit B is capped with mud taken directly from Pit C, it will not be possible to dispose of contaminated mud for a period of approximately 6 months, since removal of mud from Pit C will be underway.

Stage 3A
This stage will involve backfilling of the northern access channel (to -8 mPD) with clean grab-dredged mud or sand and raising the level of the rock fill (or construction waste) bund between Pits B and C to -8 mPD will be completed. Raising of the bund will require approximately 12,000 m^3 of fill material.

Stage 3B
To avoid a hiatus in disposal capacity, dredging of additional mud from Pit C may be undertaken at an earlier date, possibly in order to complete the capping of Pit A to original seabed level. Approximately 7.8 Mm^3 of mud would need to be dredged from Pit C to reduce its level to approximately -30 mPD.

Stage 4
Backfilling of Pit C

Stage 4A
Approximately 12.13 Mm^3 of contaminated mud will be placed in Pit C, filling it to a level of -14 mPD.

Stage 4B
On completion of contaminated mud placement in Pit C, it would be capped using clean material as in Pits A and B.

Stage 5
Backfilling Pits C's access channel and Completion of Capping for Pit C

This stage of the proposed scheme involves backfilling Pit C's access channel to -9 mPD using clean grab-dredged mud or sand and completion of the capping of Pit C to -9 mPD with approximately 1.5 Mm^3 of clean mud from an external source.

Stage 6
Further Capping for Pits A, B and C as Backfill Material Consolidates

In order to ensure restoration of the natural seabed and avoid generating a different wave climate over the CMP IV, it will be necessary to continue to hydraulically place clean mud in Pits A, B and C as previously placed materials consolidate over time.

2.4 DESIGN ISSUES

During the course of the EIA, several design components of the *Annex I* Scheme were reviewed and evaluated in order to quantify potentially adverse effects and to identify possible modifications, of both design and programme, which could be introduced either to improve the Scheme or to provide additional flexibility in pit utilisation. These included:

- the level to which the pits could be backfilled with contaminated mud (which has implications for disposal volumes and potential erosion losses);
- the bulking and consolidation of the placed materials (with respect to the volumes which can be accommodated);
- the design of the cap (with respect to its ability to physically isolate contaminated materials, its durability and ease of construction);
- the locations and dimensions of the bunds separating the three pits, the details of the backfilling of the access channels, and the methods of construction.

These issues are briefly summarised in the following sections.

2.4.1 *Backfill Levels*

The area covered by the CMP IV scheme is larger than previous pits in the East Sha Chau area. The greater area of material which is subject to the effects of storm waves has been compensated for by lowering the level to which contaminated mud can be placed from -9 mPD to -14 mPD.

According to the results of the erosion analyses described in *Section 3.11*, soft contaminated muds present in the pit during filling will be resuspended from within the CMP IV at a backfill level of -14 mPD under the combined action of the 1:10 year wave conditions plus currents but will remain stable under currents alone and less severe storm events. Furthermore, a large proportion of resuspended material will be retained in the pit. As a result of these analyses, no modification to the originally proposed design backfill level was necessary to mitigate for potential contaminant losses.

2.4.2 *Bulking and Consolidation*

The bulking of the mud during placement (as opposed to bulking during dredging and loading into barges or hoppers) and its consolidation after placement will determine the volume of mud which can be accommodated in the pits and thus has programming implications.

Data collected by the Port Works Division from four previous pits indicates that the volume of material in the pits immediately before capping is approximately 1.04 times the hopper/barge volume which is placed (*Source: FMC, 8th May 1996*). The volume increase is due to bulking during placement, partly offset by consolidation during the period before capping. A bulking factor 4% has been adopted here for the purposes of estimating the capacity of the pits to receive contaminated mud.

The barge/hopper volumes of contaminated mud which are expected to be accommodated in Pits A and B are 6.94 and 12.73 Mm^3 respectively, assuming that mud is placed up to -14 mPD. The volume indicated for Pit A makes allowance for approximately 2.2 Mm^3 of clean material which has recently been dredged to form Pit IIIc and was placed in Pit A.

The void volumes and placed hopper volumes for Pit C are given as a range since the volume of contaminated mud which can be placed in Pit C will depend on how much of the existing clean backfill is removed for use elsewhere before placement of contaminated mud commences. Both the low and high volume values assume that approximately 2.6 Mm^3 of clean mud will be placed in Pit C during the formation of Pit IIId. If all of the materials used to backfill the access channels and form the mud caps to Pits IIIc and IIId and Pits CMP IV A and B are sourced from CMP IV C, a void of approximately 4.05 Mm^3 would to be formed allowing approximately 3.89 Mm^3 of contaminated mud to be placed. These volumes could be increased significantly if material from Pit C is added to the caps of Pits A and B to raise them to the level of the surrounding seabed. If this were to be done, the potential capacity of Pit C to receive contaminated materials could be increased to about 12.13 Mm^3.

The total capacity of all three pits to receive contaminated mud is likely to be between 23.56 and 31.80 Mm^3 of contaminated mud (hopper volume) depending on the manner in which they are exploited.

The estimated volumes which can be accommodated in CMP IV are set out in *Table 2.4a*.

Table 2.4a ***Estimated Contaminated Mud Backfill Volumes for CMP IV***

Pit	Cumulative Void Volume (Mm^3)	Placed Hopper Volume (Mm^3)
A	7.22	6.94
B	13.24	12.73
C	4.05 - 12.62	3.89 - 12.13

2.4.3 *Cap Design*

Caps at previous CMPs have consisted of a 1 m thick layer of sand and a 2 m thick layer of clean mud (*Figure 2.4a)* and were placed by controlled bottom dumping from barges. Additional clean mud has been added later to compensate for long-term consolidation of the contaminated mud.

The original rationale for the design of the cap is given in Premchitt and Evans (1993)⁽¹⁾ and the present practice is set out in a recent GEO Information Note⁽²⁾ summarised below in *Box 2.4a.*

Box 2.4a *Rationale for Cap Design, East Sha Chau CMP*

Mud Layer

- Studies have shown that a 1m thick clean mud cap is required to prevent migration of contaminants and bioturbation (3) (4) (5).
- An additional 1 m thickness is placed in order to protect against storm erosion. Examination of seismic data from the East Sha Chau area showed evidence of erosion to this depth which was attributed to multiple storm events. The data also suggested that the depressions formed by such erosion were backfilled naturally.
- Final layer of 1-2 m of mud after consolidation to bring cap to the level of the original seabed. Opportunities could be investigated later, with the advice of AFD, for enhancement of benthic ecosystems by increasing habitat diversity through the placement of granular or mixed material on top of the initial caps.

Sand Layer

- During placement, sand tends to improve the consistency of the uppermost, semi-fluid contaminated mud thus facilitating placement of the main mud cap and reducing the potential for contaminated sediment resuspension during placement.
- The sand layer also provides a marker horizon which helps during investigation of the integrity of the cap and whether it has been placed successfully. (Although it is theoretically possible to distinguish contaminated backfilling material from clean capping material through sediment chemistry, the presence of uncontaminated material dredged and placed along with contaminated material makes this impractical.)

For CMP IV, the initial design presented in *Annex I* of the Study Brief, calls for placing 3 m or more of additional clean material on top of the initial 2 m layer of clean mud and 1 m of sand resulting in a cap thickness of at least 6 m. Given this substantially increased cap thickness and the requirement, indicated by FMC, that future caps will be placed by hydraulic methods, the need for the sand layer

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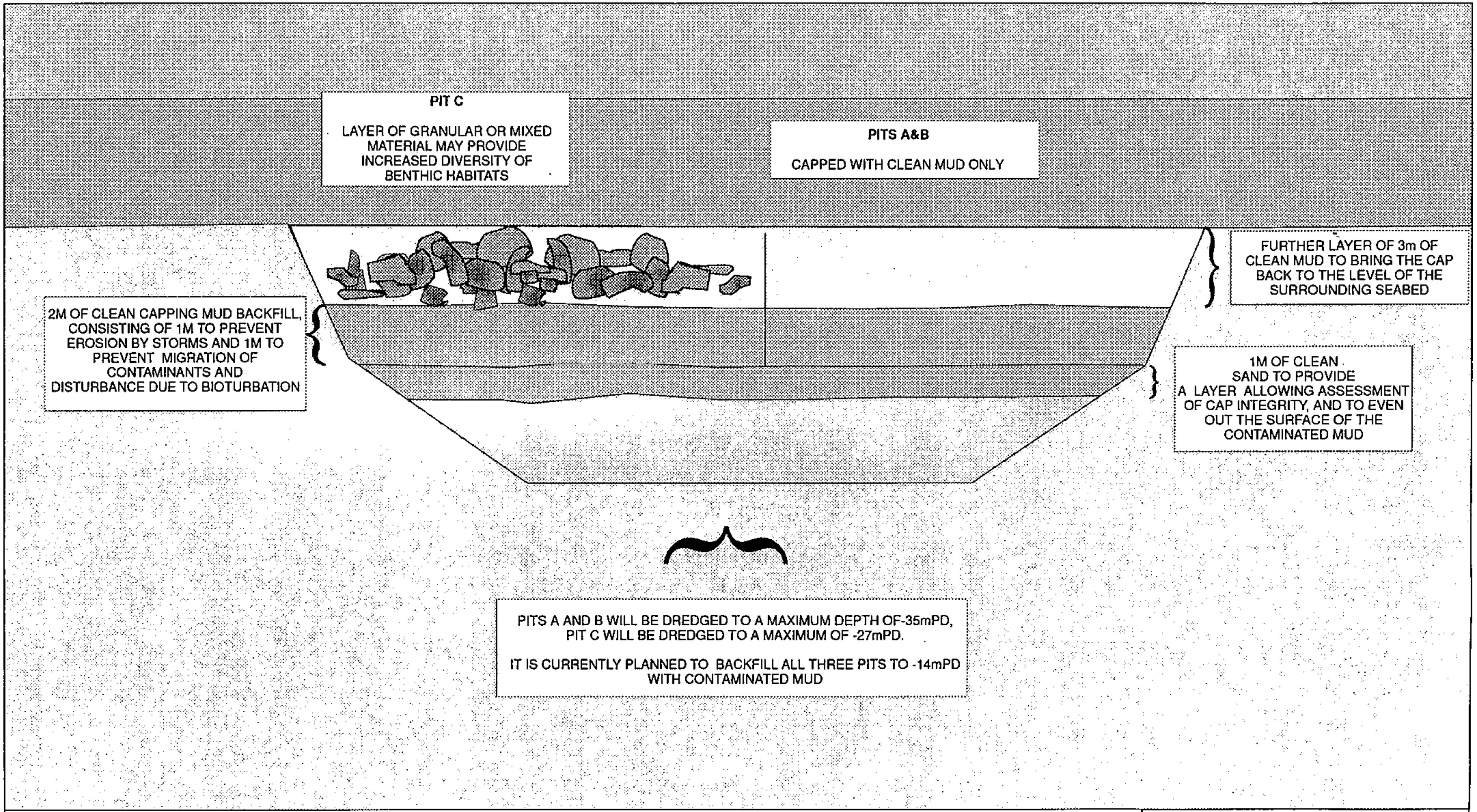
(1) Premchitt J and Evans NC (1993) Stability of spoil and cap materials at East Sha Chau contaminated mud disposal area. Special Project Report No. SPR 2/93. Geotechnical Engineering Office, CED, Hong Kong.

(2) Geotechnical Engineering Office, Civil Engineering Department, Information Note, May 1996.

(3) Gunnison D, Brannon JM, Sturgis T C, and Smith I 1987. Development of a simplified column test for evaluation of thickness of capping material required to isolate contaminated dredged material. Miscellaneous Paper D-87-2, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

(4) Brannon J M, Hoeppel RE, Sturgis T C, Smith I, and Gunnison D 1986. Effectiveness of capping in isolating Dutch Kills sediment from biota and overlying water. Technical Report D-86-2, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

(5) Brannon J M, Hoeppel RE, Sturgis T C, Smith I, and Gunnison D 1985. Effectiveness of capping in isolating contaminated dredged material from biota and overlying water. Technical Report D-85-10, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.



PIT C

LAYER OF GRANULAR OR MIXED MATERIAL MAY PROVIDE INCREASED DIVERSITY OF BENTHIC HABITATS

PITS A&B

CAPPED WITH CLEAN MUD ONLY

FURTHER LAYER OF 3m OF CLEAN MUD TO BRING THE CAP BACK TO THE LEVEL OF THE SURROUNDING SEABED

2M OF CLEAN CAPPING MUD BACKFILL, CONSISTING OF 1M TO PREVENT EROSION BY STORMS AND 1M TO PREVENT MIGRATION OF CONTAMINANTS AND DISTURBANCE DUE TO BIOTURBATION

1M OF CLEAN SAND TO PROVIDE A LAYER ALLOWING ASSESSMENT OF CAP INTEGRITY, AND TO EVEN OUT THE SURFACE OF THE CONTAMINATED MUD

PITS A AND B WILL BE DREDGED TO A MAXIMUM DEPTH OF-35mPD, PIT C WILL BE DREDGED TO A MAXIMUM OF -27mPD.

IT IS CURRENTLY PLANNED TO BACKFILL ALL THREE PITS TO -14mPD WITH CONTAMINATED MUD

FIGURE 2.4a - SCHEMATIC DIAGRAM OF CAP DESIGN FOR EAST SHA CHAU CMP IV

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is diminished. Its function of improving the consistency of the upper layer of contaminated mud is largely redundant in view of the hydraulic placement methods which are to be used and its function as a marker layer to demonstrate the integrity of the cap is a requirement only for relatively thin caps which could be breached, for example, by exceptional storm events.

Since the cap thickness is sufficient to ensure physical isolation of contaminated material and to prevent breaching due to erosion during storm events (see *Section* 3.11), the additional expense of placing the sand layer is deemed unnecessary and it will be replaced with a metre thick layer of clean mud. As the sand layer serves no specific purpose in isolating the contaminated material, and the overall cap thickness remains unchanged, this design modification is identified in this EIA as a subject for discussion by Government in the future, but does not require separate consideration in terms of environmental impact.

The potential for damage and breaching of the cap due to anchorage has been considered, but the shallow water restricts the size of vessel which can anchor in the area which, in turn, restricts the size of anchor and the penetration depth. In any event, until the pit is fully capped, the area will be a Works Area with an on-site management team which would prevent anchoring. In addition, Marine Department have indicated that there are no plans to designate the area as an anchorage nor are there likely to be any in the future, partly due to the proximity of the airport.

2.4.4 *Bund Locations and Dimensions*

Location and basic design of the bunds separating Pits A, B and C were also specified in the Study Brief. The original recommendation was to construct bunds within the existing access channels for Pits A and B to prevent migration of placed materials. Since changes in the location of the bunds, assuming they remain within the existing access channels, are not expected to result in any differences in environmental impacts associated with the project, such changes are not discussed further in this EIA.

The design and construction methods used to build the bunds may require slight adjustment depending on the material used. At present the bunds are likely to be constructed using rockfill or construction waste. Potential minor changes to the basic design and construction methods for engineering purposes are not expected to alter the environmental acceptability of the project and thus are not discussed further in this EIA.

2.5 *PROGRAMMING ISSUES*

The timescale of the proposed development is dictated mainly by the rate at which contaminated materials are expected to be generated and the desirability of maintaining continuity of the disposal facilities. Based on the latest projections, FMC have instructed that the EIA be based on the following assumptions:

- preparatory works in the area will commence prior to disposal operations;
- contaminated mud disposal will commence in August 1997; and

- the rate of delivery of contaminated mud could be 6 Mm^3 $year^{-1}$ (barge or hopper volume).

An indicative project programme, based on the *Annex I Design Scheme*, is presented in *Figure 2.5a*. Several variations of this programme are possible, particularly with respect to the timing of the construction of the bunds and the backfilling of the access channels. However as these programming alternatives are not expected to result in any changes in environmental impacts predicted to arise from the project, they will not be discussed further in this document.

As presented in *Figure 2.5a*, the programme will terminate in 2003 with the completion of the Pit C cap. The disposal operations will proceed continuously except during Stage 3, when the requirement to remove clean mud from Pit C to form the cap to Pit B may prevent any disposal of contaminated mud for a period of three to six months. To avoid a hiatus in disposal operations, several options will be considered, including dredging of additional mud from Pit C at an earlier date.

2.6 *CONSTRUCTION METHODS*

2.6.1 *Bund Construction*

The two bunds separating the three pits will be constructed using either rock fill imported from other projects or other suitable materials. The material will be delivered by barge and the bunds formed using a combination of precision disposal (ie from accurately-positioned, anchored barges) and placement by grab.

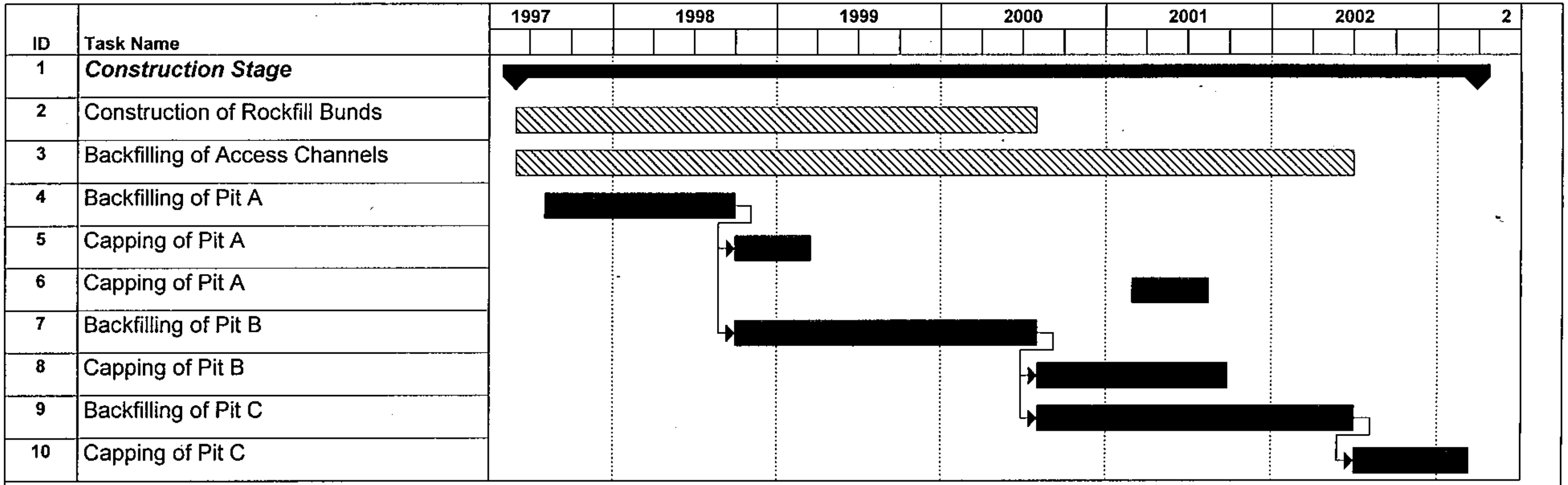
2.6.2 *Backfilling of Access Channels*

The backfilling of the southern (Pit A) and northern (Pit B) access channels will be achieved using clean mud or sand placed by bottom-dumping from barges. The initial backfilling, adjacent to the CMP pits should be formed using grab-dredged materials if mud is to be used, in order to form an acceptable slope. The material used for bulk backfilling behind the initial backfill can be mechanically or hydraulically dredged.

2.6.3 *Placement of Contaminated Mud*

The contaminated mud is likely to be either grab-dredged material delivered to site by barge or trailer-dredged mud. In both cases, placement is most easily achieved using the simple bottom-dumping methods which are presently used.

Until recently, barges delivering contaminated mud to the East Sha Chau pits were required to discharge between two anchored pontoons which supported a silt curtain. The silt curtain formed U-shaped semi-enclosure extending approximately down-current of the dumping location. Following a review of the procedures, the silt curtain was deemed to be unnecessary and was removed. A new method of placing, aimed at reducing the amount of propeller wash is being considered as a further improvement. As this placement method is not expected to alter the environmental acceptability of the project, it is not discussed further in this EIA. Alternative dumping procedures are described in *Environmental*



ID	Task Name
1	***Construction Stage***
2	Construction of Rockfill Bunds
3	Backfilling of Access Channels
4	Backfilling of Pit A
5	Capping of Pit A
6	Capping of Pit A
7	Backfilling of Pit B
8	Capping of Pit B
9	Backfilling of Pit C
10	Capping of Pit C

FIGURE 2.5a INDICATIVE PROGRAMME FOR CMP IV BACKFILLING

Monitoring and Audit for CMPs II and III at East Sha Chau, Draft Operations Manual, October 1996.

It is assumed that placement procedures at CMP IV will be in accordance with whatever best practice is in place at the time. However, because initial disposal in CMP IV will be into a much deeper and larger pit than at present, the effects of propeller wash will be significantly less than those at present and plumes formed during disposal (or by propeller wash) will drift further before they reach the edge of the pit. A greater proportion of the sediment in the plumes will have settled to the bed than is presently the case. In summary, the use of the current placement practice for CMP IV will result in no greater but rather less losses from the pit.

2.6.4 *Capping of Contaminated Mud*

The cap will be formed using hydraulic methods which are preferred because, if properly executed, there is less risk of contaminated sediment resuspension and mixing of the clean cap material with the contaminated material. This is because with hydraulic placement the rate of sediment release can be controlled and sediments are placed more gently on the seabed, thus resulting in less disturbance of previously placed material. A potential placement method is to use a combination of trailer dredger (or cutter suction dredger) and a floating pipeline terminating in a pontoon equipped with a down-pipe and, preferably, a diffuser. The diffuser discharges just above the bed as the pontoon is moved slowly across the area to be capped. This method can be used to form a more even and continuous cap and reduce the risk of localised failure or disruption during construction.

2.7 SOURCES OF SEDIMENT RELEASE

Several stages of backfilling of the proposed CMP IV, which utilize different material types and placement methods, may affect water quality. These stages, and the materials and methods tentatively proposed to be utilized in each stage, are summarized in *Table 2.7a*.

The objective of this EIA is to assess those sources of sediment release with the greatest potential for adverse environmental impacts. As result, the EIA focused on modelling the effects of release of grab- and trailer-dredged contaminated sediments via bottom-dumping at disposal points centred in CMP IV Pits A, B and C. Existing information was utilized to define realistic disposal scenarios. The modelling scenarios and results are presented in *Section* 3.7.

Other sources of sediment release were not modelled for the following reasons:

- construction of the bund is likely to have a negligible effect on water quality and sensitive receivers as the materials are assumed to be uncontaminated and effectively free of fine particles;
- the backfilling of access channels using uncontaminated grab-dredged mud will have a lesser impact than the disposal of contaminated material, since the uncontaminated mud is likely to be firmer and more cohesive than typical contaminated mud;

- capping operations will involve hydraulic placement of sand and clean mud, and possibly alternative methods of placement for granular or mixed material, which are likely to result in lower sediment release levels than those modelled for bottom dumping of contaminated material because sediments are contained within the downpipe as they pass through the water column.

Table 2.7a *Sources of Sediment Release in the CMP IV Project*

Source	Stages	Material/Placement	Assessment
Construction of bunds	1A, 2A, 3A	Rock or other suitable material via precision disposal or grabs	Negligible content of fines; impacts less than those associated with disposal of grab dredged material (Modelling Scenarios 1-3)
Damming of the access channels	1A, 2A	Grab-dredged clean mud via barges	Impacts represented by disposal of grab-dredged material (Modelling Scenarios 1-3)
Backfilling of access channels	3A, 5	Grab or trailer-dredged clean mud via barges	Impacts similar to disposal of grab dredged material (Modelling Scenarios 1-3)
Placement of Contaminated Mud	1B, 2B, 4A	Grab or trailer-dredged mud via bottom dumping	Impacts represented by disposal of grab-dredged material (Modelling Scenarios 1-3) and disposal of trailer-dredged material (Modelling Scenarios 4-7 and 9-11)
Capping	1C, 2B, 3B, 4B and 5	Sand and clean trailer-dredged mud via hydraulic placement techniques†	Impacts expected to be less than those predicted for grab-dredged (Modelling Scenarios 1-3) and trailer-dredged (Modelling Scenarios 4-7 and 9-11) material disposal.

† if granular or mixed material is to be placed for habitat enhancement, alternative methods of placement will be investigated.

2.8 MARINE TRAFFIC ISSUES

2.8.1 *Existing Traffic Flows*

While the main flow of traffic between Ma Wan and Deep Bay passes well to the north of the Borrow Pits, a substantial flow of traffic passes between Chek Lap Kok and Sha Chau. An earlier traffic survey in the area, carried out in 1994 for the Marine Impact Assessment for the laying of the Sha Chau fuel pipeline, indicated a daily flow of approximately 200 vessel movements, of which approximately 20% were high speed ferries. At the time of this earlier survey, the navigable distance between Sha Chau and Chek Lap Kok was of the order of 4,900 metres.

The existing flow of traffic, which now navigates through a reduced distance of 3,500 metres between Sha Chau and the Chek Lap Kok airport platform, was established from a radar survey carried out from the Hong Kong VTS from 10:28 hrs on May 29th 1996 to 10:23 hrs on 30th May 1996. The survey area included Chek Lap Kok Bank and Tap Shek Kok.

A total of 231 vessel movements was observed during the survey period. The breakdown of vessel types is shown in *Table 2.8a*.

Table 2.8a *Vessel Movement by Vessel Type: 29-30 May 1996*

Vessel Type	Number	Percentage
High-speed Ferries	8	3.5
Tugs and Tows	30	13.0
Other*	193	83.5
TOTAL	231	100

* unidentified vessel types including self-propelled barges, fishing boats and workboats, and small high speed craft plying to and from the airport reclamation area.

The difference between past and present levels of high-speed ferry activity is significant but it is known that the Hong Kong-Macau ferries will take the route past Sha Chau when weather conditions make the route to the south of Lantau unattractive. This may have been the case during the 1994 survey. Alternatively, the ferries may now find the Sha Chau passage less attractive due to the increased marine activity in connection with the works which are in progress in the area.

The distribution of all observed vessel movements by time of day and direction of travel is shown in *Figure 2.8a*. The majority of observed craft were westbound and the busiest time of day was 10:00-18:00 hrs. *Figure 2.8b* shows a north-south line between Sha Chau and Chek Lap Kok reclamation divided into 700-metre wide 'gates' with a histogram of movements through each gate derived from the traffic survey count. The majority of movements were through the southern gates with Gates 4 and 5 accounting for 54% of the survey sample. However, the high-speed ferries were observed to pass only through Gate 2 (eastbound) and Gates 2 and 3 (westbound).

2.8.2 *Anchorage Activities*

The area of the north of Chek Lap Kok in the Urmston Road has been used extensively as a temporary anchorage by large ocean-going vessels, either for the purposes of awaiting a berth at the Castle Peak Power Station at Tap Shek Kok, awaiting a pilot for the ports of Shekou and Chiwan, or as a typhoon shelter. The CMP IV borrow pit area is not used as an anchorage and Marine Department have indicated that are no plans to use the area as such in the future.

2.8.3 *Traffic Forecast*

During the backfilling of CMP IV, there will be some additional marine traffic working in, and sailing to and from the area. For the purposes of evaluating the potential marine traffic impacts, the following assumptions have been made:

- the construction materials for the bunds and access channels backfilling are assumed to be delivered by barge;
- most contaminated mud will be delivered by barges at an average rate of 20 barge-loads per day (the barges are assumed to have a nominal capacity of 1,000 m^3 and to be loaded to 80% of that capacity);
- some contaminated mud may be delivered by trailing suction hopper dredgers of typically 8,000 m^3 capacity and traffic associated with trailer dredger disposal is expected to be equal to or less than traffic associated with barge disposal;
- during construction of the two bunds, a grab dredger is assumed to be present to unload the barges and place the material, although materials may also be placed by precision dumping; and,
- a pontoon with office accommodation for Civil Engineering Office Port Works Division supervisory staff will be located close to the active pit for the full duration of contaminated mud placement and the capping operations.

On average, approximately 20 barges per day (or a mixture of barges and trailer dredgers) will be engaged in the disposal of contaminated mud. Most of the barges will arrive from the east. At peak periods of activity during the project, such as those periods when construction of bunds is taking place at the same time as placement of contaminated mud, barge movements could be doubled to an average of 40 per day. There may also be a cutter suction dredger, using floating and/or submersible pipelines, on site for some periods.

2.8.4 *Assessment of Marine Traffic Impacts*

Impacts on Existing Traffic

The backfilling operations will be well clear of the major shipping route through Urmston Road and are not expected to impact on that route except for occasional minor increases of traffic flow during times of peak backfilling or when backfilling is taking place at the same time as other activities such as bund construction. CMP IV is in shallow water and is thus not navigable by other than the smallest ocean-going shipping. Therefore the present usage of parts of

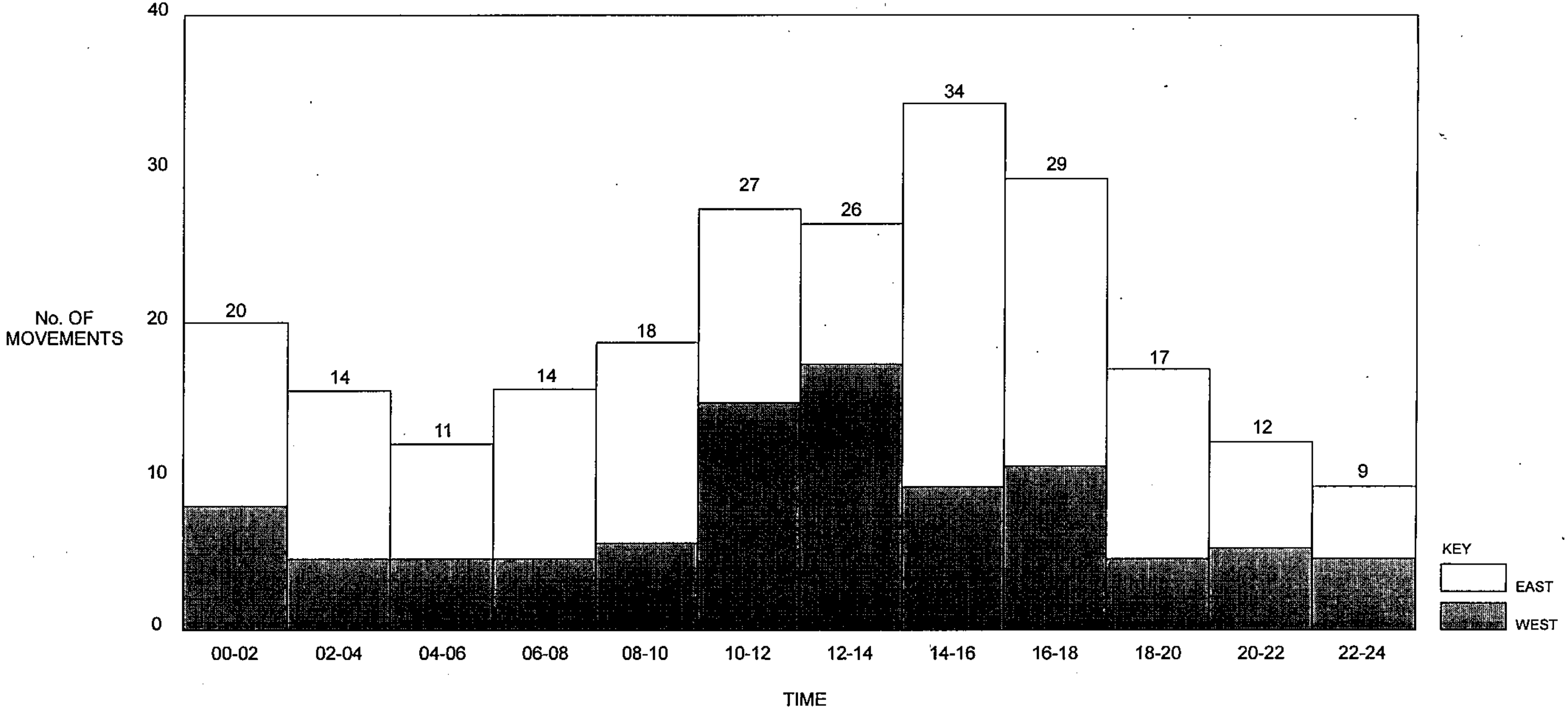


FIGURE 2.8a - MARINE TRAFFIC VARIATION BY TIME

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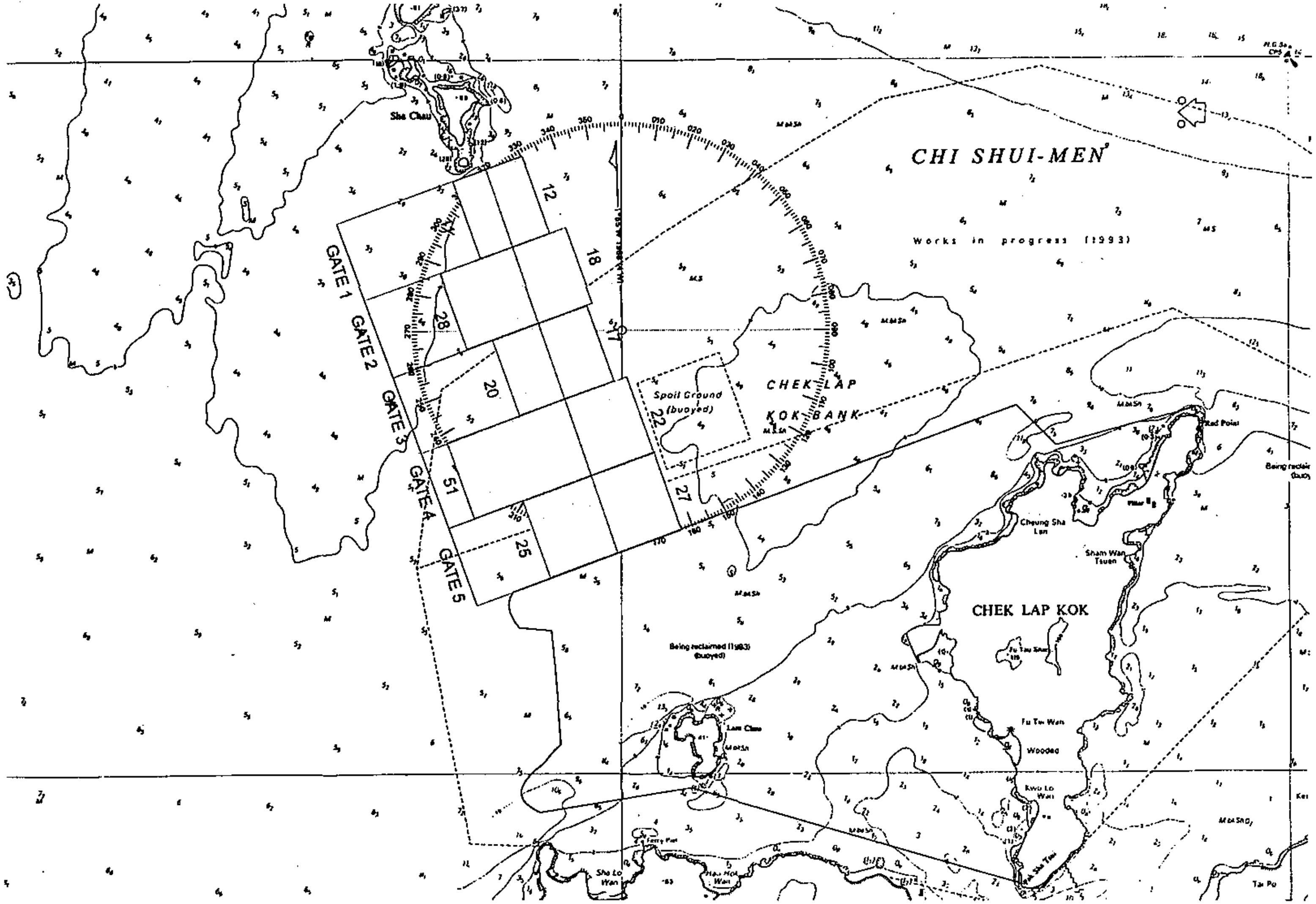

FIGURE 2.8b - GATE LOCATIONS AND HISTOGRAM OF EAST-WEST MARINE TRAFFIC MOVEMENTS

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Urmston Road as waiting areas and typhoon anchorages by large vessels will not be affected.

The present level of traffic passing through Ma Wan and Kap Shui Mun is about 1,000 vessel movement per day. Even at peak rates of backfilling and simultaneous construction works, the additional traffic which is generated, over and above that which is now involved in contaminated mud disposal at East Sha Chau, will be relatively small and probably of the order of 1-2% of the present flow through Ma Wan and Kap Shui Mun. However, in order to minimise the amount of space occupied by barges making passage through Ma Wan and Kap Shui Mun, it is recommended that tugs are secured alongside the barges and that towing astern be prohibited.

In the event that the dynamic placement procedures which are presently under consideration are adopted (see *Section 2.6.3*), tugs should at all times remain attached to the barges. Marine Department have indicated that, while drifting, tugs should display the 'Not Under Command' signals. Provided that these precautions are implemented, the dynamic placement method is not considered likely to cause disruption or risk to other traffic. Further, all marine traffic involved in the backfilling operations must comply with the General Allocation Conditions for Marine Disposal Areas and Mud Disposal Sites and any other conditions required by Marine Department.

Impacts of Existing Traffic on Backfilling Operations

The radar survey indicated that most of the existing marine traffic is engaged in marine works and that only barge traffic and small craft pass through the southerly Gates 4 and 5. Through traffic generally passes through the more northerly gates and will anticipate marine works in progress in connection with the airport development. Disruption to the backfilling operations is thus not considered to be likely.

Although Marine Department have not indicated a requirement to deploy a guard boat during backfilling operations, it may be prudent to do so during periods of peak activity, particularly if vessel movements exceed those which are forecast here. The purpose of such a vessel would be to warn other craft of the disposal and construction operations. The boat would need to be about 15 metres in length and sufficiently fast to intercept oncoming traffic. It would be marked with the word GUARD and equipped with a powerful searchlight, loudhailer and VHF radio.

3 WATER QUALITY

3.1 INTRODUCTION

This section presents an assessment of potential water quality impacts associated with the proposed disposal of contaminated material in the marine borrow areas at East Sha Chau (CMP IV). The objective is to provide a prediction of the extent, magnitude and acceptability of potential water quality impacts, and to develop and recommend practical and cost-effective mitigation measures where necessary.

This section of the DEIA presents information on existing hydrodynamic, water quality and sediment quality characteristics of the Study Area for background. It also describes the results of eleven modelling scenarios which evaluate the potential water quality impacts associated with disposal of contaminated mud in Pits A, B and C of the CMP IV. Impacts are assessed with reference to suspended sediment, dissolved oxygen and nutrient plumes, suspended sediment concentrations at sensitive receivers, and sediment deposition for each scenario. The extent of the area in which the water quality objective (WQO) is predicted to be exceeded, and the expected concentrations of metals and organic pollutants resulting from disposal are presented for a representative scenario.

In addition to these potential water quality impacts several other key issues must be addressed in order to determine if the project is environmentally acceptable. These issues include:

- the environmental consequences of pore water release during consolidation of contaminated material both before and after capping (*Section 3.10*);
- the effect of wave, storm and tidal currents on erosion of material disposed inside the CMP IV and on the stability of CMP IV caps (*Section 3.11*);
- potential cumulative impacts associated with backfilling of CMP IV and, 1) simultaneous dredging or disposal in other parts of CMP IV, or 2) in other projects in the Study Area (*Section 3.12*).

3.2 STATUTORY REQUIREMENTS AND EVALUATION CRITERIA

The acceptability of water quality impacts will be determined through comparisons with statutory and other requirements. Under the Water Pollution Control Ordinance, Hong Kong waters are subdivided into 10 Water Control Zones (WCZ) each of which has a designated set of statutory Water Quality Objectives (WQO) which are designed to protect the marine environment and its users.

The proposed CMP IV is situated within the Northwestern WCZ (NWWCZ) for which the following WQOs apply:

- **Suspended Solids:** Suspended solids should not be raised above ambient levels by in excess of 30% nor cause the accumulation of suspended solids which may adversely affect aquatic communities;

- **Dissolved Oxygen:** Dissolved oxygen (DO) within 2m of the bottom should not be less than 2 mg l^{-1} for 90% of the samples; depth averaged DO should not be less than 4 mg l^{-1} for 90% of the samples and not less than 5 mg l^{-1} for fish culture subzones;
- **Nutrients:** Nutrients should not reach levels sufficient to cause excessive algal growth and annual mean depth averaged inorganic nitrogen should not exceed 0.5 mg l^{-1};
- **Ammonia:** The un-ionized ammoniacal nitrogen level should not be more than 0.021 mg l^{-1}, calculated as the annual average (arithmetic mean)
- **Toxins (A):** Waste discharges shall not cause the toxins in water to attain such levels as to produce significant toxic, carcinogenic, mutagenic or teratogenic effects in humans, fish or any other aquatic organisms, with due regard to biologically cumulative effects in food chains and to toxicant interactions with each other;
- **Toxins (B):** Waste discharges shall not cause a risk to any beneficial use of the aquatic environment.

Although the WQO for ammonia would apply to backfilling at CMP IV, the effects of nitrogen release from sediments will be assessed using the nutrient WQO. Compliance with other WQOs will not be addressed in this DEIA since disposal plumes are not predicted to reach any of the WCZ subzones for which these other WQOs apply.

3.3 BASELINE CONDITIONS

3.3.1 Bathymetry

Bathymetric surveys of the existing contaminated mud pits and the surrounding seabed were conducted by Electronic and Geophysical Services (EGS) in January 1995 (1). Results showed that the undredged seabed is level with a mean depth of -5 mPD to -6 mPD. However within the area presently gazetted for disposal of contaminated mud (see *Figure 1.1a*) the seabed is highly variable reaching -17 mPD in some areas.

3.3.2 Hydrodynamics

The hydrodynamic regime in the vicinity of the CMP IV is complex and varies with a number of factors including the lunar cycle (spring and neap cycle), the season and the rate of flow of the Pearl River. In general, the main ebb tide currents flow south along the Urmston Road, with a subsidiary flow bifurcating northwest of Chek Lap Kok to flow south down the west coast of Lantau, and southeast around the east of Chek Lap Kok Island. Flood tides show the reverse pattern.

During the dry season the influence of the Pearl River is at its least because of reduced flows, resulting in typically well-mixed coastal waters. In contrast

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(1) Electronic and Geophysical Services (February 1996). Swath Bathymetry Survey at East Sha Chau, Final Report.

during the summer wet season, the flow of the Pearl River increases and the coastal waters become highly stratified as the large influx of brackish water overlies the denser, more saline oceanic waters near the sea bed.

Currents in the area are generally strongest on dry season spring tides. The strength of the currents have been measured in two studies. The first found moderate to low speeds (generally less than 0.4 m s^{-1}) predominated with speeds rising to 1.0 - 1.5 m s^{-1} during spring tides[2]. The second study, which looked only at spring tides, recorded a maximum of 0.6 m s^{-1} [3]. Acoustic Doppler Current Profiler surveys were undertaken in the vicinity of the CMP IV pits on the spring tide of 19-20 January 1996 (dry season) and the spring and neap tides of July-August 1996 (wet season). These data were used in calibration and validation of the Telemac model for this Study (see *Section 3.6.1*). This study found current speeds of up to 1.1 m sec^{-1} on spring tides and up to 0.7m sec^{-1} on neap tides.

3.3.3 *Water Quality*

Changes in the hydrodynamic regime that result from changes in the flow of the Pearl River have a major influence on the water quality in the Study Area. During the summer wet season there is a large influx of freshwater from the Pearl River which results in steep salinity gradients. The river water typically carries high silt and organic pollutant loads which impact the ambient water quality. In contrast, during the winter dry season, freshwater input is much lower, and conditions are more typically oceanic, as saline water moves northwards into the Pearl River Delta and the water bodies become well-mixed.

Data collected by the Environmental Protection Department (EPD) under the Routine Water Quality Monitoring Programme has been utilised in order to provide a preliminary assessment of water quality parameters in the Study Area (*Figure 3.3a*). As recommended by EPD in comments on the Initial Assessment Report, data from 1994 has been excluded from the baseline dataset for the purposes of establishing baseline SS levels. It was recommended that 1994 data be avoided since it may be unrepresentative of ambient conditions due to a number of construction projects taking place at this time. For the purposes of initially determining compliance with water quality objectives, *Table 3.3a* provides 1995 data on those parameters relevant to the NWWCZ WQOs. Both wet and dry season means have been calculated using the assumption that the wet season extends from mid-April to mid-October. Although it appears anomalous, the data indicate that suspended sediment concentrations at all depth intervals are substantially higher in the dry season than in the wet season.

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(2) CES & BCL (August 1994). East Sha Chau Monitoring Programme, Final Report (November 1992 - December 1993).

(3) Hydraulics and Water Research (Asia) Ltd, March 1993. Disposal of Contaminated Mud at East Sha Chau: An Assessment of the Stability of Dumped Spoil and Capping Layers.

Table 3.3a *Baseline Conditions for SS, DO and Total Inorganic Nitrogen from Stations NM2, NM3, NM5 and NM6 during 1995.*

Parameter	**Dry Season**					**Wet Season**				
	Mean	**SD**	**Max**	**Min**	**90th Percentile**	**Mean**	**SD**	**Max**	**Min**	**90th Percentile**
SS (mg l^{-1})										
Surface	28.50	24.61	88.00	11.00	65.70	6.42	1.59	8.70	3.80	8.26
Middle	40.33	35.29	96.00	11.00	84.80	7.28	2.37	12.00	4.50	9.44
Bottom	46.45	42.00	120.00	11.00	120.00	12.08	9.06	32.00	7.10	26.60
Depth Averaged	38.00	34.16	120.00	11.00	87.60	8.49	5.79	32.00	3.80	9.40
Total Inorganic Nitrogen										
Surface	0.24	0.16	0.62	0.04	0.38	0.56	0.25	0.93	0.24	0.87
Middle	0.21	0.17	0.56	0.00	0.37	0.44	0.14	0.73	0.28	0.58
Bottom	0.21	0.13	0.39	0.07	0.38	0.32	0.19	0.55	0.00	0.53
Depth Averaged	0.22	0.15	0.62	0.00	0.38	0.44	0.22	0.93	0.00	0.72
DO (mg l^{-1})										
Surface	6.83	0.54	7.76	6.19	7.49	7.40	2.46	11.49	4.74	10.99
Middle	6.63	0.60	7.66	5.68	7.38	6.39	2.47	10.22	3.99	10.00
Bottom	6.62	0.51	7.27	5.74	7.26	5.73	2.09	8.95	3.77	8.85
Depth Averaged	6.69	0.54	7.76	5.68	7.41	6.55	2.39	11.49	3.77	10.15

Note: [1] Depth averaged values are calculated from the whole data set ie all surface, middle and bottom values.

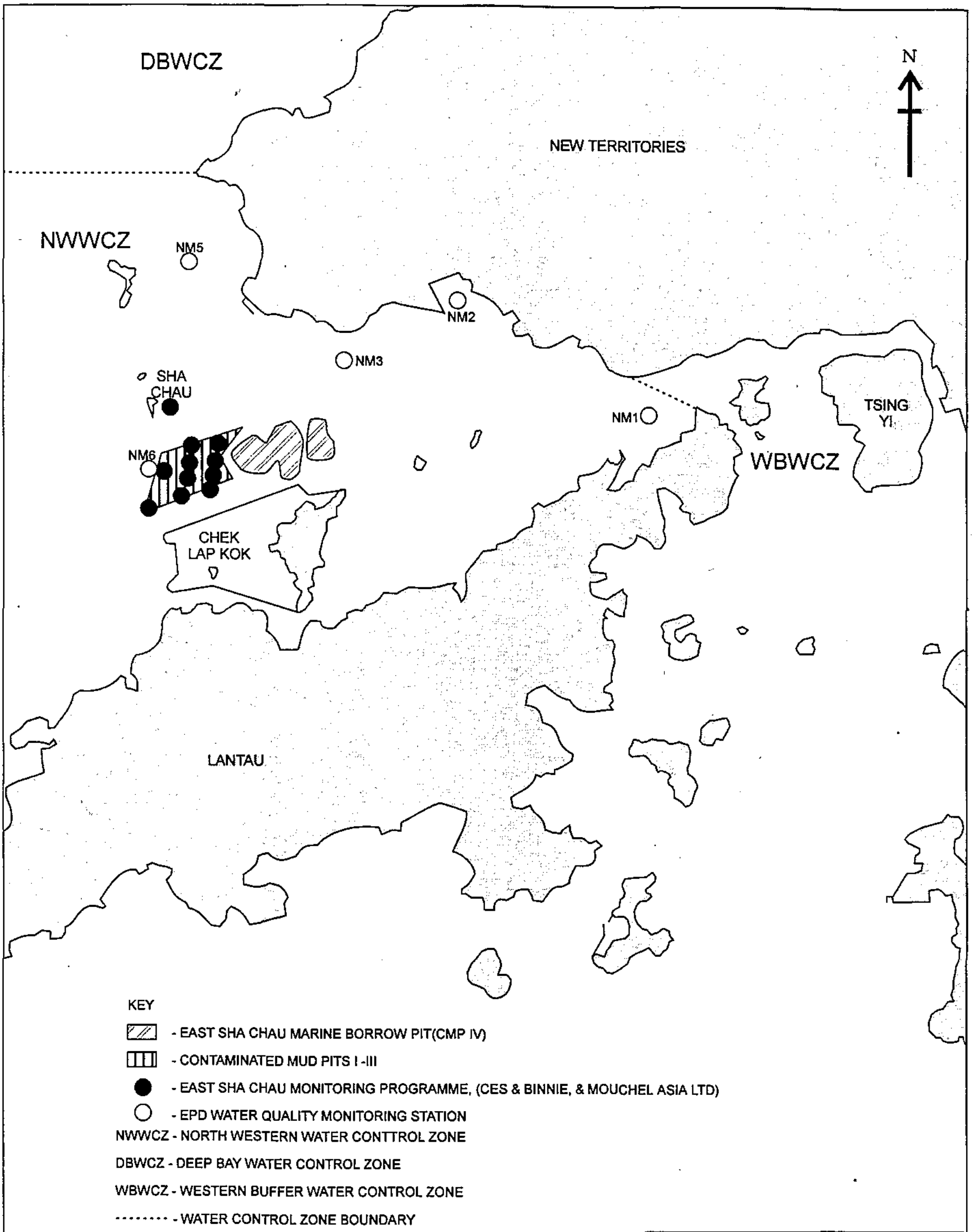

FIGURE 3.3a - LOCATION OF WATER QUALITY MONITORING STATIONS IN THE VICINITY OT THE EAST SHA CHAU CMP IV

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The NWWCZ's WQO for suspended solids is defined as 30% above ambient. EPD maintains a flexible approach to the definition of ambient levels, preferring to allow definition on a case-by-case basis rather than designating a specific statistical parameter as representing ambient. For a recent backfilling EIA in the study area, ie the North of Lantau/South Tsing Yi MBA EIA, EPD suggested the 90th percentile as the most appropriate measure of ambient conditions. The 90th percentile offers advantages over such parameters as the mean, which can be substantially biased if the database is skewed, and the maximum, which may represent a rare and/or anomalous event, and it is thus appropriate as a measure of ambient for this DEIA.

The 90th percentile data in *Table 3.3a* is used to calculate suspended solid WQOs as follows:

- Suspended Solid WQO (dry season):	113.88 mg l^{-1} (absolute) 26.28 mg l^{-1} (elevation)
- Suspended Solid WQO (wet season):	12.22 mg l^{-1} (absolute) 2.82 mg l^{-1} (elevation)

As an alternative approach, EPD have also indicated that under certain circumstances, the maximum permissible impact on water quality can be defined as an elevation of 10 mg l^{-1} above the existing SS concentrations[4].

In addition to the EPD Routine Water Quality Monitoring Programme, other relevant data sets have been compiled through both pit-specific and cumulative Environmental Monitoring and Audit (EM&A) programmes for the existing East Sha Chau CMPs (see *Section 3.5*). Although it was intended to analyse these datasets, in addition to EPD datasets, for this DEIA, comparable 1995 EM&A datasets are not presented here due to difficulties in compiling and standardizing datasets collected under different EM&A contracts.

Even though SS WQOs have been developed, it is important to note that SS levels in the region are naturally highly variable due to the variable output of the Pearl River. During geophysical monitoring carried out in the ESC area in the 1996 wet season, SS concentrations of over 100 mg l^{-1} were recorded during spring tides at mid- and lower levels of the water column[5]. In this survey concentrations showed a rapid and irregular fluctuation of many tens of mg l^{-1} in amplitude which indicates that the seabed near the ESC CMP IV is highly fluid.

Information on metal concentrations in the water column in the East Sha Chau Contaminated Mud Pit area is presented in *Table 3.3b*. These data were collected between June and November 1995 during the CMP environmental monitoring and audit programme.

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[4] Memo from Deborah Cha, EPD to Peter Whiteside, CED, 25 November 1996.

[5] East Sha Chau Borrow Pits EIA for Backfilling of Pits with Contaminated Mud: Collection of Field Data for Calibration of Hydraulic Model. Wet Season Measurements, Final Report. (August 1996). EGS for ERM HK LTD.

Table 3.3b *Metal concentrations (Soluble Portion in µg l^{-1}) in Water from East Sha Chau Environmental Monitoring Programme Reference Stations*[(6)]

Metal	Maximum Possible Estimate of Mean [a]	Minimum Possible Estimate of Mean [b]
Cadmium	0.37	0.08
Chromium	1.6	1.2
Copper	7.0	1.8
Lead	11.0	0
Mercury	1.8	0.7
Nickel	4.4	2.4
Zinc	0.017	0.007

[a] obtained by replacing all non-detect data points with the detection limit

[b] obtained by replacing all non-detect data points with zero

It is noted that while the report states the concentration of zinc is reported in µg l^{-1} (ppb), the concentrations appear to actually have been measured in mg l^{-1} (ppm). Use of these data in this EIA takes this discrepancy in account.

3.3.4 *Sediment Quality*

EPD's Routine Sediment Monitoring Programme data have been used in this EIA to provide an indication of the sediment quality baseline. Additional datasets, derived from pit-specific and cumulative EM&A programmes at the existing ESC CMPs, were considered for this DEIA. However, due to difficulties in identifying unimpacted from impacted data points and the inconsistencies introduced into the dataset by excluding certain stations during certain periods,. the sediment baseline has been compiled using EPD Routine Sediment Monitoring Programme data only.

Baseline sediment conditions are described below for stations NS2, NS3, NS4 and NS6 (in the same locations as water quality monitoring stations NM2, NM3, NM5 and NM6, respectively (see *Figure* 3.3*a*)) of the EPD Routine Sediment Monitoring Programme. Data on non-metal parameters in these sediments are derived from the most recent, published dataset[(7)] and summarised in *Table* 3.3*c*. Data on heavy metal and organic pollutants in sediment from Stations NM2, NM3, NM4 and NM6 were supplied by EPD for the period January 1994 to December 1995, and are summarised in *Table* 3.3*d*. Note that EPD-measured sediment parameters do not include all seven of the metals used in sediment classification (ie the EPD testing programme substitutes Fe for Ni).

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(6) Binnie and CES. Environmental Monitoring and Audit of Contaminated Mud Pits at East Sha Chau, Final Summary Report, October 1996.

(7) Marine Water Quality in Hong Kong for 1994. EPD 1995

Table 3.3c *Summary of sediment parameters in Stations NS2, NS3, NS4 and NS6 in 1994*

Parameter	NS2	NS3	NS4	NS6
Particle size distribution (%<63μm)	>=80	>=80	60-79	>=80
Eh (-mV)	100-149	<99	<99	<99
Total Organic Carbon (%w/w)	<=0.4	<=0.4	0.5-0.6	0.5-0.6
Total Nitrogen (mg kg dry solids^{-1})	300-499	300-499	<=299	300-499
Total Phosphorous (mg kg dry solids^{-1})	<=199	<=199	<=199	<=199

Note: Top 100 mm of sediment analysed.

Table 3.3.d *Heavy Metal Content of Sediment from Stations NS2, NS3, NS4 and NS6 during the period January 1994 to December 1995 (all values in mg kg $^{-1}$)*

Parameter	Minimum	Maximum	Mean	SD
Station NS2				
Cd	0.05	0.2	0.1	0.071
Cr	14	43	28.5	13.33
Cu	7	64	34.25	23.67
Hg	0.5	0.5	0.05	0
Fe	17000	37000	26500	10472.19
Pb	20	47	33	12.62
Zn	43	120	80.75	35.43
Station NS3				
Cd	0.05	0.2	0.1125	0.063
Cr	28	36	32.25	3.3
Cu	21	26	24	2.16
Hg	0.05	0.05	0.05	0
Fe	32000	39000	34250	3304.04
Pb	35	36	35.25	0.5
Zn	80	95	88.25	6.65
Station NS4				
Cd	0.05	0.2	0.1	0.071
Cr	24	37	28.25	6.13
Cu	16	26	21	5.23
Hg	0.05	0.05	0.05	0
Fe	30000	51000	39500	8736.9
Pb	35	43	38	3.56
Zn	76	98	85.5	9.47

Parameter	Minimum	Maximum	Mean	SD
Station NS6				
Cd	0.1	0.6	0.4	0.22
Cr	32	45	39.25	5.44
Cu	24	84	45.25	26.75
Hg	0.05	0.08	0.06	0.015
Fe	31000	42000	35250	4716.99
Pb	40	42	41	0.82
Zn	91	120	105.25	12.53
Composite				
Cd	0.05	0.3	0.12	0.075
Cr	14	45	32.06	8.50
Cu	7	84	31.125	18.93
Hg	0.05	0.08	0.053	0.009
Fe	17000	51000	33875	8204.67
Pb	20	47	36.81	6.65
Zn	43	120	89.94	20.01

EPD's Routine Sediment Quality Monitoring Programme does not include monitoring for PCBs, PAHs or other organics. However, these contaminants are measured as a component of the present EM&A programme at ESC. Samples collected at reference stations at Lung Kwu Chau and the Brothers in December 1995, February and April 1995 have been analysed. A summary of the concentrations found at the reference stations are presented in *Table 3.3e*. It should be noted that levels contaminants were below the detection limit in the majority of samples.

Table 3.3e ***PCB and PAH levels in Sediments recorded during ESC EM&A programme[8]***

Contaminant Group	Substance	Range of Concentrations (μg kg^{-1})	
		Lung Kwu Chau	The Brothers
PAH - Low MW	Acenaphthylene	ND to 701.4	ND to 43.7
	Phenanthrene	ND to 42.6	ND to 58.6
PAH - High MW	Fluoranthene	ND to 44.5	ND to 76.6
	Benzo(a)pyrene	ND to 33	ND
PCBs		ND to 98.5	ND to 1947.6

Note: ND= not detected at analytical detection limit
detection limit for Acenaphthylene=25 μg kg^{-1}
detection limit for other PAHs=1 μg kg^{-1}
detection limit for PCBs=1 μg kg^{-1}

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[8] Environmental Monitoring and Audit for Contaminated Mud Pits II and III at East Sha Chau. Monthly Monitoring Reports. Mouchel Asia Ltd.

3.4 SENSITIVE RECEIVERS

A number of sensitive receivers which may be affected by the changes in water quality resulting from backfilling activities are located within the Study Area. These have been identified below in accordance with the Hong Kong Planning Standards and Guidelines. Facilities, sites and areas which are sensitive to changes in water quality are illustrated in *Figure 3.4a* and discussed below. Those sensitive receivers within close proximity to predicted plumes, and several directional indicators, were selected for plotting the results of the modelling scenarios in *Annexes D-N*. These locations represent a subset of those discussed below and include NE Brothers (directional indicator only), Castle Peak Power Station, Lung Kwu Chau, Sha Chau (four points), Sha Chau Beach, Chek Lap Kok Water Intakes (three points) and Tai O (directional indicator only).

3.4.1 *Bathing Beaches*

A number of gazetted and non-gazetted bathing beaches located along the Tuen Mun coastline may be affected by water quality impacts arising from the proposed backfilling activities. These include Lung Kwu Lower Beach, Lung Kwu Upper Beach, Butterfly, Castle Peak, Kadoorie, Old Cafeteria, New Cafeteria, and Golden Beaches. Water quality at these beaches is generally poor due to a number of untreated sewage discharges along the Tai Lam coastline. Nevertheless, with future improvements in sewerage and sewage treatment, it is expected that water quality at these beaches will improve and they will become increasingly important as recreational areas.

3.4.2 *Cooling Water Intakes*

There are a number of water intakes around the Study Area that have specified SS criteria to protect the abstraction systems (eg filters and pumps) and maintain appropriate water quality for the designated use.

Castle Peak Power Station has a 5 km radius within which the water quality must be maintained below 150 mg l^{-1} of SS, although the tolerable level of SS for cooling water is considered by EPD to be much lower than this. The proposed CMP IV is located at approximately 5 km from the power station. Black Point Power Station, situated approximately 10 km to the north, is scheduled to be commissioned in 1996 and is anticipated to have similar requirements. There are additional intakes at Tsing Yi, Tsuen Wan, Tuen Mun and Chek Lap Kok (2 intakes plus 1 proposed).

3.4.3 *Fisheries and Mariculture Zones*

There are several fisheries and mariculture areas in the western waters of Hong Kong which have individual water quality criteria. These are the Ma Wan Mariculture Zone, Ma Wan Fishery, Tung Wan Tsai Fishery, Pennys Bay Fishery, Tai Pak Wan Fishery, Silvermine Bay Fishery, and the Kau Yi Chau Fishery. Water quality protection guidelines set by AFD, and applicable to both fisheries and mariculture zones, require that SS levels remain below 50 mg l^{-1} and do not exceed the highest level recorded in the area during the five years before commencement of works.

The study area also contains habitats which serve as commercial finfish and shrimp nursery and/or spawning grounds. Impacts to these and other transitory or mobile sensitive receivers were not plotted as discrete points for evaluation in the water quality assessment and are discussed separately in *Section 4*. Another area of ecologically sensitive habitat, the Sha Chau Islands, are represented by a series of discrete points, North, South, East and West Sha Chau, for purposes of compliance evaluation in the water quality assessment.

3.5 *WATER QUALITY IMPACTS ASSOCIATED WITH THE EXISTING CMPS*

Environmental monitoring and audit programmes(9) conducted at the previous and existing East Sha Chau CMPs (Pits I-IIId) provide data on metal, suspended sediment and dissolved oxygen concentrations in the vicinity of the proposed CMP IV and allow evaluation of the impacts associated with use of the existing CMPs. These data were reviewed as part of a recent evaluation of Hong Kong's contaminated mud disposal practices(10).

In its review of data collected since June 1995, the study found no evidence of trends in elevated concentrations of metals or suspended sediments at stations immediately adjacent to active and recently capped disposal pits relative to reference stations. Although SS levels were occasionally elevated following disposal events, the elevations were considered small and/or brief in comparison to other contributors to SS concentrations such as industrial/ anthropogenic activity and the discharge of the Pearl River. Based on earlier EM&A data, the review assumed a concentration of 100 mg l^{-1} represented the maximum baseline conditions (ie the maximum naturally occurring concentration).

In contrast to the findings regarding metals and suspended sediments, the previous EM&A programme indicated a concern with dissolved oxygen levels. Throughout the monitoring period (1993-1995) low concentrations (<4 mg l^{-1}) were periodically detected in the vicinity of the CMPs. The low dissolved oxygen levels have not been linked to disposal activities, and may represent a sampling artifact. However, the data suggest that future monitoring of disposal operations should include more detailed observations of DO levels.(11)

3.6 *MODELLING OF WATER QUALITY IMPACTS*

Mathematical modelling has been conducted to predict the fate of sediment suspended into the water column during disposal operations and the resulting water quality impacts. This has been achieved using the TELEMAC 3D suite of models. A tidal flow model was used to generate hydrodynamic predictions for use in a sediment plume model which, in turn, generated predictions of suspended sediment concentrations and other water quality parameters. The model coverage, the TELEMAC model mesh and the model bathymetry are shown in *Figures 3.6a, b* and *c*. Detailed descriptions of the TELEMAC 3D flow model and the sediment plume model are given in *Annexes B* and *C*, respectively.

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(9) CES & Binnie (August 1994) *op cit*

(10) EVS Environment Consultants (1996). Review of Contaminated Mud Disposal Strategy and Status Report on Contaminated Mud Disposal Facility at East Sha Chau, prepared for Civil Engineering Department, Hong Kong Government

(11) EVS (1996). *op cit*

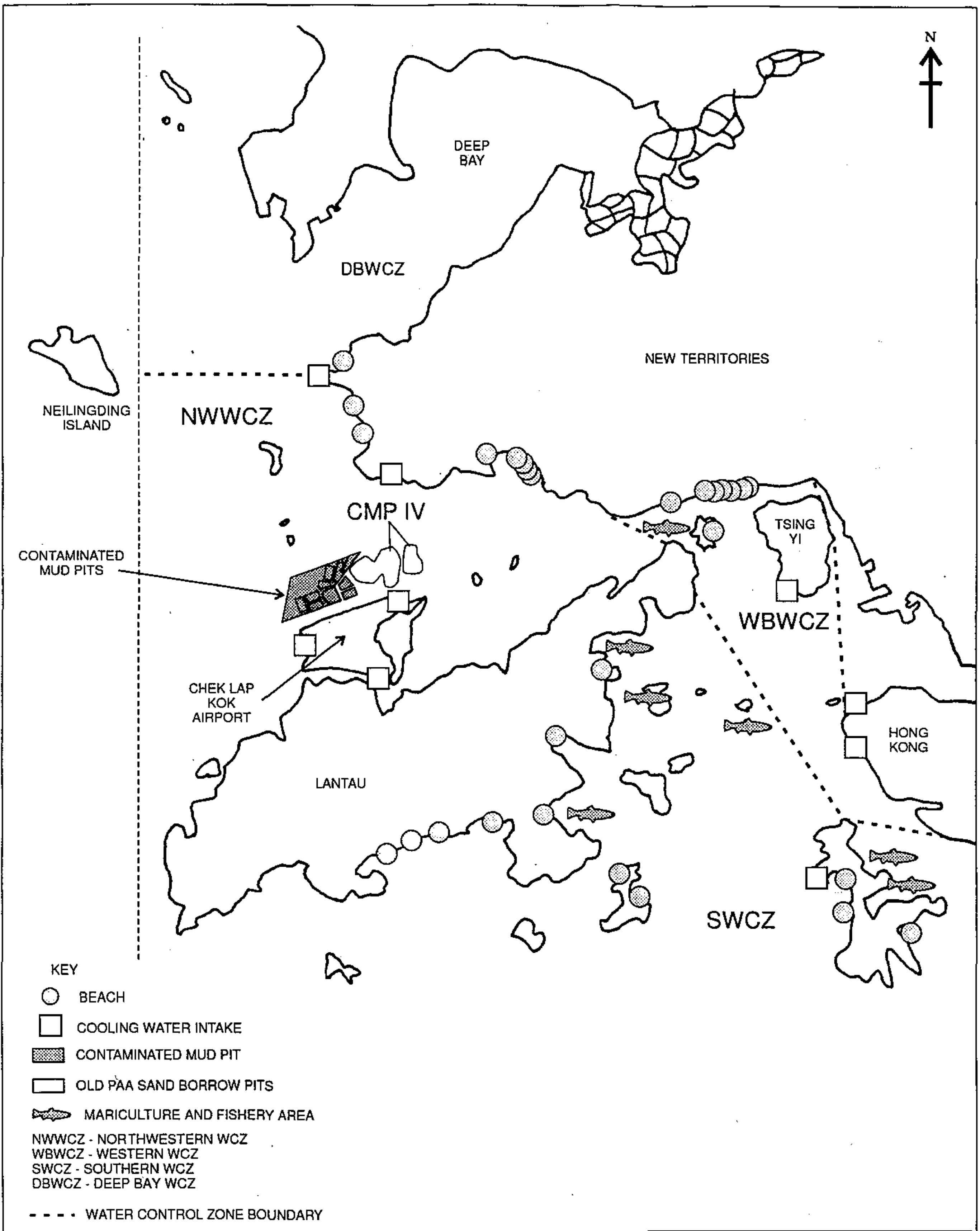

FIGURE 3.4a - IDENTIFIED WATER SENSITIVE RECEIVERS, LOCATED WITHIN THE VICINITY OF EAST SHA CHAU MARINE BORROW PITS (CMP IV)

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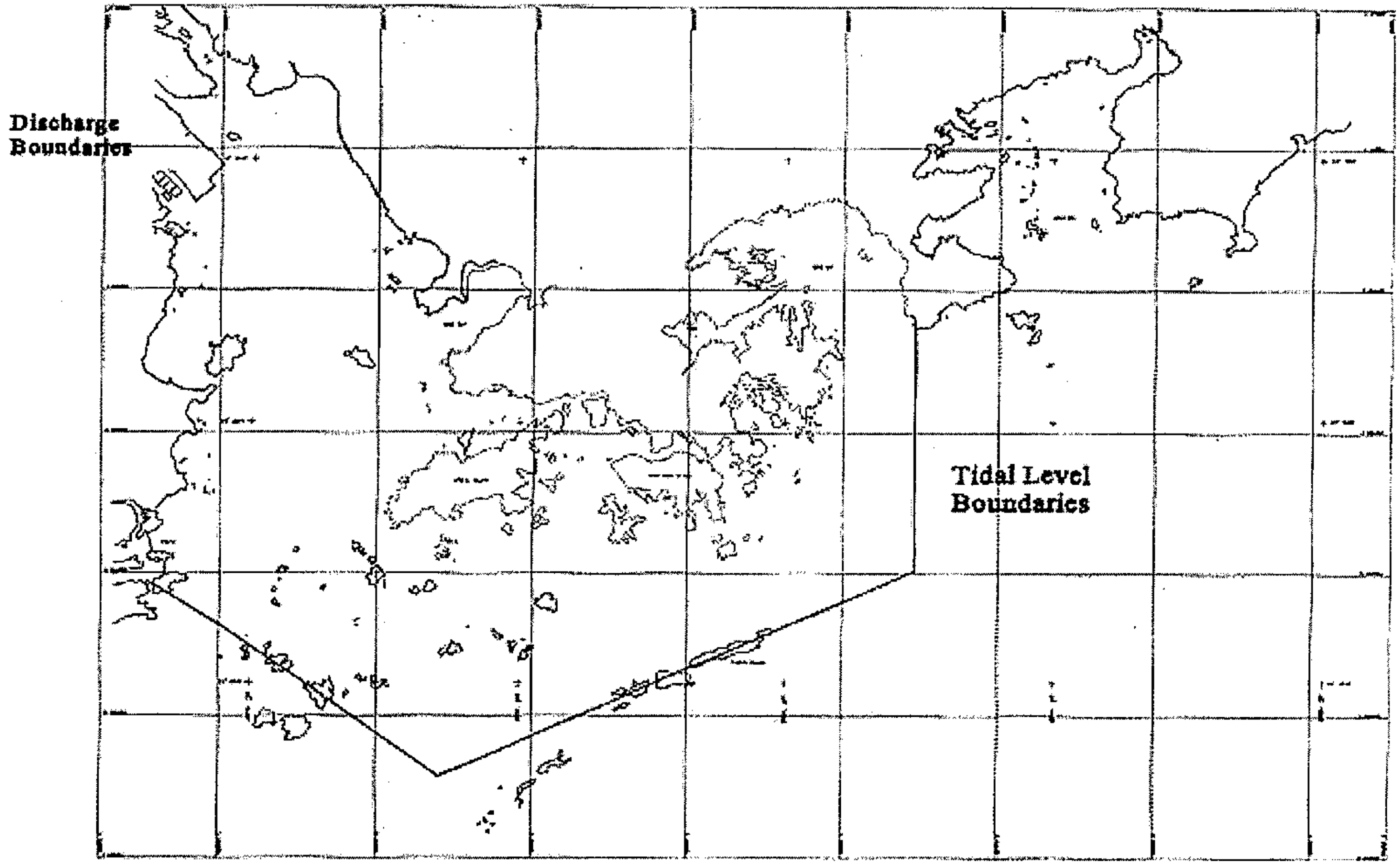

FIGURE 3.6a - EXTENT OF MODEL COVERAGE

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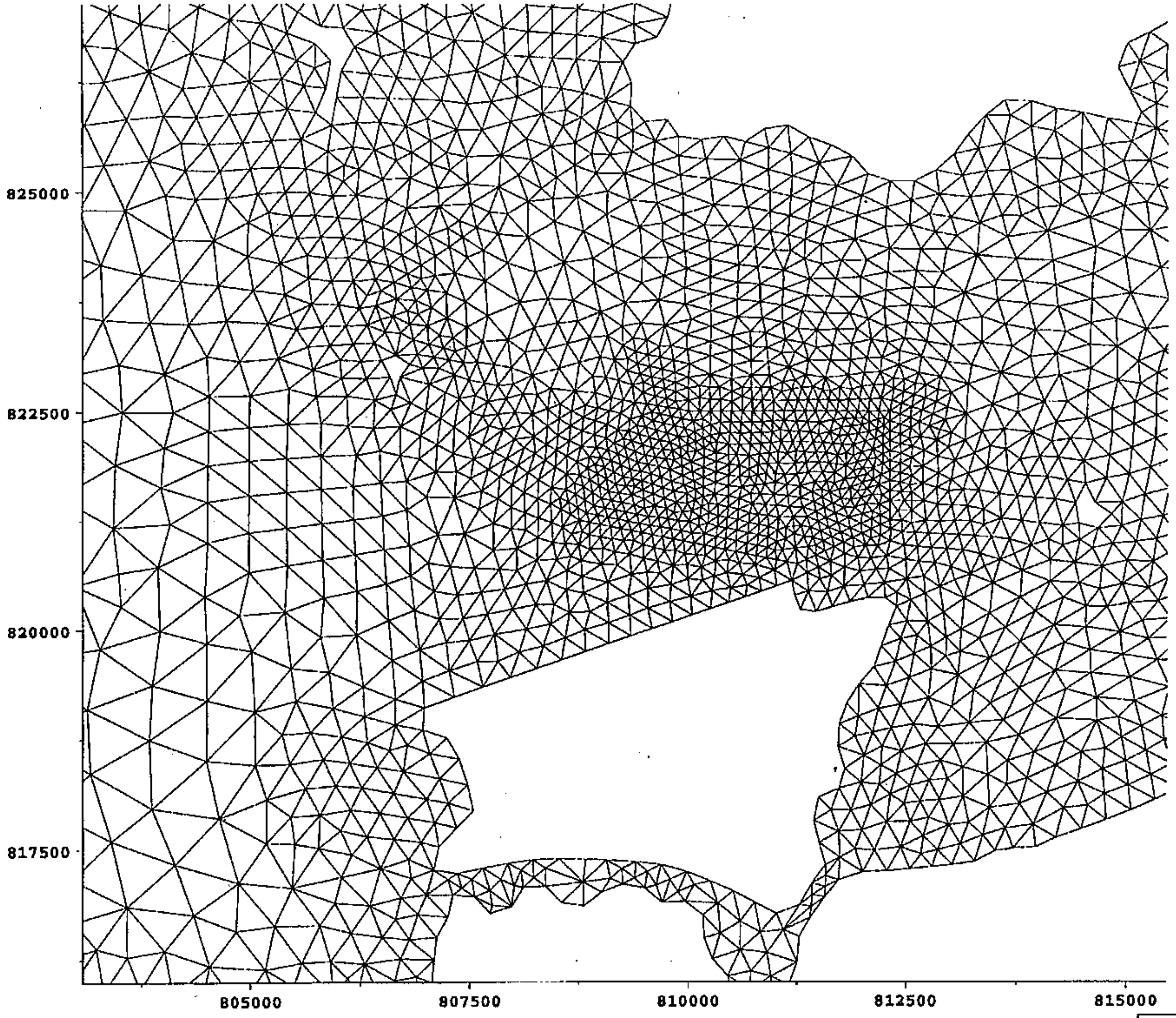

FIGURE 3.6b - LAYOUT OF MODEL MESH

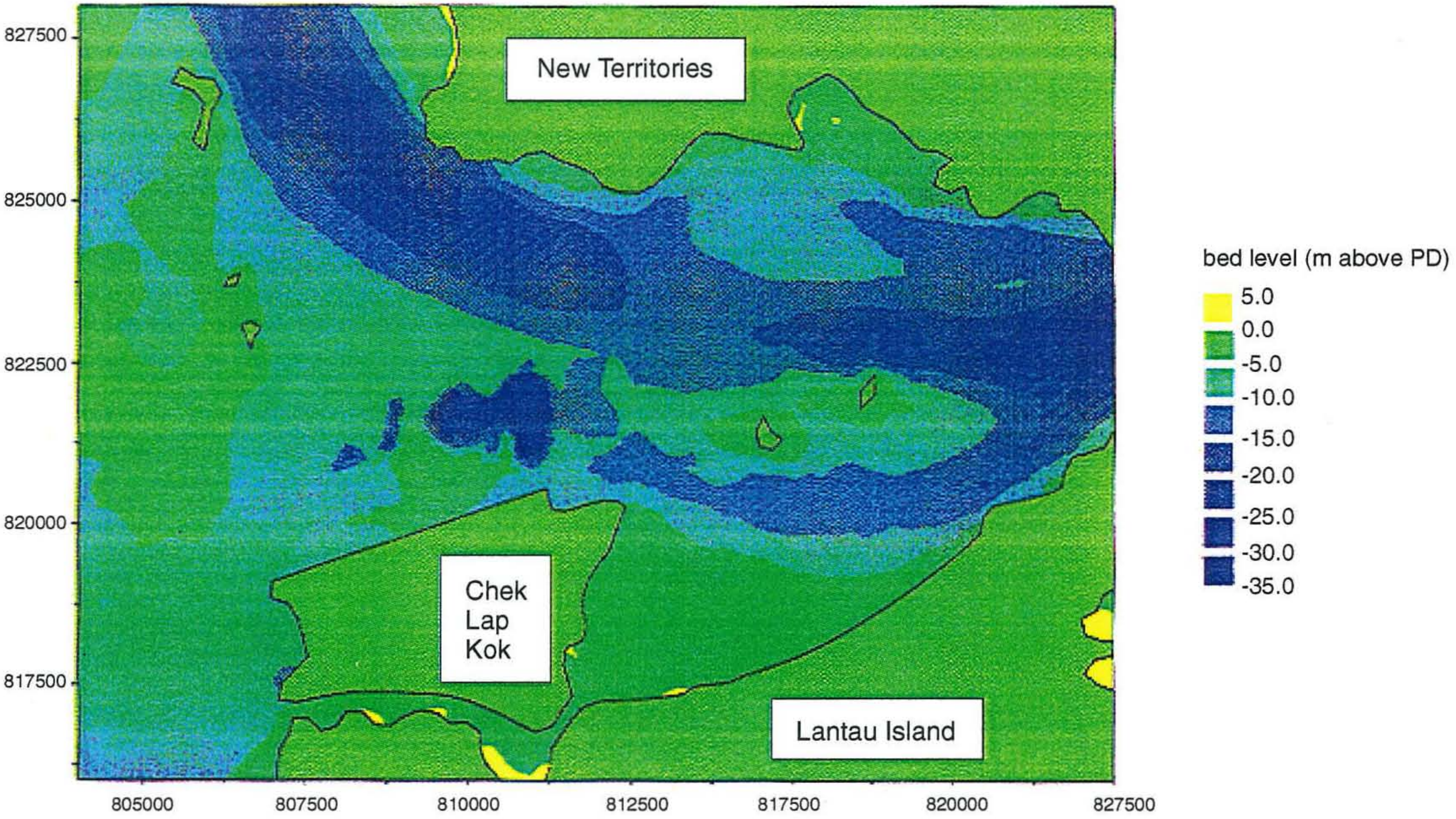

FIGURE 3.6c - MODEL BATHYMETRY

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3.6.1 *Flow Model*

The TELEMAC flow model was set up to simulate 4 specific tides and calibrated using a large tidal level, water velocity and salinity data set collected from 1990-1993 under the same or very similar tidal conditions. Having calibrated the model for historic conditions, the large reclamations constructed over the past 6 years were inserted into the model's bathymetric data set together with the present day dredging associated with CMPIV. The model was then used to simulate the same 4 tidal conditions and the results compared with new field data collected in the 1996 dry and wet seasons(12)(13).

Dry Season Validation

In the dry season, it was found that, at any point, there was little variation in flow direction over the water depth and that the velocity profile over the excavated pits extended all the way to the seabed. As a result, for ease of comparison, the field data and model results were depth averaged. *Figures 3.6d* and *3.6e* present the model results and field data at times of peak flood and ebb tidal flows. The eastern most pit, not being fully constructed, has much less effect on both the modelled and observed currents. Water speeds fall to low values over the other two pits before accelerating and spreading out as they emerge from the western most pit. The observed general reduction in water speed caused by the deeper pits is simulated by the model.

Wet Season Validation

In presenting the observed wet season water velocities, the observations were averaged over a surface layer which extended from the water surface to -6mPD and a bed layer which covered the remainder of the water column. In order to compare the simulated and observed water velocities, the model results were averaged over the same layer structure. For the wet season spring tide (*Figure 3.6f*) the model reproduces the overall flow patterns in the surface and bed layers on the flood and ebb tides. For the neap tide the model tends to underestimate peak surface layer water speeds over the pits which may be accounted for by the flow directions being more sensitive to the degree of stratification. Observed and simulated tidal velocities for the neap tide are shown in *Figure 3.6g*.

Model Validation Conclusions

Overall, the changing flow directions over the pits and the bifurcation of the main ebb tidal flows to the west of the pits were simulated well. When assessing the results of the validation simulations based on different observed and simulated tides, the important comparisons to be made relate to changes in flow directions and water speeds over the pit where field data was available. In this respect, it was concluded that the validation of the model had been successful. When using the simulated flow fields to provide the hydraulic input to the sediment plume simulations, it should be noted that the sediment plume

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(12) EGS. East Sha Chau Borrow Pits Backfilling of Pits with Contaminated Mud EIA, Collection of Field Data for Calibration of Hydraulic Model. Final Report HK105196, February 1996.

(13) ERM (1996). East Sha Chau Borrow Pits EIA for Backfilling of Pits with Contaminated Mud, Collection of Field Data for Calibration of Hydraulic Model. Wet Season Measurements. EGS Final Report HK111196, August 1996.

behaviour will be different on different tides. From the calibration and validation simulations, however, it can be concluded that the model is reproducing flow fields which are representative of those observed on large amplitude spring and small amplitude neap tides in the wet and dry seasons acceptably well.

3.6.2 *Sediment Plume Model*

Introduction

The TELEMAC 3D sediment plume model, a revised version of the WAHMO SEDPLUME model was used for this study. It was specifically designed to simulate processes of sediment transport, deposition and re-erosion for narrow sediment plumes formed during dredging or disposal activities.

Sediment Transport Prediction

The sediment plume model simulates the transport and dispersion of sediment in suspension using hydrodynamic data from the TELEMAC 3D model and a random walk technique to simulate dispersion. The model accounts for the processes of deposition and erosion at the seabed unless these features are suppressed by the user *(see Section 3.7.1)*.

The plume model simulates the loss of sediment to suspension by introducing particles into the model area at specified locations and positions within the water column. The particles are released at a set rate and are given a fixed mass to simulate the rate of sediment loss. The particles are then tracked throughout the model and, at specified storage intervals, the number of particles in each cell is summed and the concentration of sediment calculated. The output of the sediment plume model is based on a square grid which can be set at variable resolution to reflect the desired precision, and may be finer than the smallest element in the flow model. The sediment plume model uses the same layering system as the model of tidal flows and gives a detailed representation of the vertical structure of the sediment plumes. A more detailed description of the sediment plume model is given in *Annex C*.

3.6.3 *Model Sensitivity Testing*

In response to concerns regarding underprediction of current speeds and the effect this could have on the model's results, a sensitivity test was undertaken to assess the differences in predictions resulting from artificially increasing the flow model current speeds and re-running the sediment plume model using the factored current speeds.

The sensitivity test was performed for Scenario 4 (see *Section 3.7*). The current speeds for the dry season spring tide were multiplied by a factor of 1.25 so that peak ebb current speeds in the model agreed with the calibration field data. The result of the factoring was to uniformly increase current speeds throughout the model area which improved the agreement between observed and modelled peak current speeds, particularly the peak ebb, at the majority of the field data stations. However, at some of the stations the factoring lead to an over-prediction in peak current speeds. This was particularly evident at Station W5, which is the closest station to the north of CMP IV, where both the peak ebb and flood speeds were significantly over-predicted.

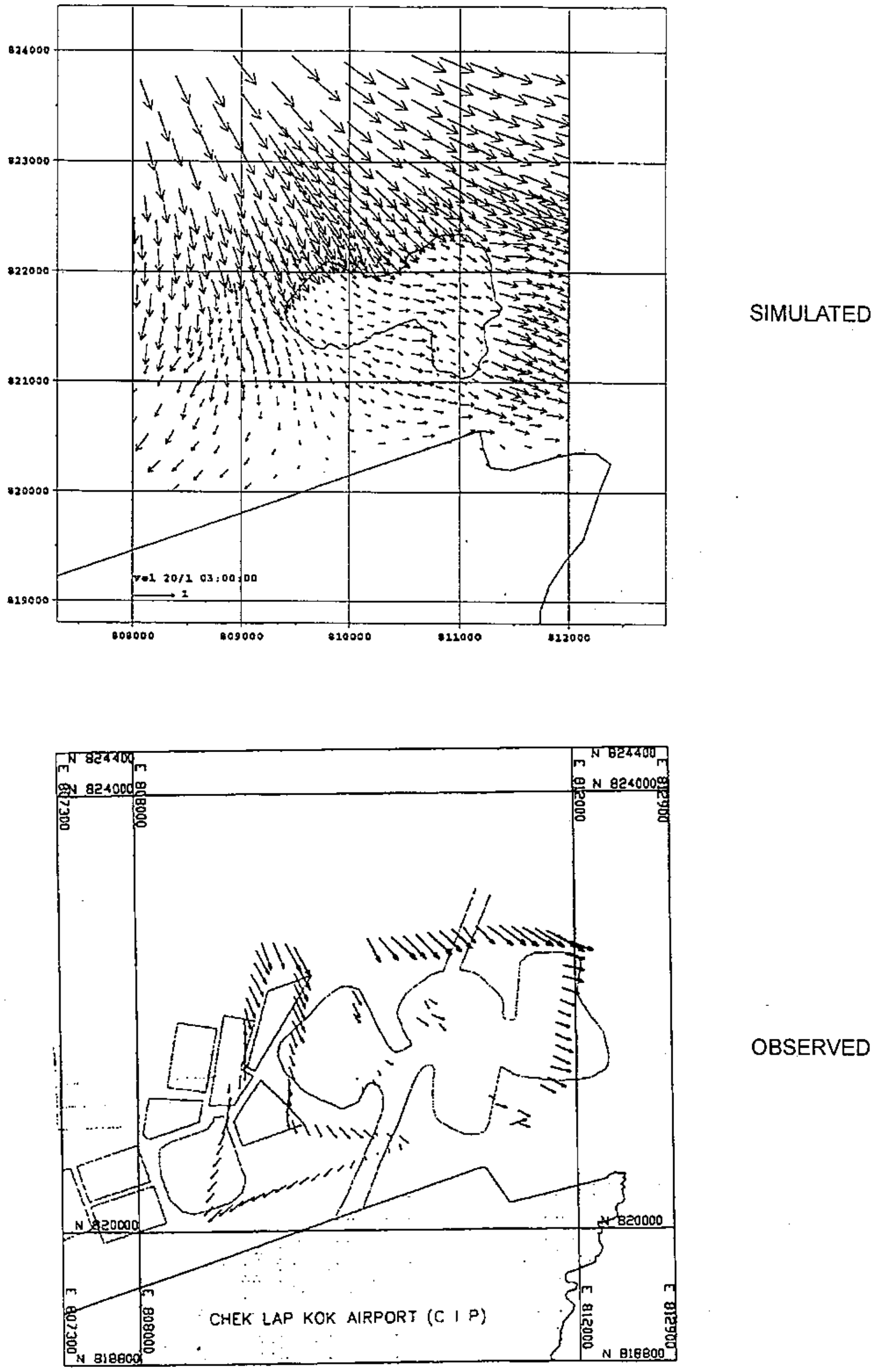

FIGURE 3.6d - OBSERVED AND SIMULATED CURRENT VELOCITY AND DIRECTION ON THE DRY SEASON SPRING TIDE (EBB)

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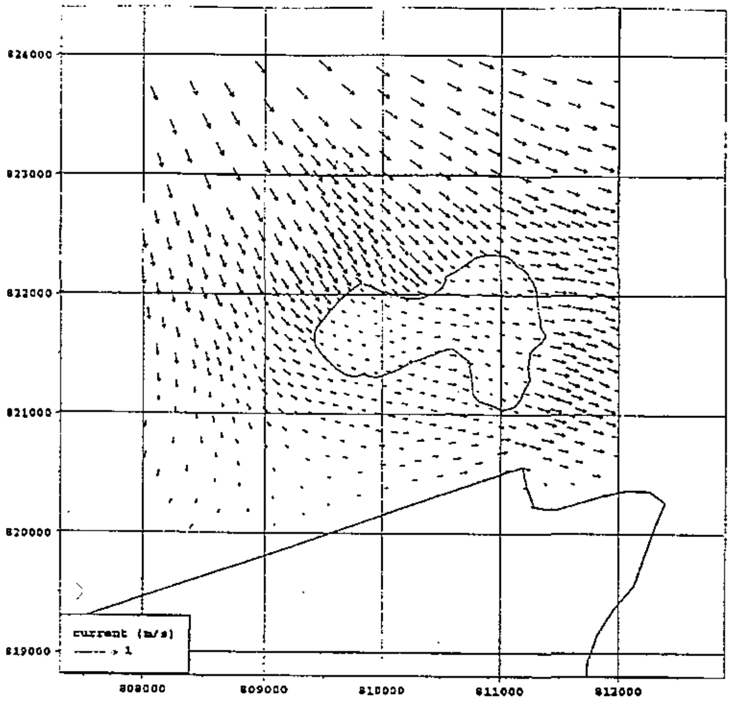

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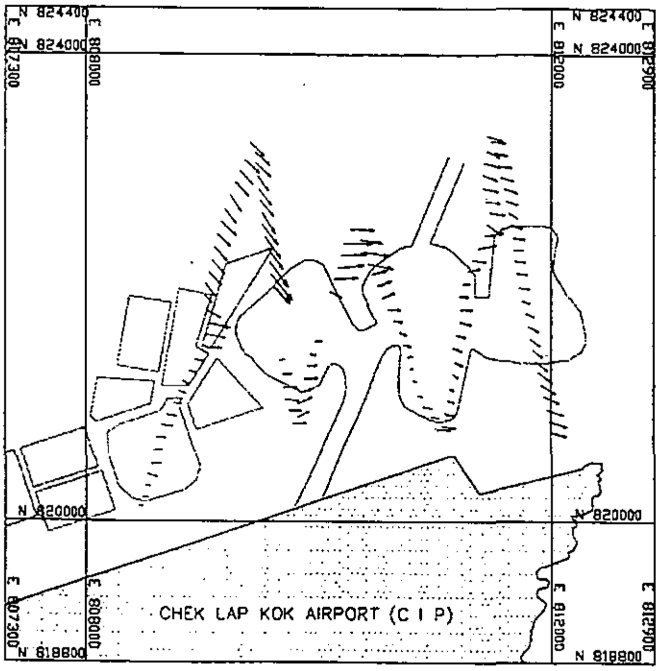

OBSERVED

FIGURE 3.6e - OBSERVED AND SIMULATED CURRENT VELOCITY AND DIRECTION ON THE DRY SEASON NEAP TIDE (EBB)

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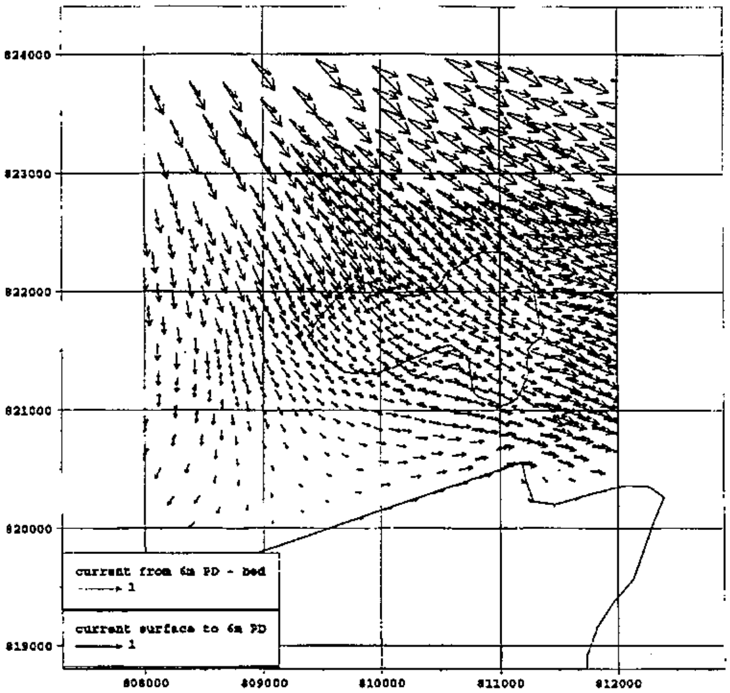

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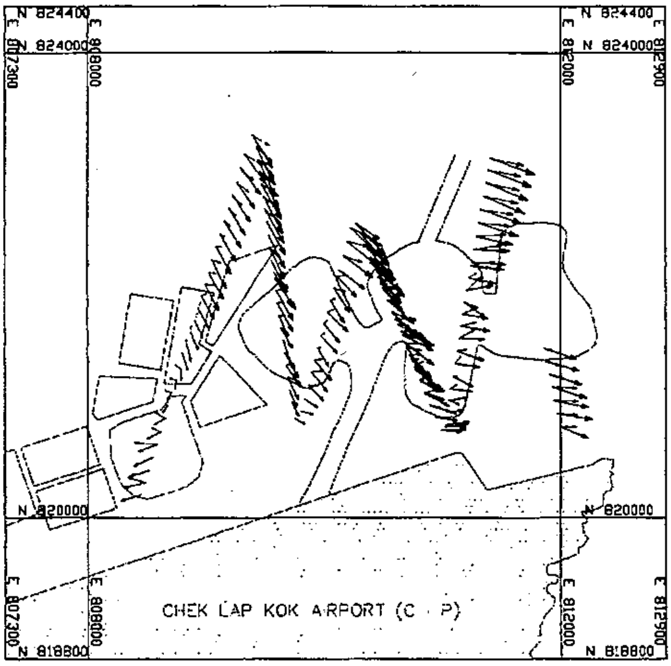

OBSERVED

FIGURE 3.6f - OBSERVED AND SIMULATED CURRENT VELOCITY AND DIRECTION ON THE WET SEASON SPRING TIDE (EBB)

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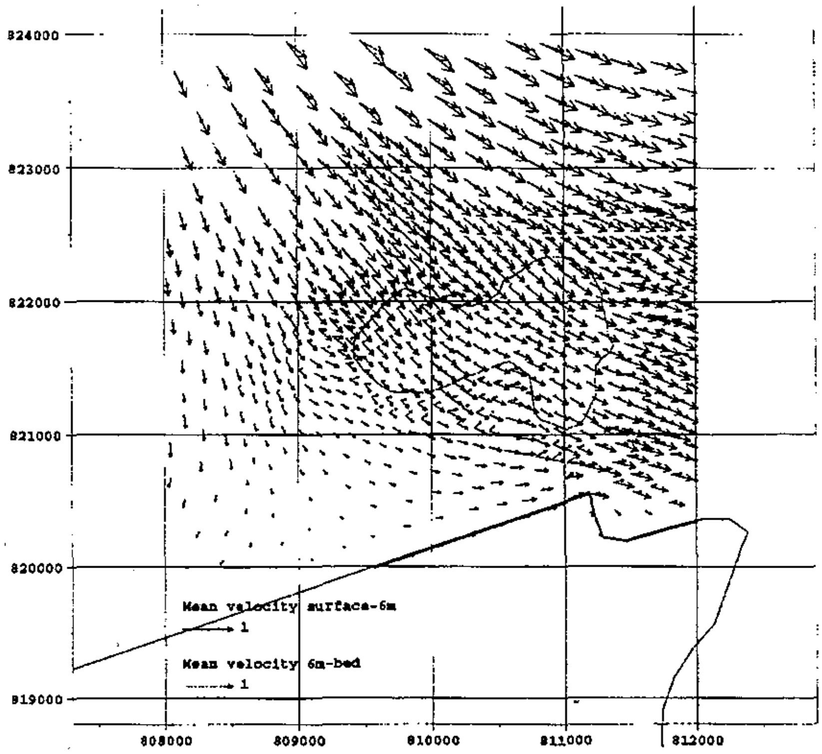

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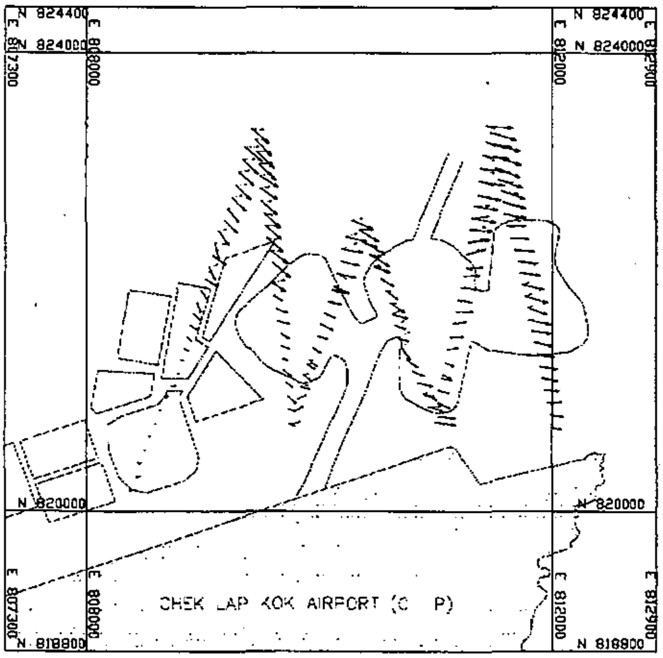

OBSERVED

FIGURE 3.6g - OBSERVED AND SIMULATED CURRENT VELOCITY AND DIRECTION ON THE WET SEASON NEAP TIDE (EBB)

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The factored current speeds were used in the sediment plume model and the results were compared to the original Scenario 4. The factored Scenario 4 results showed that the suspended sediment would be carried further on the flood tide than in the original Scenario 4 but the width of the plume was reduced. On the ebb tide the factored Scenario 4 showed that sediment was carried back past Lung Kwu Chau, rather than back along the Urmston Road, and combined with increased re-erosion caused by the higher current speeds. In general, although the area affected by the plume was different, concentrations of suspended sediment within the plume were similar indicating lower current speeds corresponding to those used in the original modelling do not substantially affect the results of the plume modelling exercises.

3.6.4 *Model Input*

Modelling of Barges

The initial modelling of barge-dumping impacts is based on an assumed annual rate of delivery of 6.0 Mm^3 (barge volume). Barges are assumed to be of 1,000 m^3 capacity, and loaded with 800 m^3 of dredged material. In order to estimate the total mass of dry solids discharged per disposal event these figures must be used in conjunction with an assumed dry density for dredged material. A discussion of the derivation of a dry density figure is provided below.

Measurements made on composite samples taken from barges which dumped contaminated mud during the 1995 loss measurements at East Sha Chau gave dry densities in the range 0.72 - 1.24 t m^{-3}. In evaluating this range to select an appropriate input value for the model, it was noted that the higher end of the range was derived from very sandy materials (40-55% sand) from capital dredging works in the Yuen Long-Kam Tin area. As this sand content is considerably higher than the sand content in typical contaminated mud in Hong Kong (15-20% sand), it was considered that the high end of the dry density range was not representative. Furthermore, modelling of material with a lower sand content (and thus lower dry densities) is conservative since the higher the content of sand within the material to be disposed, the lower the losses of fine sediment to suspension. This results because the higher density of the sand will tend to accelerate the descent of material from the dredger once the doors are opened which in turn leads to a reduced time for the descent of the gravity flow to the seabed and hence reduced stripping losses. For these reasons, the low end of the dry density range, ie 0.75 t m^{-3} was selected for model input.

If the dry density of 0.75 t m^{-3} is applied to a 800 m^3 volume of dredged material, the mass of dry sediments released per disposal event is 600 tonnes. This amount of sediment is assumed to be released instantaneously at intervals of 70 minutes in the centres of Pits A and B with their present depth, ie a water depth of 35 metres.

In order to derive a realistic sediment loss rate, the losses during and immediately after disposal from barges were investigated during two surveys undertaken in Pits IIc and IId in early 1995 (14). A total of nine barge-dumping events were monitored using acoustic techniques. Three events took place at or near slack water and no quantitative estimates of loss could be established. For the remaining six events, undertaken at current speeds of 0-1 m sec^{-1}, measured losses ranged between 1.2 and 3.1% of the total mass of dry solids discharged. Loss rates were found to be dependent on the disposed material type, and correlated poorly with current speeds. Based on these data, the assumed loss rate was set at 3%, which in this assessment resulted in the loss of 18 tonnes of sediment to suspension per disposal event.

The 1995 measurements did not permit the initial size of the plume to be estimated. However, the measurements made at the edges of the pits very clearly showed that the width and concentration of the plumes were considerably greater near the bed than those in the near-surface area. For the purposes of modelling, a vertical cylinder of water underlying the barge was assumed to represent the initial area of sediment release. As the diameter of the cylinder was estimated to lie somewhere between the actual opening of the hopper door (ie release point of sediment) and the footprint of material when it reaches the seabed, the diameter of the cylinder was approximated as the total length of the hoppers of the barges which transport contaminated mud to the existing East Sha Chau CMPs, ie 50 m. Assuming a vertical cylinder of water with a depth of 32 metres and a diameter of 50 m results in an initial sediment concentration of 286 mg l^{-1}. This is similar to the maximum concentrations observed during the 1995 measurements at East Sha Chau.

Modelling of Trailers

The modelling of trailer-dumping impacts was based on a daily rate of delivery of 16,000 m^3 (hopper volume) except for one scenario which tested a delivery rate of 40,000 m^3 (Scenario 8). The higher rate (ie 40,000 m^3 day^{-1}) was subsequently found to overestimate demand for contaminated mud disposal; Scenario 8 is therefore included for reference only. The trailers were assumed to be fully loaded and to have a hopper capacity of 8,000 m^3. A hopper density of 1.35 t m^{-3} was assumed which is likely to be higher than the average density which is achieved in contaminated mud. This leads to a dry density of 0.556 t m^{-3} and a total mass of dry solids released, per disposal event, of 4,448 t.

Loss rate input parameters for modelling of trailer dredgers were not available for the East Sha Chau area. However, measurements of discharges from two trailer dredgers in the East Tung Lung Chau MBA, in water depths of 28-30 metres at natural seabed, showed losses of between 0.9 and 8.7% at a nominal range of 300 metres from the discharge point(7). The range of observed loss rates is likely due to the different efficiencies of the two disposal plant. Since water depth is substantially shallower at East Sha Chau (6-8 metres at natural seabed), it was not considered representative to use the higher loss rate (ie 8.7%), and therefore an intermediate value of 5%, which has been used in previous modelling of trailer dredgers and is somewhat higher than most losses reported in the literature, was selected. It is considered that a loss rate of 5% adequately accounts for loss rates from trailer dredgers with differing efficiencies disposing in water depths of 6-8 metres. In order to confirm that this loss rate is

(14) Dredging Research Limited (1995) Measurements of sediment loss during dumping from barges at the East Sha Chau Contaminated Mud Pits. Draft report to Geotechnical Engineering Office, Civil Engineering Department, Hong Kong under Agreement CE 2/93.

(7) Dredging Research Limited (1996). Measurements of Sediment Transport after Dumping from Trailing Suction Hopper Dredgers in the East Tung Lung Chau Marine Borrow Area, Draft Report to GEO, CED.

representative, measurements of loss rates from trailer dredgers disposing at CMP IV will be conducted during backfilling of the pits.

The initial solids concentration in the disposal plume was derived from an assumed plume diameter of 65 metres (approximating the length of the hopper) with the sediment uniformly distributed throughout the plume over the full depth of the water column. For water depths of 14 metres, representing backfilling at the highest level in CMP IV, an initial solids concentration of 4,787 mg l^{-1} was derived. An initial concentration of 1,915 mg l^{-1} was derived for discharge into an empty pit 35 metres deep. These figures are likely to be conservative since it is known that steep concentration gradients develop immediately after dumping and the majority of the solids are concentrated in the lower part of the water column.

A summary of model input parameters for barge and trailer modelling is provided in *Table 3.6a*.

Table 3.6a *Summary of Model Input Parameters*

Parameter	**Barges**	**Trailers**
Daily Disposal Volume	16,800 m^3	16,000 and 40,000 m^3
Volume Disposed per Disposal Event	800 m^3	8,000 m^3
Frequency of Disposal Events	70 min	12 hr/4.8 hr
Dry Density of Dredged Material in Vessel	0.75 t m^{-3}	0.556 t m^{-3}
Mass of Solids Released per Disposal Event	600 t	4,448 t
Percent Loss (to dispersion)	3%	5%
Mass of Solids Lost (to dispersion) per Disposal Event	18 t	222.4 t
Initial Sediment Concentration upon Disposal	286 mg l^{-1}(pit empty)	1,915 mg l^{-1} (empty pit) 4,787 mg l^{-1} (full pit)
Sediment Oxygen Content	15,000 mgO kg^{-1}	15,000 mgO kg^{-1}
Sediment Nutrient Content	860 mgN kg^{-1}	860 mgN kg^{-1}

3.6.5 *Calculation of Dissolved Oxygen and Nutrient Levels*

For the purposes of this assessment, the sediment plume model predictions of resulting suspended sediment concentrations are used to derive predictions of dissolved oxygen and nutrient levels.

Dissolved oxygen depletion is calculated from the predicted suspended sediment concentrations using the following relationship:

$DO_{dep} = C*SOD*K*0.001$

where DO_{dep} = dissolved oxygen depletion in mg l^{-1}
C = tidal average suspended sediment concentration in kg m^{-3}
SOD = sediment oxygen demand in mgO kg^{-1} sediment
K = daily oxygen uptake factor = 0.23

The analysis does not allow for reaeration but this is expected to be a minor factor in the above relationship and thus have a negligible effect on the results. Elevations of nutrient concentrations resulting from release of dredged material are calculated from the predicted suspended sediment concentration by assuming that the nutrients associated with the sediment lost to suspension are transported and diluted at the same rate as the sediment in suspension.

Model inputs for dissolved oxygen and nutrient assessments were derived from EPD routine sediment quality. These data showed values of up to 15,000 mgO kg^{-1} sediment for the sediment oxygen demand and 860 mgN kg^{-1} sediment for the nutrient content of the sediment. These values were chosen as conservative estimates of sediment dissolved oxygen and nutrient content for the EIA assessments.

3.6.6 Methodology for Contaminant Modelling

Contaminant concentrations in sediments to be disposed at the proposed CMP IV were approximated by Interim Sediment Quality Values - Low (ISQV -L) currently under consideration by Government. The ISQV-L is proposed for future use in classifying material proposed for disposal into categories representing uncontaminated, suitable for confined aquatic disposal and unsuitable for confined aquatic disposal.

ISQV-L values were selected as the most representative values for contaminants to be disposed at CMP IV for a number of reasons. The draft ISQV-L values are identical to the Class C levels for all currently regulated contaminants except mercury. Chemical analysis of sediments disposed in CMPs IId, IIIa and IIIb are presented in *Table 3.6b*. These data indicate that mean metals concentrations were lower than Class C levels and that an overwhelming majority of individual values were also below these levels.

A recent study involving testing for contaminants of concern at twelve sites in Hong Kong also provides data on actual contaminant concentrations in sediment. However, these sites have already been dredged and the materials disposed at the existing CMPs. Thus these sediments are, in theory, also represented by the contaminant concentrations presented in *Table* 3.6*a*. While there will be occasions where dredged materials exceeding the ISQV-L values and the existing Class C criteria will be disposed, the data presented above show the ISQV-L values are an accurate representation of long-term average sediment quality. Although use of higher values to approximate disposed concentrations would provide a more conservative approach, selection of higher values in the absence of agreed regulatory criteria was considered unduly speculative, as well as unrepresentative, and thus inappropriate.

Table 3.6b *Metals Concentrations for Class C Sediment Criteria (EPD TC No. 1-1-92) and Source Material Sampled from Pits IId, IIIa and IIIb.*

Metal	Class C Criterion in mg kg^{-1} (ppm)	Source Material from Pit IId (June to August 1995) in ppm mean (% of values below Class C criterion)	Source Material from Pit IIIa (September 1995 to July 1996) in ppm mean (% of values below Class C criterion)	Source Material from Pit IIIb (August to October 1996) in ppm mean (% of values below Class C criterion)
Cd	1.5	0.6 (NA)	0.39 (98%)	0.11 (100%)
Cr	80	32.1 (NA)	29.14 (96%)	28.23 (97%)
Cu	65	64.1 (NA)	61.20 (71%)	36.19 (91%)
Hg	1	0.3 (NA)	0.05 (99%)	0.06 (100%)
Ni	40	26.3(NA)	16.56 (96%)	14.89 (97%)
Pb	75	52.8 (NA)	33.83 (98%)	35.42 (96%)
Zn	200	120.1 (NA)	75.26 (98%)	84.87 (99%)

(Source: FMC data)

The modelled contaminants fall into four categories: metals, low molecular weight PAHs, high molecular weight PAHs and PCBs. Selection was based upon the following criteria:

- it is a contaminant of concern in Hong Kong sediments;
- a partitioning coefficient is available from the literature; and
- an ISQV-L is available.

The contaminants selected for modelling include:

- *Metals*: Cadmium, Chromium, Copper, Mercury, Nickel, Lead, and Zinc (other metals and metalloids such as Arsenic and Silver, which are specified as contaminants of concern by the Classification and Testing of Sediments for Marine Disposal Study, are not proposed for modelling because there are no baseline data with which to compare modelling results, and because the metals group was believed to be adequately represented by the seven heavy metals);
- *Low Molecular Weight PAHs*; Acenaphthylene, Phenanthrene;
- *High Molecular Weight PAHs*: Fluoranthene, Benzo(a)pyrene;

  (PAHs proposed for modelling were selected by choosing the PAH with the highest partitioning coefficient and the PAH with the lowest partitioning coefficient within each of the two groups. Although ambient concentrations in Hong Kong waters are unknown, PAHs are monitored in sediments for the present EM&A programme at ESC);
- *PCB*: Total PCBs.

In response concerns regarding tributyltin (TBT), concentrations of this contaminant resulting from disposal of sediment containing TBT were also estimated. In the absence of regulatory criteria for disposal of sediment containing TBT, the concentration of TBT in sediments to be disposed at CMP IV was estimated as 0.72 mg kg^{-1} which corresponds to the maximum TBT value observed during recent sediment sampling of twelve contaminated sites in Hong Kong.(8) TBT was modelled separately from other contaminants due to the lack of available partitioning coefficients. For the purposes of this assessment, low and high partitioning coefficients were selected as 1 x 10^{6} (equivalent to the lowest partitioning coefficient for a metal) and 1 x 10^{3} (equivalent to the highest partitioning coefficient for a metal), respectively. All other parameters were identical to those used in the modelling of other contaminants (see below).

Contaminants adsorbed to sediment particles are expected to either remain adsorbed to the sediment, settling or dispersing in direct proportion to suspended sediment concentrations, or desorb from the sediment particles and enter solution. Contaminants desorbing from sediments and dispersing as components of the water column were modelled through separate modelling runs. Contaminants adsorbed to sediment particles were analysed based on sediment plume Scenario 4 (see below), which was selected as a representative worst case of disposal operations. This scenario involved two disposal events (of 8,000 m^{3} hopper volume each) which were assumed to release 222,400 kg of sediment each. Scenario 4's sediment concentrations were processed in two ways: based on the low end of the range of partitioning coefficients for each contaminant, and desorption based on the high end of the range of partitioning coefficients for each contaminant. This approach thus brackets the range of impacts ensuring that the actual expected concentration lies somewhere within the range of predicted concentrations. Partitioning coefficients and ISQV-Ls for the contaminants to be modelled are presented in *Table* 3.6c.

Table 3.6c *Partitioning Coefficients and ISQV-Ls for Contaminant Modelling*

Contaminant Group	**Substance**	**Partitioning Coefficient (l kg^{-1})**	**ISQV-L**[d]
Metals	Cadmium	3,162-1x10^{5}[a]	1.5 mg kg^{-1} dry wt
	Chromium	N/A	80 mg kg^{-1} dry wt
	Copper	1x10^{4}-1x10^{5}[a]	65 mg kg^{-1} dry wt
	Lead	1x10^{5}-1x10^{6}[a]	75 mg kg^{-1} dry wt
	Mercury	1x10^{5}-1x10^{6}[a]	0.15 mg kg^{-1} dry wt
	Nickel	1x10^{4}-31,623[a]	40 mg kg^{-1} dry wt
	Zinc	1x10^{4}-1x10^{5}[a]	200 mg kg^{-1} dry wt
PAH - Low MW	Acenaphthylene	75[b][c]	44 μg kg^{-1} dry wt
	Phenanthrene	420[b][c]	240 μg kg^{-1} dry wt
PAH - High MW	Fluoranthene	1140[b][c]	600 μg kg^{-1} dry wt
	Benzo(a)pyrene	165,000[b][c]	430 μg kg^{-1} dry wt

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(8) EVS data provided by CED GEO in memo GCFM 5/2/20-36 dated 31 December 1996

Contaminant Group	Substance	Partitioning Coefficient ($l\ kg^{-1}$)	ISQV-L[d]
Monocyclic Aromatic Hydrocarbons and Chlorinated Hydrocarbons	Total PCBs	$1\times10^{6(a)}$	22.7 $\mu g\ kg^{-1}$ dry wt
Organometallics	TBT	N/A	N/A

Notes:

[a] Source: Canadian Water Quality Guidelines. Canadian Council of Resources and Environmental Ministers. 1987.
[b] Source: ERL. Health Effects from Hazardous Waste Landfill Sites, Report for the UK Department of the Environment. 1993.
[c] Assumes a 3% organic carbon content.
[d] Source: EVS. Classification and Testing of Sediment for Marine Disposal. 1996.

Formulae for calculation of contaminant concentrations in both desorbed and adsorbed phases are provided below.

The adsorbed contaminant concentration (in mg l^{-1}) is calculated by:

$$A\times(B\times\frac{C}{222400})\times10^{-6}$$

where

A = contaminant concentration in sediment (in mg kg^{-1})
B = predicted suspended sediment concentration at the point of interest (see Scenario 4 results for reference) (in mg l^{-1})
and
C = mass of sediment lost to suspension per disposal event by trailer dredger (in kg)(9).

The desorbed contaminant concentration (in mg l^{-1}) is calculated using the following formula:

$$\frac{\frac{A}{1000}\times B}{1+(K_d\times\frac{A}{\pi\times65^2\times15.5}\times0.001)}\times C\times0.001$$

where

A = mass of sediment lost to suspension per disposal event (in kg)(9)
B = contaminant concentration in sediment (in mg kg^{-1})
C = dilution due to off-site dispersion (in units m^{-3})(10)
and
K_d = Partitioning Coefficient (in l kg^{-1}).

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(9) This EIA assumed 222,400 kg of sediment was lost in each trailer dredger disposal event.

(10) The maximum concentration used in the EIA = 0.0001 units m^{-3} and the minimum concentration = 0.000001 units m^{-3}.

3.7 SEDIMENT PLUME MODELLING SCENARIOS AND RESULTS

3.7.1 *Scenarios Simulated by the Sediment Plume Model*

The TELEMAC 3D sediment plume model has been used to simulate eleven scenarios of disposal into the proposed CMP IV. Scenarios 1 through 3 were conducted for the IAR and simulated the disposal of grab-dredged material into Pits A and B. Scenarios 4 through 7 modelled a similar volume of trailer-dredged material disposed in Pit A during four seasonal-tidal states (ie dry and wet seasons, spring and neap tides). Scenario 8 was designed to test the worst case conditions from Scenarios 4-7 (ie Scenario 4) at a higher rate of disposal (ie 40,000 m^3 day^{-1}). As described in *Section 3.6.1*, this scenario was subsequently found to overestimate disposal demand and is thus included for reference only. Scenarios 9 through 11 tested the sensitivity of the results of the Scenario 4 to changes in the release point (ie Pit A versus Pit C) and the backfill level of the pits (ie full versus empty). Modelling scenarios are summarized in *Table 3.7a*.

Table 3.7a *Summary of Modelling Scenarios*

Scenario Number	Season-Tide	Backfilling Rate (m^3 day^{-1} hopper volume)	Pit Level	Disposal Point	Disposal Plant (all disposal = bottom dumping)	Re-Erosion Term
1	Dry Season Spring Tide	16,800	Empty	Pit A	Barge	No
2	Dry Season Spring Tide	16,800	Empty	Pit B	Barge	No
3	Dry Season Spring Tide	16,800	Empty	Pit A	Barge	Yes
4	Dry Season Spring Tide	16,000	Full	Pit A	Trailer	Yes
5	Dry Season Neap Tide	16,000	Full	Pit A	Trailer	Yes
6	Wet Season Spring Tide	16,000	Full	Pit A	Trailer	Yes
7	Wet Season Neap Tide	16,000	Full	Pit A	Trailer	Yes
8*	Dry Season Spring Tide	40,000	Full	Pit A	Trailer	Yes
9	Dry Season Spring Tide	16,000	Empty	Pit A	Trailer	Yes
10	Dry Season Spring Tide	16,000	Full	Pit C	Trailer	Yes
11	Dry Season Spring Tide	16,000	Empty	Pit C	Trailer	Yes

Note: * Scenario 8 is included for reference only (see *Section 3.6.1*).

Initial modelling scenarios (Scenarios 1 and 2) were performed without inclusion of the TELEMAC model's re-erosion term which incorporates re-erosion of materials deposited on the seabed from previous disposal events. By suppressing the re-erosion term, the results of Scenarios 1 and 2 are limited to suspended sediments resulting from plumes only. The remaining scenarios (Scenarios 3-11) all include the re-erosion term and thus reflect both plumes from the most recent disposal event and re-erosion of previously deposited material. The timing of disposal events for each modelling scenario was selected based on the number of disposal events per day (ie based in the volume to be disposed and the plant to be used) and with reference to the tidal conditions which would represent a worst case.

3.7.2 *Format of Modelling Results*

The modelling results for Scenarios 1 through 11 are presented in *Annexes D* through *N* and described and interpreted below. The results for each scenario consist of:

- brief text describing the modelling results;
- suspended sediment contour plots showing concentrations at ebb and flood tides for surface and bed layers(*Figures D1-N1*);
- plots of suspended sediment concentrations at four depth intervals throughout the tidal cycle for 12 sensitive receivers in the immediate vicinity of the proposed CMP IV (*Figures D2-N2*);
- sediment deposition contour plots showing the volume and location of deposited sediments (*Figures D3-N3*);
- dissolved oxygen depletion and nutrient elevation contour plots showing the concentrations and areal extent of predicted deficits and elevations (*Figures D4-N4*).

In addition to these results for individual scenarios, predicted mean concentrations of metal and organic contaminants are presented in *Annex O* and described in *Section 3.9*.

3.8 *COMPLIANCE OF MODELLED SCENARIOS WITH WATER QUALITY OBJECTIVES*

This section describes Scenarios 1 through 11 in terms of compliance with water quality objectives for suspended sediments, dissolved oxygen and nutrients. Discussion of contaminants is provided in *Section 3.9*.

Suspended Sediments

Predicted concentrations of suspended sediment at sensitive receivers are provided for Scenarios 1-11 in *Annexes D-N*, respectively. These plots indicate for most scenarios, only minor elevations in suspended sediments are predicted. Comparison of predicted elevations to WQOs for suspended sediments is provided in *Table 3.8a*.

As presented in the table, neither the dry season WQO (26.28 mg l^{-1}) nor the wet season WQO (2.82 mg l^{-1}) is predicted to be exceeded by any of the dry season and wet season scenarios, respectively. The assessment criterion of 10 mg l^{-1} is also not predicted to be exceeded at any of the sensitive receivers in any of the scenarios. As the WQOs and assessment criterion are more conservative (ie lower) than any of the sensitive receiver specific criteria, the predicted elevations in SS concentrations are also compliant with all sensitive receiver specific criteria. The maximum suspended sediment concentration predicted for any of the scenarios is 4.2 mg l^{-1} at Sha Chau Beach in Scenario 4. Due to the lack of predicted exceedances of WQOs and the low absolute predicted elevations, impacts due to suspended sediments are not expected in association with the proposed CMP IV backfilling.

Table 3.8a *Comparison of Predicted Elevations in Suspended Sediments with WQOs*

Scenario (Season)	Exceedance of Dry Season WQO? (Elevation ≤26.28 mg l^{-1})	Exceedance of Wet Season WQO? (Elevation ≤2.82 mg l^{-1})	Exceedance of Assessment Criterion of 10 mg l^{-1}	Sensitive Receivers with Predicted Elevations≤2.82 mg l^{-1}
1 (Dry)	No	N/A	No	None
2 (Dry)	No	N/A	No	None
3 (Dry)	No	N/A	No	None
4 (Dry)	No	N/A	No	Lung Kwu Chau = 3.9 Sha Chau (North) = 3.6 Sha Chau (East) = 3.7 Sha Chau Beach = 4.2
5 (Dry)	No	N/A	No	None
6 (Wet)	N/A	No	No	None
7 (Wet)	N/A	No	No	None
8 (Dry)	No	N/A	No	None
9 (Dry)	No	N/A	No	Sha Chau (North) = 3.0 Sha Chau (East) = 2.9 Sha Chau (West) = 2.9 Sha Chau Beach = 3.1
10 (Dry)	No	N/A	No	Lung Kwu Chau = 2.7 Sha Chau (North) = 3.2 Sha Chau Beach = 3.8
11 (Dry)	No	N/A	No	None

Annex O shows the areas where an elevation in suspended sediment concentration which would cause an exceedance of water quality objectives may occur at some point in the tidal cycle. The plots presented show the area in which suspended sediment elevations may exceed:

- the WQO of 26.28 mg l^{-1} for the dry season (based on Scenario 4);
- the assessment criterion of 10 mg l^{-1} for the dry season (based on Scenario 4);
- the WQO of 2.82 mg l^{-1} for the wet season (based on Scenario 6);
- the assessment criterion of 10 mg l^{-1} for the wet season (based on Scenario 6).

It is important to note that the areas outlined in black are not contours, and thus while short-term, localized exceedances of the WQO will occur within these circumscribed areas, the entire area will not be affected and areas outside the circumscribed areas are never predicted to experience WQO exceedance.

Dissolved Oxygen and Nutrients

Neither the maximum predicted dissolved oxygen deficit nor the maximum predicted nutrient elevation are likely to result in non-compliance with the WQOs for dissolved oxygen and nutrients. For dissolved oxygen in the study area, the bed layer DO averaged 6.62 mg l^{-1} in the dry season and 5.73 in the wet season (*Table 3.3b*). Depth averaged ambient DO mean concentrations were 6.69 mg l^{-1} in the dry season and 6.55 in the wet season (*Table 3.3a*). The maximum predicted DO deficits for the modelled scenarios were no higher than 0.1 for ten of the modelled scenarios whereas Scenario 8 showed a maximum deficit of 0.2 mg l^{-1}. These predicted depletions are very small and, in combination with ambient levels, will not result in levels lower than those required by the WQOs, ie 2 mg l^{-1} for the bed layer, 4 mg l^{-1} for the depth averaged value and 5 mg l^{-1} for fish culture zones in either wet or dry seasons.

Similarly, the maximum predicted nutrient elevation (0.01 mg l^{-1} for Scenario 8 and 0.004 mg l^{-1} for all other Scenarios) in conjunction with the depth averaged total inorganic nitrogen levels of 0.22 in the dry season and 0.44 mg l^{-1} in the wet season (*Table 3.3b*) would not cause the nutrient WQO (0.5 mg l^{-1}) to be exceeded.

3.9 RESULTS AND DISCUSSION OF CONTAMINANT MODELLING

The results of modelling contaminants released from the disposal of dredged materials are presented in *Annex P*. These figures show the tidally-averaged concentration for each modelled contaminant based on suspended sediment concentrations predicted by Scenario 4. As described in the methodology above (*Section 3.6.5*), estimates for both adsorbed and desorbed contaminants were made for both surface and bed layers of the water column.

Maximum predicted concentrations (ie concentrations at the actual point of discharge; presented in the top row in *Annex P*) were evaluated against measured ambient levels from the East Sha Chau monitoring programme and compared to European Community (EC) Water Quality Standards in *Table 3.9a*. EC water quality standards are utilized in this assessment in the absence of quantitative water quality objectives for these contaminants in Hong Kong waters.

Comparison to EC water quality standards, which are presented as dissolved concentrations, requires summation of predicted dissolved concentrations arising from backfilling operations with ambient (soluble) concentrations (see *Table 3.3b*). However, this comparison is not meaningful for this study since predicted concentrations are less than 2.5% of ambient values (9.5% using minimum estimate of the mean) for all metals.

Predictions of dissolved chromium concentrations could not be made due to the lack of a suitable partitioning coefficient. However, as the dissolved concentration would be considerably lower than the suspended concentration, the calculations have assumed that the suspended concentration equals the dissolved concentration as a worst case. As no EC water quality standards or ambient values are available for PAHs and PCBs, no contrasts between predicted concentrations and these values were possible.

In order to provide a preliminary assessment of TBT, input values were estimated as explained in *Section 3.6.5*. This assessment is highly conservative in that it uses the maximum observed concentration of TBT observed in a recent sediment sampling exercise at twelve of Hong Kong's most contaminated sites. In addition, maximum partitioning coefficients for the desorbed (dissolved) phase were utilized and the resulting concentrations are expected only in the immediate vicinity of the disposal site. The resulting concentration of 0.00769 $\mu g\ l^{-1}$ is below the U.S. EPA Aquatic Life Advisory Concentration of 0.01 $\mu g\ l^{-1}$. Given that even under this highly conservative assessment TBT concentrations are below levels of concern, it is unlikely that any unacceptable impacts related to TBT will result from disposal of contaminated mud at CMP IV.

This discussion has shown that predicted concentrations of contaminants resulting from a representative operational scenario at CMP IV are extremely low (<2.5% of ambient values for metals using maximum estimate of the mean). As the modelled contaminants represent a range of chemical compounds with varying partitioning coefficients and input values (ie ISQVs), the range of results is likely to be broadly representative of other contaminants of concern. In addition, as predicted contaminant concentrations are extremely low, and modelling results for other operational scenarios are very similar (see *Section 3.8*), modelling of contaminants for other operational scenarios considered in this EIA is unlikely to produce detectably different results. In summary, the predicted contaminant concentrations resulting from operations at CMP IV are negligible when compared to the ambient levels and international water quality standards and thus no unacceptable impacts are anticipated.

Table 3.9a ***Results of Contaminant Modelling and Comparison to Water Quality Standards (in ug l^{-1})***

Contaminant	Maximum Estimate of the Mean Ambient Concentration - Soluble Fraction (in water) (see *Table 3.3b*)	Minimum Estimate of the Mean Ambient Concentration - Soluble Fraction (in water) (see *Table 3.3b*)	Water Quality Standard - Dissolved	Maximum Predicted Dissolved Concentration	Maximum Predicted Suspended Concentration	Predicted Dissolved Concentration as a Percentage of Ambient Max (Min)
Cadmium	0.37	0.08	2.5 (Coastal)† 5 (Estuarine)†	7.6×10^{-3}	1.5×10^{-2}	2.05% (9.50%)
Chromium	1.6	1.2	15 (Coastal)†	NA	8×10^{-1}	NA (NA)
Copper	7	1.8	5 (Coastal)†	1.2×10^{-1}	6.5×10^{-1}	1.71% (6.67%)
Lead	11	0	25 (Coastal)†	1.5×10^{-2}	7.5×10^{-1}	0.14% (NA)
Mercury	1.8	0.7	0.3 (Coastal)† 0.5 (Estuarine)†	3×10^{-5}	1.5×10^{-4}	0.002% (0.004%)
Nickel	4.4	2.4	30 (Coastal)†	7.5×10^{-2}	4×10^{-1}	1.70% (3.12%)
Zinc	0.017‡	0.007‡	40 (Coastal)†	3.8×10^{-1}	2	2.24% (5.43%)
Acenapthylene	NA	NA	NA	9.1×10^{-4}	4.4×10^{-4}	NA
Phenanthrene	NA	NA	NA	3.7×10^{-3}	2.4×10^{-3}	NA
Fluoroanthene	NA	NA	NA	6×10^{-3}	6×10^{-3}	NA
Benzo(a)pyrene	NA	NA	NA	5.3×10^{-5}	4.3×10^{-3}	NA
Total PCBs	NA	NA	NA	4.7×10^{-7}	2.27×10^{-4}	NA
Tributyltin (TBT)	NA	NA	0.01*	7.69×10^{-3}	7.2×10^{-3}	NA

† Environmental Quality Standards and Assessment Levels for Surface Water (from HMIP (1994) Environmental Economic and BPEO Assessment Principals for Integrated Pollution Control).

‡ These values are likely to have been misreported as 0.017 and 0.007 µg l^{-1} and are thus interpreted as 17 and 7 µg l^{-1} for this assessment.

* US EPA Aquatic Life Advisory Concentration for Seawater cited in Lau MM (1991), Tributyltin Antifoulings: A Threat to the Hong Kong Marine Environment, Arch. Environ. Contam. Toxicol., 20: 299-304

3.10 PORE WATER MIGRATION AND CONTAMINANT FLUX

The consolidation of the contaminated materials after placement, and the resulting expulsion of contaminated pore waters has the potential to effect water quality and was investigated during the EIA. The evaluation was based on a analysis using conservative assumptions and widely-accepted principles. Laboratory consolidation tests and contaminant flux testing of the sediments to be placed in the pits were not deemed necessary for this evaluation. The total flux of contaminants from the cap and underlying contaminated mud is the sum of the advective flux due to consolidation and the diffusive flux due to molecular activity. The consolidation of the mud layers, and the advective and diffusive fluxes were calculated as a part of this evaluation.

3.10.1 *Consolidation Analysis*

A consolidation analysis was performed to estimate the volume and rate of pore water expulsion. As no consolidation test data for the muds were available, the consolidation parameters were estimated based on test results for sediments with physical index properties (ie grain size distribution and Atterberg liquid and plastic limits) which are similar to those of the contaminated sediments and capping materials in previous pits at East Sha Chau. The computer programme, Primary consolidation and Secondary compression and Desiccation of Dredged Fill (PSDDF) was used to estimate the rate and magnitude of consolidation of the backfill materials(11). The assumed backfill configuration in the pits was as set out in *Table 3.10a*. The full thickness of capping material was assumed to be placed before any consolidation of the contaminated fill material had taken place. This assumption gives rise to higher rates of consolidation and pore water expulsion and is thus very conservative.

Table 3.10a ***Backfill Configuration Assumed for Consolidation Analyses***

	Pits A and B	Pit C
Additional Mud Cap	3m	3m
Initial Mud Cap	2m	2m
Sand Cap	1m	1m
Contaminated Mud Layer	21m	13m
Total Fill Thickness	27m	19m

The estimated total primary consolidation due to self-weight and the placement of the total cap thickness was 3.8 metres for Pits A and B and 2.5 meters for Pit C. The peak rate of water expulsion occurs during the first year and decays very rapidly thereafter (*Figure 3.10a*). The rates of pore water expulsion are summarised in *Table 3.10b*.

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(11) Stark TD (1996) Program Documentation and User's Guide: PSDDF Primary Consolidation, Secondary Compression and Desiccation of Dredged Fill, Instruction Report EL-96-XX, U.S. Army Engineer Waterways Experiment Station, Vicksburg MI

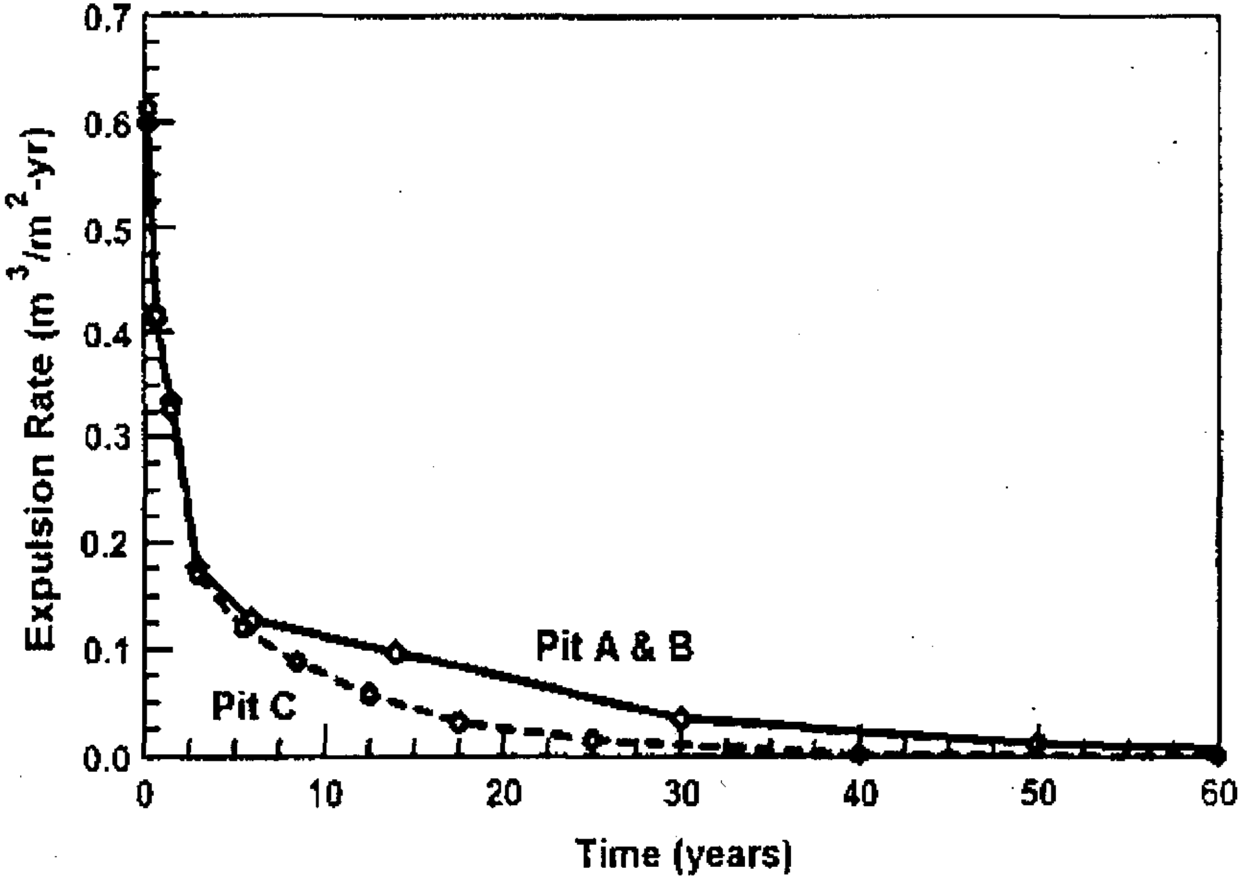

FIGURE 3.10a - PREDICTED PORE WATER EXPULSION RATE FOR PITS A, B AND C

ERM-Hong Kong, Ltd
6th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

Table 3.10b *Estimated Rates of Pore Water Expulsion*

	Pits A and B	Pit C
Peak Rate	0.60	0.60
Rate After 50 Years	0.01	0.00

3.10.2 *Advective Contaminant Flux*

The advective flux of contaminants was calculated based on the equilibrium partitioning principles and the results of the consolidation analysis. Pore water concentrations in both the cap and contaminated mud layers will remain in equilibrium with leachable metals concentrations. The leachable metals concentrations were estimated on the basis of previous leach tests conducted on a number of estuarine sediments(12). The resulting pore water concentrations were calculated using very conservative partitioning coefficient values(13). The advective fluxes were then calculated based on the pore water expulsion rate due to consolidation. Because the caps for all three pits are essentially identical, the peak advective fluxes are also essentially identical. The estimated peak advective flux rates occur immediately after placement of the capping layers and range between 0.7 mg m^{-2} per year for mercury and 2143 mg m^{-2} per year for zinc. The fluxes decrease with time, in line with the trend of decreasing rate of consolidation. The results of the analysis of advective flux are summarised in *Table 3.10c*.

Table 3.10c *Summary of Results of Peak Advective Flux in mg m^{-2} per year*

	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Pits A and B	4.48	251	269	0.72	167	317	2093
Pit C	4.59	257	275	0.73	171	324	2143

3.10.3 *Diffusive Contaminant Flux*

The diffusive flux of contaminants was calculated using the Waterways Experiment Station Capping Model (WESCAP). The model is a refined version of the RECOVERY model which was originally developed to estimate fluxes of contaminants from contaminated sediment layers to overlying water(14). The WESCAP model can estimate the long-term diffusive fluxes in a system comprising a completely mixed water column, a completely mixed surface layer and a variable underlying sediment contaminant profile. The estimated peak diffusive flux rates from the WESCAP modelling varied from 1.1 mg m^{-2} per year for mercury to 3306 mg m^{-2} per year for zinc and decreased to very low rates

(12) Palermo MR et al. (1993) Long-Term Management Strategy for Dredged Material Disposal for Naval Weapons Station, Yorktown, Virginia, Naval Supply Center Cheatham Annex, Williamsburg, Virginia, and Naval Amphibious Base, Little Creek, Norfolk, Virginia, Phase II: Formulation of Alternatives, Misc. Paper EL-93-1, US Army Engineers Waterways Experiment Station, Vicksburg MS

(13) Palermo MR et al. (1989) Evaluation of Dredged Material Disposal Alternatives for US Navy Homeport at Everett, Washington," Technical Report EL-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS

(14) Boyer JM et al (1994) "RECOVERY, a mathematical model to predict the temporal response of surface water to contaminated sediments", Technical Report W-94-4, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

within a time period of a few years. Because the caps for Pits A, B and C are identical, the diffusive rates from the three pits are also identical. The results of the analysis of diffusive flux are summarised in *Table 3.10d*.

Table 3.10d ***Summary of Results of Peak Diffusive Flux in mg m^{-2} per year***

	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Pits A and B	7.09	394	425	1.10	268	504	3306
Pit C	7.09	394	425	1.10	268	504	3306

The WESCAP model was also used to estimate the long-term changes in sediment contaminant concentrations which occur due to diffusion. These results indicate that the surface of the capping layer will gradually become cleaner over a timescale of hundreds of years.

3.10.4 Potential Impacts on Water Quality

The total contaminant fluxes due to advective and diffusive fluxes are summarised in *Table 3.10e*.

Table 3.10e ***Total Predicted Contaminant Fluxes Due to Pore Water Expulsion***

	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Total Contaminant Flux in mg m^{-2} per year for Pits A & B	11.6	645	694	1.8	435	821	5399
Total Contaminant Flux in mg m^{-2} per year for Pit C	11.69	651	701	1.84	439	828	5449

These peak fluxes, background water contaminant concentrations, and flow velocities in the area of the pits were used to calculate the potential increase in background contaminant concentrations.

The peak tidal flow velocities would result in an exchange rate for the volume of water overlying the pits of approximately one hour. As a conservative measure, the exchange rate was assumed to be one day. The background water column concentrations for metals, the increase in water column concentrations due to the total flux, and the percent increase due to the total flux is summarized in *Table 3.10f*. As indicated below, the increase in water column metals concentrations is negligible.

Table 3.10f *Mean Background Water Column Metals Concentrations and Percent Increases Per Day in Concentration Due to Peak Fluxes*

	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Background Concentration (μg l^{-1})	0.37	1.6	7.0	1.8	4.4	11.0	17.0
Increase in Water Column Concentration (μg l^{-1})	0.00026	0.0014	0.016	0.00004	0.0098	0.018	0.12
Percent Increase for Pits A & B	0.07	0.87	0.23	0.0022	0.22	0.16	0.7
Percent Increase for Pit C	0.07	0.87	0.23	0.0022	0.22	0.16	0.7

The results of the flux evaluations indicated that the advective flux occurs over a period of decades and that diffusive flux reaches a very low steady state within a few years. The peak flux rates occur during the first year after capping. All contaminants released to the water column through pore water expulsion will be diluted throughout the course of the year by tidal currents. Fluxes are thus very low, decay rapidly and have a negligible effect on the overlying water quality. In addition, sediment metal concentrations in the capping materials decrease gradually in the long term.

3.11 STABILITY OF CONTAMINATED MATERIAL AND THE CAP LAYERS

This section presents the results of the erosion and stability analyses conducted for CMP IV. These results allow evaluation of the amount of contaminated material that is expected to erode from the uncapped pit under tidal and wave (storm) action and the stability of the pit cap under similar circumstances. Conclusions regarding the recommended backfill level and the suitability of the cap design are presented at the close of this section.

3.11.1 *Relevant Information From Previous Assessment of CMP I Cap*

Assessment of the susceptibility of contaminated material disposed in the pit to erosion and evaluation of the stability of the capped layers at CMP IV is facilitated by information gained through previous studies at CMP I(15). Although there are important differences between CMP I and CMP IV, field work conducted at CMP I just prior to Typhoon Koryn in 1993 allows a detailed assessment of the effects of major storm events on material stability.

As of late June 1993, CMP I had been filled with grab-dredged contaminated material to a level of approximately -9 mPD and was awaiting placement of a three metre thick layer of capping material. Measurements of mud densities were made in the pit at this point to determine the extent to which soft material deposits had formed on the surface of the disposed material. Shortly after collection of these data, Typhoon Koryn passed over the pit and within several days repeated measurements were collected. Comparison of these before- and

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(15) HWR (Asia) 1993. Disposal of contaminated spoil at East Sha Chau - An assessment of the stability of dumped spoil and capping layers. Report HWR 059.

after-typhoon data allows the loss of material during the typhoon to be described and quantified.

Prior to the typhoon, the pit was found to contain soft mud of 1-4 metres thickness with bulk densities of 1,050 to 1,300 kg m^{-3}. Post-typhoon measurements indicated that all material remaining within the pit had a bulk density of greater than 1,200 kg m^{-3} with some materials as dense as 1,400 kg m^{-3}. Therefore, these data demonstrate that material with bulk density greater than 1,200 kg m^{-3} was stable under Typhoon Koryn (estimated as a 1:10 to 1:50 storm event) at levels between -8.5 and -12.5 metres (ie the bottom of the pit). However, since CMP IV may receive both grab- and trailer-dredged material, and trailer dredging and disposal may result in placed material with lower bulk densities, it is important to consider the fate of the soft materials present in CMP I prior to, and absent after, the typhoon.

There are two possible explanations for the absence of soft materials after passage of the typhoon: either all soft material rapidly consolidated to densities greater than 1,200 kg m^{-3} or all material with densities less than 1,200 kg m^{-3} was eroded during the storm. As it seems unlikely that all material would have consolidated to a bulk density which would resist erosion, it is suggested that soft material was eroded until the typhoon passed or until the density of the exposed material resisted further erosion. To determine whether all of the available soft material was eroded, further calculations have been performed. These calculations assumed an average material dry density of 175 kg m^{-3}, a critical stress for erosion of 0.69 N m^{-2}, a current/wave induced bed shear stress of 1.5 N m^{-2} and a time of 12 hours, and concluded that only about 24 kg m^{-2} (or 15%) of the mass of soft material would be eroded. The principal implication of this conclusion is that even under severe storm events, erosion losses are limited by the bed stresses and storm duration rather than the availability of soft material for erosion. As a result, if trailer dredged material had been placed at CMP I, resulting in larger volumes of soft material, the erosion losses would probably have been no greater than for the grab dredged material.

3.11.2 *Assessment of CMP IV*

Although there are important differences between the hydrodynamic features of CMP I and CMP IV (eg tidal flow patterns), wave conditions and peak tidal currents should be very similar between the sites (*Figure 3.11a*). Based on analyses for CMP I, *Table 3.11a* provides bed shear stresses expected under different tidal and wave events at various backfill levels. Because of the similarities in wave and tidal conditions between CMP I and CMP IV, *Table 3.11a* can be used to estimate bed stresses for CMP IV. At the backfill level of -14mPD proposed for CMP IV, tidal flow induced bed stresses at CMP I are small and well below the value (0.3N m^{-2}) required to erode the soft mud component. Assuming the same peak water speeds over CMP IV, bed stresses will only be sufficient to erode the soft mud component (>0.3N m^{-2}) during the once per year storm event or more severe storm events.

Based on the calculated bed stresses presented in *Table 3.11a*, it can be seen that the backfill level of -14mPD for CMP IV compared to -9mPD for CMP I will result in a significant reduction in the frequency for the potential re-suspension of the contaminated material in a typical year (ie bed shear stresses are more frequently below 0.3 N m^{-2} for a bed level of -14m). It is still likely that should a severe storm occur before capping at CMP IV, there will be re-suspension of some soft

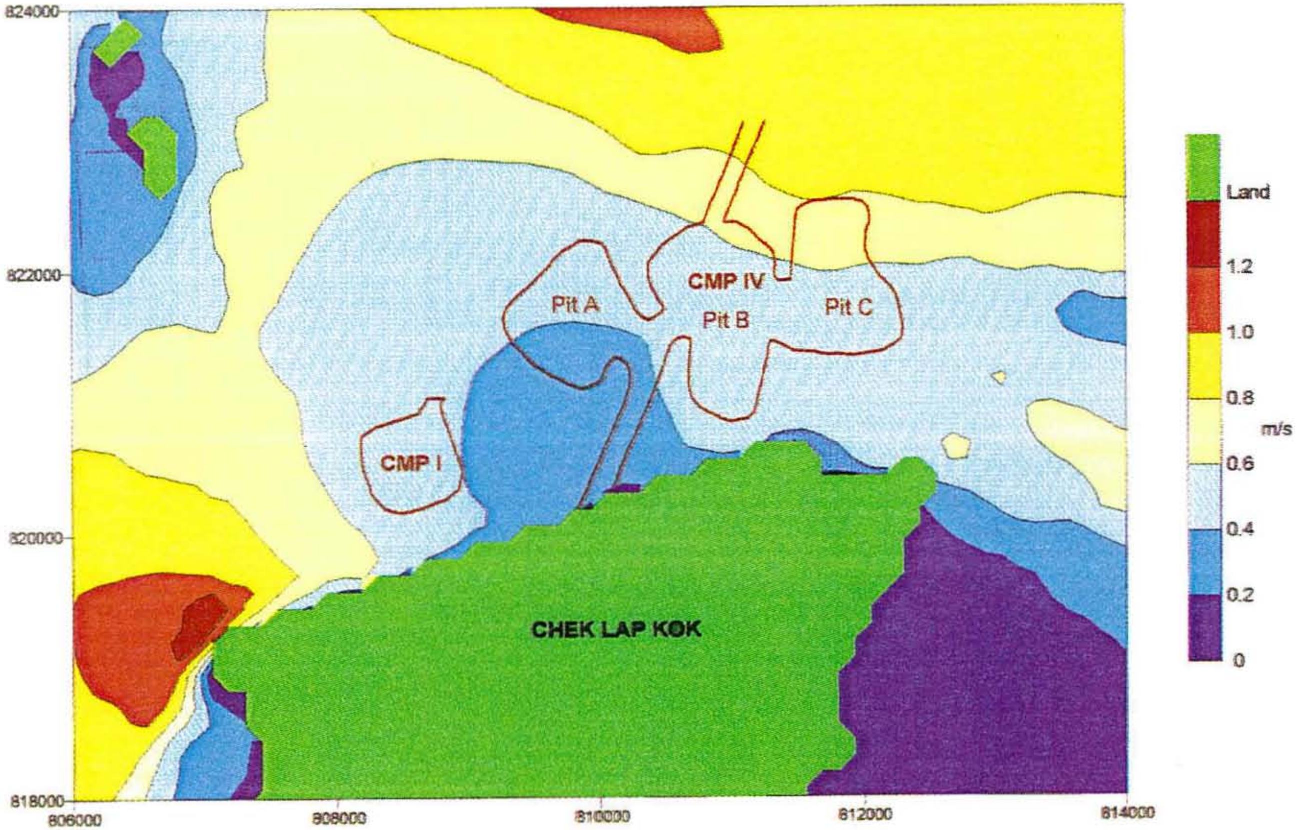

FIGURE 3.11a - CURRENT VELOCITIES OVER THE EAST SHA CHAU CMP'S SHOWING THE SIMILARITY BETWEEN PITS CMP I AND CMP IV

contaminated material. However, it is probable that a larger proportion of the resuspended material will be contained within the pit at CMP IV as compared to CMP I, as CMP IV will be backfilled to a lower level than CMP I, therefore a greater proportion of the resuspended material will remain below the lip of the pit. It should also be noted that at -14mPD, even under the 100 year storm event, bed stresses will be insufficient to erode material with a density of 1,200kg m^{-3}.

Some of the material to be placed at CMP IV will be hydraulically dredged rather than mechanically dredged and thus CMP IV may contain a proportionally larger volume of soft material than CMP I. However, as indicated above for CMP I, even if the introduction of trailer dredged material increases the proportion of soft mud present in CMP IV, the erosion losses during storms are again likely to be limited by the wave induced bed stresses and storm duration, not the volume of soft material. Therefore, the presence of a larger proportion of trailer dredged soft material should not increase the potential for erosion losses under the 1:50 year storm event.

Table 3.11a shows that at the backfill level of -9mPD for CMP I, bed stresses exceed the critical stress for erosion of soft material (0.3N m^{-2})) during the 10 times per year event combined with peak wet season currents but that for a backfill level of -14mPD, the critical stress is only just exceeded under the annual storm event combined with wet season currents. CMP IV can be considered to consist of 3 individual pits which will be filled and capped separately as detailed in the development plan. At the backfill level of -14mPD, the plan areas of Pits A and B are approximately 1.3Mm^2 while Pit C has a surface area of 1Mm^2.. This can be contrasted with the plan area of CMP I of approximately 0.5Mm^2 at the backfill level of -9mPD. In order to assess the potential for losses of soft material from CMP IV compared to CMP I, the combined wet season current and wave induced bed stresses given in *Table 3.11a* were used to calculate both the annual and severe storm event loss rates presented in *Table 3.11b*.

Table 3.11a *Bed shear stresses due to different events*

Bed Level (m PD)		-5	-6	-7	-8	-9	-11	-13	-14	-19
currents only (spring tide)	dry season	0.22	0.18	0.16	0.15	0.14	0.12	0.10	0.09	0.05
	wet season	0.33	0.28	0.25	0.23	0.22	0.19	0.17	0.16	0.11
	typhoon	0.66	0.57	0.50	0.46	0.43	0.38	0.34	0.32	0.22
waves[(b)] only	0.1	0.30	0.26	0.23	0.20	0.18	0.14	0.12	0.10	0.06
	1	0.47	0.42	0.37	0.34	0.31	0.26	0.22	0.20	0.14
	10	0.63	0.56	0.51	0.47	0.43	0.37	0.32	0.29	0.21
	50	2.68	2.29	1.98	1.73	1.53	1.22	0.64	0.60	0.46
	100	3.33	2.86	2.48	2.18	1.93	1.55	1.27	1.16	0.53
waves[(b)] and wet season currents	0.1	0.63	0.54	0.48	0.43	0.40	0.33	0.29	0.26	0.17
	1	0.80	0.70	0.62	0.57	0.53	0.45	0.39	0.36	0.25
	10	0.96	0.84	0.76	0.70	0.65	0.56	0.49	0.45	0.32
	50	3.01	2.57	2.23	1.96	1.75	1.41	0.81	0.76	0.57
	100[(a)]	3.99	3.43	2.98	2.64	2.36	1.93	1.61	1.48	0.75

(a) Includes typhoon flows rather than wet season.
(b) The return periods are quoted in years.

Table 3.11b *Estimated Losses from CMP I and CMP IV under Various Storm Events*

Event	Loss from CMP I (Area = 0.5Mm2) (Level = -9mPD)	Loss from CMP IV (Area = 1.3Mm2) (Level = -14mPD)
10 instances of 10 times/year storm (6 hr duration each) in one year	7,560t	0
1 annual storm event (6 hr duration)	1,740t	1,180t
1:10 year event (6 hour duration)	2,650t	2,950t
1:50 year event (12 hour duration)	21,924t	18,100t

From these results it can be seen that, allowing for the larger surface area and the lower backfill levels for the pits within CMP IV, the potential for losses of soft material from CMP IV is considerably lower than from CMP I on a typical annual basis. For severe storm events, potential losses from CMP I and CMP IV are similar. The cap materials are to be placed using hydraulic methods which will almost certainly result in an initially large proportion of soft material. However the initial consolidation of the upper few centimetres of material, during placement in thin layers, will be rapid and the vast majority of the cap material is expected to achieve a density greater than 1,200 kg m^{-3} during cap construction. Any erosional losses which do occur would be limited by bed stresses and storm durations and would not be significant in view of the considerable thickness of the cap. For example, a cap with a density of 1,200 kg m^{-3} placed up to a level of -6mPD would be eroded by only 0.14m during a 1:50 year storm and 0.23 m during a 1:100 year storm. A cap comprising soft material would be eroded by less than 0.5m during a 1:100 year event. Based on information from CMP I, there is no evidence of any erosion of the capping layer. If erosion has taken place at any time, this has been compensated subsequently by natural deposition from suspension.

3.11.3 *Conclusions Regarding Erosional Stability*

Soft contaminated mud will be present in the pits during filling. This material will be resuspended from within the CMP IV at a backfill level of -14mPD under the combined action of 1:10 year wave conditions plus currents but will remain at an acceptable level of stability under currents alone and less severe storm events. Based on the assumed properties of the soft mud, it was calculated that even the severe storm events could not erode all of the soft material generated in CMP I and that erosion losses were governed by the wave and current induced bed stresses and storm durations rather than the availability of soft material for erosion. This being the case, any proportionally larger volume of soft surface material generated in CMP IV from trailer dredged mud should not increase the potential for erosion losses during storm events.

The individual pits in CMP IV will each have surface areas at the proposed backfill level of -14mPD which are 2 to 2.6 times larger than the exposed surface area of contaminated mud in CMP I when it was capped at around -9mPD. However, a comparison of potential losses from CMP IV and CMP I based on a critical stress for erosion of 0.3N m^{-2}, predicted that the potential losses from CMP

IV would be less than those from CMP I under frequently occurring conditions, and similar under extreme storm conditions. Despite the increased plan areas of the pits in CMP IV, the increased protection afforded by the lower backfill level appears to reduce the potential for erosion losses. It should also be noted that at the lower backfill level, a greater proportion of the re-mobilised material is likely to be retained in the pit than at a higher backfill level.

Based on field observations at CMP I, the cap design for CMP IV will satisfactorily isolate contaminated material from release due to erosional stresses. Cap materials will be eroded during storm events but erosion will be limited by bed stresses and storm durations. Even under extreme events, ie those with return periods of 1 year or greater (similar to Typhoon Signal No. 8), erosional losses will be insignificant compared with the total thickness of the cap. Available bathymetric data indicates that large-scale consolidation of the softer material in the pit following capping occurs in a uniform manner and does not appear to affect the integrity of the capping layer.

3.12 *CUMULATIVE IMPACTS*

The acceptability of cumulative impacts can be initially inferred from the results of the modelling scenarios of the project itself. Since predicted elevations/depletions in suspended sediment, dissolved oxygen, nutrients and contaminants will be negligible in comparison to both ambient levels and applicable water quality objectives and standards, it is unlikely that backfilling activities at CMP IV will contribute significantly to cumulative water quality impacts within the study area. Therefore it is predicted that environmental effects of the CMP IV backfilling, in conjunction with other concurrent projects, will not cause detectably greater impacts than those resulting from the concurrent projects alone.

While cumulative impacts resulting from backfilling of CMP IV in conjunction with other projects in the study area were considered, they were not modelled for this EIA for the following reasons:

- the Aviation Fuel Receiving Facility dredging is now complete and thus cannot contribute to concurrent impacts in the study area;

- the sediment plumes arising from the Area 38 and River Trade Terminal projects do not cross the Urmston Road and therefore do not interact with predicted plumes resulting from CMP IV backfilling;(16) (17)

- the Container Terminal 9 project will take place along the southeast coast of Tsing Yi and it has been shown that plumes from the South Tsing Yi area do not extend into the East Sha Chau area;(18)

- the Tonggu Waterway project, while potentially contributing water quality impacts to the study area, is still at the planning stage and thus it is difficult to make meaningful estimates of sediment release rates, dredging locations and sediment quality.

(16) ERM Hong Kong Ltd (1994) Environmental Impact Assessment for the Tuen Mun Area 38 Special Industries Area.
(17) ERM Hong Kong Ltd (1996) Environmental Impact Assessment for the River Trade Terminal
(18) ERM Hong Kong Ltd (1995) Environmental Impact Assessment for the Backfilling of Marine Borrow Areas: North of Lantau and South Tsing Yi.

Given these findings, assessment of cumulative impacts through modelling of multiple, concurrent projects was not deemed necessary. Since backfilling of CMP IV is not likely to result in impacts greater than those associated with environmentally-acceptable disposal of contaminated mud at existing CMPs, and since on-going monitoring has found no evidence of trends in elevated concentrations of contaminants, disposal at CMP IV is also predicted to be environmentally acceptable.

3.13 *IMPLICATIONS OF STUDY FINDINGS FOR PROJECT MITIGATION*

3.13.1 *Assessment Approach*

In predicting environmental impacts for this EIA study, a variety of issues required careful judgment to select input parameters and assessment techniques. In cases where existing information allowed selection of a representative value with a strong degree of certainty, representative values were selected (eg dry density values, loss rates from trailers, and use of the ISQV-L). However, where it was unclear which of a range of values was most representative, a conservative (ie environmentally-protective) estimate was used (eg use of the worst case tide, contaminants evaluated at the highest occurring concentration). In other cases, such as prediction of hydrodynamic flow rates and selection of partitioning coefficients for contaminant modelling, a range of estimates was used, thereby bracketing the impact within high and low predictions.

Since a requirement of the study is produce practical and cost effective recommendations for mitigation, it is necessary to provide realistic, while at the same time, conservative impact predictions. For these reasons, impact predictions are based on a scenario involving the maximum rate of disposal of material with a high concentration of all contaminants on the worst case tide assuming maximum loss of contaminants and evaluation of results at the highest occurring contaminant concentration. It can thus be considered as a maximum credible impact scenario and it has been used as the basis for the discussion of mitigation measures below.

3.13.2 *Mitigation Measures*

It is critical that appropriate measures are applied to the disposal procedures to ensure that water quality impacts from backfilling, and subsequent erosion of disposed material, can be kept to a minimum and therefore minimise potential environmental impacts on identified sensitive receivers. Sediment losses and subsequent impacts upon sensitive receivers, will depend on disposal rates, the nature of the material being disposed, and site-specific hydrodynamic characteristics.

Specific design-based mitigation measures evaluated in this EIA and the recommended design features include:

- Backfilling Level: the originally proposed backfilling level of -14 mPD was assessed through analysis of erosion of uncapped contaminated material and it was found that material would only be eroded during the most severe annual storm event (or more severe storm events). This is considered acceptable since, under most storm events, losses from CMP IV would be less than those at CMP I. The greater depth of CMP IV and the greater thickness of its cap serve as mitigation measures against erosional losses.

- Cap Thickness: the original cap design of 6m, consisting of 1m of sand (or clean mud), 2m of clean mud, and 3m of additional clean mud or granular/mixed material, was found be resistant to erosion under extreme storm events (ie with a return period of 1 year or greater, similar to Typhoon Signal No. 8). Therefore, the proposed cap design is acceptable.

- Backfilling Rates: modelled rates of backfilling were defined based on realistic estimates of demand for contaminated mud disposal capacity and included 16,800 m^3 day^{-1} for barges, and 16,000 m^3 day^{-1} for trailers. These rates were found to be in compliance with applicable water quality objectives and standards. Only limited modelling of higher rates of disposal has been undertaken and if higher rates of disposal are envisaged these should be investigated through further modelling. Until such higher disposal rates are agreed within Government, the disposal rates should be limited to those stated above.

- Plant Specifications: scenarios involving material placement by bottom dumping from both barges and trailer dredgers were modelled and found to be acceptable at the backfilling rates assumed above. Therefore, bottom dumping from both barges and trailers is acceptable;

- Temporal Restrictions on Disposal: these assessments assumed only one vessel disposing at any one time. Therefore, disposal operations should be limited to one vessel per pit (Pit A, Pit B and Pit C) at any one time;

- Spatial Restrictions on Disposal: assuming all vessels dispose within the pit boundaries, no spatial restriction on disposal have been identified.

The Operations Plan, which will be released as a separate document to this EIA, will provide a detailed guide of the environmentally important aspects of management of disposal operations, incorporating the design requirements identified above. In addition to providing engineering specification for pit management, it also includes a recommendation that periodic bathymetric monitoring of the caps, as carried out to date at the existing CMPs, should be continued for the purposes of ensuring cap integrity is maintained.

In addition to the design-based mitigation measures identified in the Operations Plan, a number of other management measures will be implemented to further minimize water quality impacts. These measures are given in "*Management Procedures for Contaminated Mud Disposal at East Sha Chau, Handbook for Management of Contaminated Mud Disposal, Port Works, CED, July 1993*" and "*Appendix B - Requirements for Contaminated Mud Pit Management Scheme, FMC General Conditions of Allocation, 12 July 1995*".

3.14 ENVIRONMENTAL MONITORING AND AUDIT

A water quality monitoring and auditing programme will be conducted during disposal operations to verify whether impact predictions are representative and to ensure the disposal does not result in unacceptable impacts. Where monitoring shows disposal operations are resulting in deterioration of water quality beyond the predictions, and to unacceptable levels, appropriate mitigative measures, such as changes in the operational design, will be introduced.

The details of the environmental monitoring and audit (EM&A) programme will be presented in the EM&A Manual, which will be released as a separate document. As the disposal operations at CMP IV will not be fundamentally different from those at the existing CMPs, monitoring and audit procedures will be adapted from the present programme. The EM&A Manual will represent a continuation of approved monitoring and audit practices at the CMPs, while also, where appropriate, incorporating enhanced features and recently developed improvements in monitoring methodologies.

The EM&A Manual will include site-specific monitoring and auditing protocols for all phases of the backfilling operations. Such protocols will include but not be limited to the location of monitoring stations, parameters and frequencies, monitoring equipment, data management procedures, and reporting of monitoring results. Environmental audit specifications will be developed for all phases of the works, including an organisational and management structure, procedures to ensure compliance with mitigation measures, environmental quality performance limits, and procedures for reviewing results and auditing compliance with specified performance limits.

In addition to the monitoring and audit requirements discussed above, site management will play an important role in controlling impacts. On-site management practices, such as supervision by a 24-hour on-site management team and provision on all licensed barges of automatic self-monitoring tracking devices, which are presently in use at the existing ESC CMPs, will be refined for use at CMP IV. These and potential new measures will assist in preventing inaccurate dumping and controlling environmental impacts associated with disposal activities.

3.15 CONCLUSIONS

Water quality impacts associated with the proposed disposal of contaminated material at the East Sha Chau CMP IV were evaluated through use of a three-dimensional hydrodynamic model, TELEMAC, which predicts concentrations suspended sediment, dissolved oxygen, nutrients and contaminants resulting from various operational scenarios. Disposal of material from both barges (16,800 $m^3 day^{-1}$) and trailers (16,000 and 40,000 $m^3 day^{-1}$) was modelled for Pits A, B and C at both empty and full phases. Validation of TELEMAC for both wet and dry season spring and neap tides was achieved through comparison of modelled current velocities against those observed in the field.

All modelled scenarios complied with both the water quality objectives (for wet and dry seasons) and an assessment criterion of 10 mg l^{-1}. The maximum elevation in suspended sediment concentration was 4.2 mg l^{-1} at Sha Chau Beach in Scenario 4. This scenario was selected as a representative case on which to base contaminant modelling for seven metals, four PAHs and PCBs. All contaminants for which data on ambient concentrations was available, showed that predicted concentrations would not result in any measurable increase in ambient levels. As predicted levels are small fractions of ambient, predicted impacts will not cause a breach of applicable water quality standards. Modelling of pore water advective and diffusive flux rates indicated that contaminant fluxes due to pore water expulsion are very low with rates decaying rapidly and having a negligible effect on water quality.

The potential for erosion of the uncapped contaminated mud and the cap itself has been investigated. Analyses have shown that adequate protection from mobilization of contaminated mud during storm events is provided by adopting a maximum backfilling level of -14 mPD. Analyses have also shown that even the erosional forces associated with the most severe storm event would be incapable of breaching the cap and that any erosion of the cap would be compensated by natural deposition processes.

4 COMMERCIAL FISHERIES RESOURCES

4.1 *INTRODUCTION*

This section presents an assessment of the potential impacts to commercial fisheries resources which may arise as a result of the proposed contaminated mud disposal at the ESC CMP IV. The objectives of the assessment are as follows:

- assessing the value of the habitat to fisheries production using direct and indirect measures;
- calculating the potential gains and losses to fisheries production based on areal production estimates;
- evaluating the extent to which the area is used by commercial fishing vessels; and
- utilising critical concentration thresholds for marine organisms;

An assessment of potential impacts to the Marine Ecological Resources (non-fisheries) of the East Sha Chau area are detailed in *Section 5*.

4.2 *SUMMARY OF FINDINGS FROM THE INITIAL ASSESSMENT REPORT*

A review of existing commercial data for the study site, situated to the north of Lantau Island, was conducted for the Initial Assessment Report (IAR) to collate, and where appropriate incorporate, information on the existing commercial fisheries present in the area.

Several surveys of fish assemblages in the East Sha Chau (ESC) area have been conducted and are summarised below(1)(2)(3)(4). Demersal trawl catches from the region were dominated in these studies by the ponyfish (*Leiognathus brevirostris*) and the lionhead (*Collichthys lucida*). The pelagic fishery was reported to be dominated by the toothed croaker (*Otolithes argenteus*) and the long jaw herring (*Thrissa hamiltoni*). All of the studies reported high spatial and temporal variation in catch size and composition. Production levels in the ESC region are considered to be much lower than areas in the eastern waters of Hong Kong. The important feature of the fishery from ESC was considered to be the high production levels for prawns(5)(6). The high abundances of juveniles and eggs from ichthyoplankton trawls indicated that the ESC region is an important nursery and spawning area. A survey by EVS consultants reported that there is no evidence of any change in abundance, biomass or distribution of fisheries resources in the area that could be attributed to the mud disposal

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(1) Richards J & Wu RSS (1985). Inshore fish community structure in a subtropical estuary. Asian Marine Biology 2: 57-68

(2) Greiner-Maunsell (1991) Environmental Assessment of Construction Impacts. New Airport Master Plan. Working Paper No. 23. Chapters 8 & 9.

(3) Binnie Consultants Ltd (June 1995). Fisheries Survey of Hong Kong Waters Ichthyoplankton Assessment Report. GEO, CED.

(4) EVS Environment Consultants (May 1996). Review of Contaminated Mud Disposal Strategy and Status Report on Contaminated Mud Disposal Facility at East Sha Chau. CED

(5) Binnie Consultants Ltd (March 1995). Fisheries Survey of Hong Kong Waters Gill-net, Trawl, Ichthyoplankton and Reproductive Assessment Report. GEO, CED.

(6) Agriculture & Fisheries Department. (1991). Port Survey Data

activities at East Sha Chau(7).

4.3 BACKGROUND INFORMATION ON COMMERCIAL FISHERIES RESOURCES

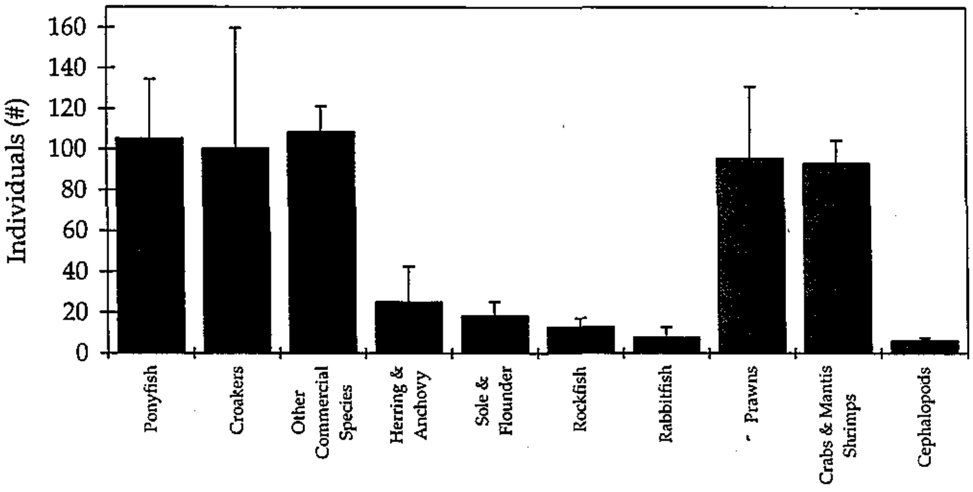
The following subsections will present the most recent information available on the fisheries resources in the area surrounding East Sha Chau CMP IV obtained from the AFD-funded Fisheries Resources and Fishing Operations in Hong Kong Waters Study conducted by ERM.

4.3.1 *Demersal Fisheries Resources*

Information has been compiled, from the above study, on the demersal fisheries resources of the area surrounding East Sha Chau. Shrimp trawls have been carried out monthly (March - September 1996) at two stations in the area, one of which is located in between Lung Kwu Chau and Sha Chau Islands (T17) and the other station is located close to The Brothers group of islands (T16) (*Figure 4.3a*). The data presented and discussed below are combined for the two sites.

Total catches from the shrimp trawls indicated that the most numerically abundant commercial fish species collected over the seven month sampling period in the East Sha Chau region were the ponyfish, *Leiognathus brevirostris*, and the croakers, *Collichthys lucida* and *Johnius belengeri*. There were also high numbers of other commercial species(8) collected from the area (monthly mean = 99 ± 16 SE) (*Figure 4.3a*). There were differences in species composition of the catch between months, for example the long jaw herring, *Thrissa kammalensis*, (Clupeiformes) was rarely observed in catches, however, in June 128 individuals were caught (*Table 4.3a*).

Figure 4.3a ***The ten most abundant demersal fisheries groups collected from monthly shrimp trawls (March - September) in the East Sha Chau Region (Mean number of individuals + SE for T16 & T17).***



The invertebrate portion of the catch was large and was dominated by various commercially important species of mantis shrimp, mainly *Oratosquilla anomala* and *Harpiosquilla harpax*. In terms of biomass, however, the invertebrate catch

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(7) *op cit* (EVS May 1996)

(8) ERM-Hong Kong Ltd (September 1996). Fisheries Resources & Fishing Operations in Hong Kong Waters Study. Determined from a list of target species included in the Final Stock Assessment Model Selection Working Paper

was dominated by the crabs *Charybdis cruciata*, *Portunus pelagicus* and *P. sanguinolentus*. The main prawn species collected in the region were *Metapenaeopsis barbata* and *Metapenaeus affinis*.

Table 4.3a ***Demersal fisheries resources (total number of individuals) collected from monthly shrimp trawls at Lung Kwu - Sha Chau & The Brothers stations***

Fisheries Resource		**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Ponyfish	Leiognathidae	32	136	129	253	45	48	94
Croakers	Sciaenidae	27	3	3	450	76	65	78
Other commercial	Species	110	152	84	158	86	88	82
Herring & Anchovy	Clupeiformes	26	10	2	128	2	7	1
Flatfish	Pleuronectiformes	51	4	2	39	14	6	12
Rockfish	Scorpaeniformes	8	1	0	25	29	20	7
Rabbitfish	*Siganus oramin*	0	3	0	1	5	8	37
Breams	Sparidae, Nemipteridae	0	10	0	4	6	10	0
Sand Borer	*Sillago* sp	6	2	0	1	7	3	4
Pomfrets	Stromateidae	0	7	1	1	9	3	4
Lizardfish	Synodontidae	0	1	0	8	11	2	1
Mullet	Mugiliformes	1	11	0	3	0	0	0
Threadfin	*Polynemus sextarius*	1	1	0	1	0	10	0
Cardinalfish	Apogonidae	0	1	0	1	5	7	0
Sharks and Rays	Chondrichthyes	0	0	0	0	6	1	2
Eels	Anguilliformes	2	0	0	0	2	1	1
Mackerel	Scombroidei	0	1	0	3	0	0	0
Scad	*Trachurus japonicus*	1	1	1	0	0	0	0
Shrimp Scad	*Caranx kalla*	0	0	0	0	1	0	0
Tigerfish	*Therapon* sp	0	0	0	0	0	1	0
Groupers	Serranidae	0	0	0	0	0	0	1
Crustacean Species								
Prawn		34	15	10	35	112	46	50
Crabs & Mantis shrimps		8	48	19	54	73	28	39
Molluscan Species								
Cephalopods		2	1	1	6	11	2	5
Shelled Molluscs		1	1	0	2	0	0	0
Total		440	460	304	1261	721	540	464

Value of the Region to Hong Kong Fisheries

The waters north of Lantau have previously been regarded as highly productive for the prawn and shrimp fishery[9]. Information from otter trawls conducted in the area in December & January 1994 indicated that 237 prawns were collected, this ranked the region as the most productive for prawns in Hong Kong when compared to six other regions.

Recent information from the East Sha Chau area has indicated, however, that numbers of prawns are low in the area when compared to the rest of Hong Kong.

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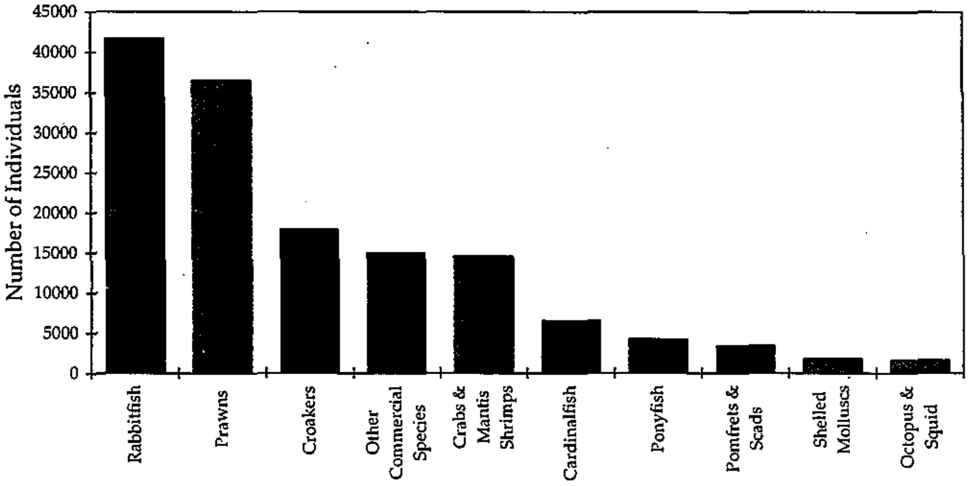
[9] Binnie Consultants Ltd (March 1995) Fisheries Survey of Hong Kong Waters Gill-net, Trawl, Ichthyoplankton and Reproductive Assessment Report. GEO, CED.

The maximum number caught during any one month at Lung Kwu-Sha Chau (T17) was 182 individuals. This compares to Outer Tolo Harbour in April, where over 2000 individuals of one species of prawn alone were caught. Overall the catch of prawns landed in the East Sha Chau area made up less than 2 % of the total catch of prawns from Hong Kong during the study period.

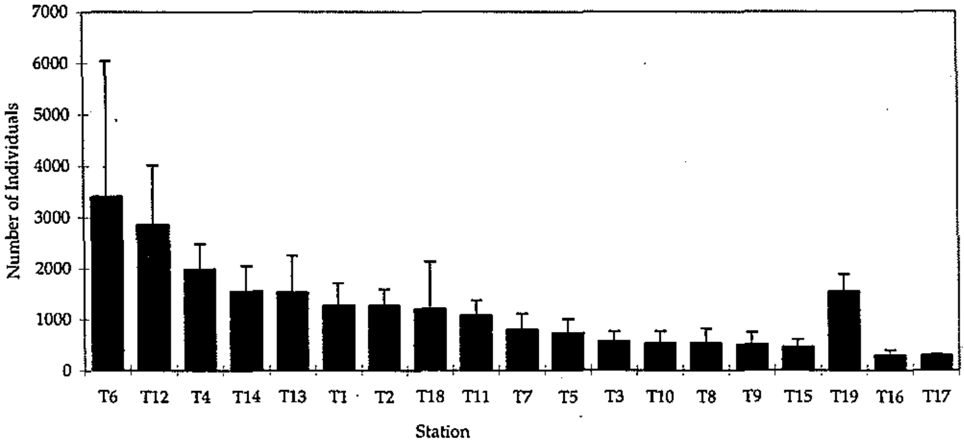
The most abundant commercially important resource in the Hong Kong catch was the rabbitfish, *Siganus oramin* with over 40,000 individuals caught during the sampling period *(Figure 4.3b)*. This fish, however, was always caught in low numbers at East Sha Chau (*Table 4.3a*). Catches from East Sha Chau contained a higher percentage (17 %) of other commercial fish (commercially less important species) compared to the overall Hong Kong catch (10 %).

Figure 4.3b. ***The ten most abundant demersal fisheries groups collected from monthly shrimp trawls (March - September) at nineteen stations throughout Hong Kong (total number of individuals).***



Mean monthly total abundance was lower at The Brothers (T16) and Lung Kwu-Sha Chau (T17) than any of the other seventeen stations monitored during the study period (*Figure 4.3c*).

Figure 4.3c. ***Abundance of demersal fisheries resources collected from monthly shrimp trawls (March - September) at nineteen stations throughout Hong Kong (monthly mean number of individuals + SE).***



Productivity estimates which are based on biomass, also indicated that these two stations have low fisheries value, relative to other areas in Hong Kong. Productivity was estimated at 0.091 g m^{-2} for The Brothers, ranking the station 14th out of the 19 stations in Hong Kong, and 0.093 g m^{-2} for Lung Kwu-Sha Chau (ranked 13th). The productivity estimates can be compared to 0.46 g m^{-2} at the top ranked station, Sharp Island (*Table 4.3b*).

In summary, the review of existing information on demersal fisheries resources in the ESC CMPIV region revealed that, compared to other parts of Hong Kong, catches are low.

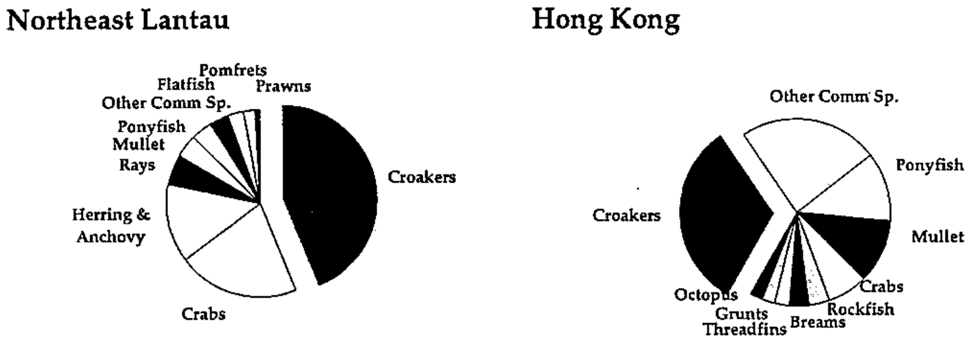
Table 4.3b ***Demersal Fisheries Production in Hong Kong from March - September 1996***

Station	Code	Total Number of Individuals Caught	Total Catch Yield (g)	Productivity ($g\ m^{-2}$)	Productivity Rank
Sharp Island	T6	23820	171715	0.460	1
South Cheung Chau	T12	19970	109892	0.294	2
South Lantau	T14	10857	97435	0.261	3
Tai Long Wan	T19	3076	23394	0.218	4
Tap Mun	T4	13867	65772	0.176	5
Kat O	T1	8943	63701	0.171	6
Soko Islands	T13	10688	61643	0.165	7
South Lamma	T11	7539	51964	0.139	8
North Lamma	T15	3223	47161	0.126	9
Outer Tolo Harbour	T2	8914	45711	0.122	10
Basalt Island	T7	5565	40787	0.109	11
Deep Bay	T18	8403	39677	0.106	12
Lung Kwu - Sha Chau	**T17**	**2064**	**34789**	**0.093**	**13**
The Brothers	**T16**	**2094**	**34065**	**0.091**	**14**
Double Haven	T5	5140	32802	0.088	15
Ninepins	T8	3734	30531	0.082	16
Stanley	T10	3736	27637	0.074	17
Waglan Island	T9	3543	24147	0.065	18
Inner Tolo Harbour	T3	3962	16573	0.044	19

4.3.2 *Pelagic Fisheries Resources*

The dominant species collected from gill nets deployed at a sampling station in Northeast Lantau (G10, *Figure 4.3a*) belonged to the family Sciaenidae. The lionhead, *Collichthys lucida*, alone made up approximately 40 % of the total biomass and 78 % of the number of individuals caught (*Figure 4.3d*). The remainder of the catch biomass consisted mainly of the anchovy, *Thrissa kammalensis*, the mantis shrimp *Oratosquilla oratoria* and the crab, *Charybdis cruciata*.

Figure 4.3d. ***Comparison between the ten most abundant pelagic fisheries groups collected from gillnets deployed at Northeast Lantau and overall in Hong Kong (total biomass).***


Northeast Lantau

Hong Kong

The catch from Northeast Lantau differed from the overall Hong Kong catch in terms of species composition by containing a higher percentage of crabs, mantis shrimps and croakers (Sciaenidae). The ponyfish, *Leiognathus brevirostris*, made up less of the catch from NE Lantau than the Hong Kong catch where it dominated at many stations. Overall the Hong Kong catch had higher species richness than the catch from Lantau. The gill net catches were almost exclusively composed of commercially important species (other commercial species = 2 %). This is in contrast to the demersal trawls in which other commercial species made up 16 % of the catches.

The Northeast Lantau area is very productive for pelagic fisheries. When stations across Hong Kong were ranked in terms of mean monthly catch biomass, the Northeast Lantau station ranks 2nd out of 11 (*Table 4.3c*). This result is consistent with the findings of the 1991 AFD Port Survey which revealed that the North Lantau area had high yields for gill-net fisheries. The importance of the area to the Hong Kong catch of the lionhead, *Collichthys lucida*, is highlighted by the fact that of the 647 individuals collected in Hong Kong waters during the seven month sampling programme 43 % were from the Northeast Lantau station.

In summary, the review of existing information on pelagic fisheries resources in the ESC CMPIV region revealed that, compared to other parts of Hong Kong, catches are high. Catches are dominated by the lionhead, crabs, mantis shrimps and long jaw herrings.

Table 4.3c *Pelagic fisheries resources in Hong Kong*

Station	Code	Total Biomass (g)	Mean Monthly Biomass (g)	Rank
Shek Kwu Chau	G8	9121	3040.0	1
NE Lantau	G10	5840.9	1947	2
S Lamma	G7	5109	1703	3
The Ninepins	G6	4654.3	1551.4	4
Deep Bay	G11	3930	1310	5
Kat O	G1	3561	1187	6
Peng Chau	G9	3372	1124	7
Double Haven	G2	2773	924.3	8
Bluff Island	G5	1986.6	662.2	9
Shelter Island	G4	1732.6	577.5	10
Inner Tolo Harbour	G3	959	319.7	11

4.3.3 *Spawning and Nursery Areas*

A number of studies have been conducted to assess the importance of the study area as a fish spawning and nursery ground. Quantitative ichthyoplankton surveys conducted at seven stations throughout Hong Kong waters in April 1995 showed a contrast between eastern and western waters. Western waters were identified as the major spawning grounds for fish stocks in Hong Kong(10). Shrimp trawls (adapted to assess juvenile resources) have been conducted on a monthly basis between April and September 1996 at The Brothers, as part of the ongoing AFD Fisheries Resources and Fishing Operations in Hong Kong Waters Study. Notwithstanding the findings of the previous studies, these results indicate that in comparison to other stations in Hong Kong, catches had low numbers of individuals and low species richness.

Trawl catches at The Brothers contained 27 species of juvenile fish and 16 species of juvenile invertebrates. Other commercial species were the largest (in terms of numbers of individuals) part of catch. The dominant family of commercially important fish caught in the area were the croakers (Sciaenidae), comprising 20% of the catch. Invertebrates collected in the area consisted of various species of prawns, crabs and mantis shrimps and comprised 29% of the total catch (*Figure 4.3e*).

The species composition of catches from Hong Kong as a whole indicate that prawns are numerically the most abundant organisms. The most abundant juvenile fish species across Hong Kong were the ponyfish (*Leiognathus brevirostris*), and the rabbitfish (*Siganus oramin*). These two species were rarely caught in the area surrounding CMPIV. Juvenile flatfish were rarely caught inHong Kong, however, 20% of the Hong Kong catch was collected at the Brothers.

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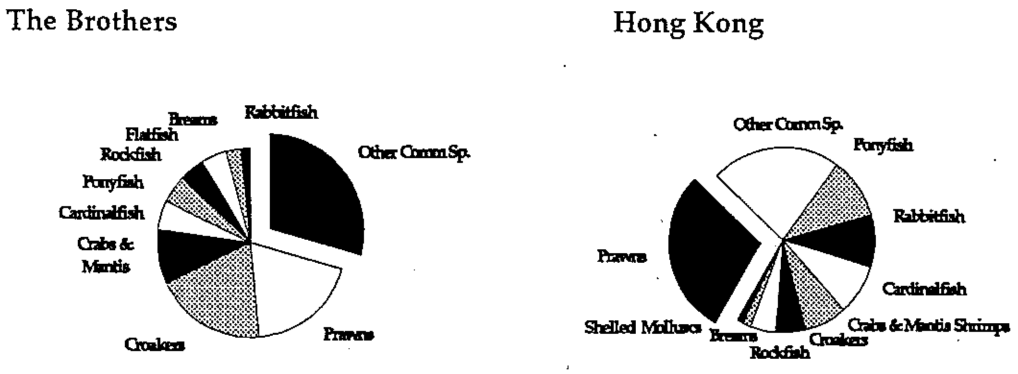
(10) Binnie Consultants Ltd (June 1995). Fisheries Survey of Hong Kong Waters Ichthyoplankton Assessment Report. GEO, CED.

Figure 4.3e. *Comparison between the ten most abundant juvenile fisheries groups collected from shrimp trawls at The Brothers and overall in Hong Kong (total individuals).*


The Brothers

Hong Kong

Comparison of the value of the area as a spawning ground with respect to other nursery and spawning areas in Hong Kong indicates that for the period April to September the station closest to CMPIV at the Brothers ranks 10th out of the 12 study stations in terms of number of individuals caught. The mean monthly number of individuals caught was low (121 individuals), as compared to over 800 from the station at Luk Chau. The area surrounding CMPIV is, therefore, not important as a nursery and spawning ground for commercial fish species relative to other areas sampled in this Study.

Table 4.3d *Catches from Shrimp Trawls at Spawning and Nursery Areas in Hong Kong*

Station	Code	Sampling Period	Total Number of Individuals	Mean Monthly Number of Individuals	Rank
Luk Chau	S7	Apr/Jun/Aug	2507	835.7	1
Long Harbour	S3	Apr/Jun/Aug/Sep	1974	493.5	2
Shek Kwu Chau	S9	May/Jul/Sep	1213	404.3	3
Wu Kwai Sha	S4	Apr-Aug	1987	397.4	4
Double Haven	S2	Apr/Jun/Aug	838	279.3	5
Lai Chi Wo	S1	May/Jul/Sep	831	277	6
South Tong Fuk	S10	Apr/Jun/Aug	746	248.7	7
Tung O Wan	S8	May/Jul/Sep	665	221.7	8
Leung Shuen Wan	S5	Apr/Jun/Aug	569	189.7	9
The Brothers	**S11**	**May/Jul/Sep**	**364**	**121.3**	**10**
W Sharp Island	S6	May/Sep	227	113.5	11
Deep Bay	S12	Apr/May/Jun/Aug /Sep	353	70.6	12

4.3.4 *Fishing Operations in the East Sha Chau Region*

As part of the ongoing AFD fisheries survey, fishing operations in Hong Kong waters are monitored by helicopter surveys. Of the 31 boats observed actively fishing in the ESC area between June and September 1996, 25 (80%) were trawl vessels. Shrimp trawling is a very common activity in Hong Kong waters. In the current Study, 56 shrimp trawlers were observed fishing during the above period, of these boats 13 (23%) were in the ESC region. Hang trawling is common only in the western waters of Hong Kong and of the 27 hang trawlers observed fishing during June - September, 12 (44%) were in the ESC region.

The larger trawlers (pair and stern), which yield the largest catches in Hong Kong, were never observed fishing in the area around East Sha Chau during the above period. Pair trawlers are known to fish in the area during certain months of the year (winter months), corresponding to the abundance of commercially important migratory species. At other times of the year, abundances of demersal fish are not high enough to warrant fishing by the larger vessels.

4.4 SENSITIVE RECEIVERS

Based on the literature review undertaken as part of the IAR, and comments on the report, the following ecologically sensitive receivers which may be affected by the proposed backfilling operations have been identified, as shown in *Figure 5.4a*, and are listed below:

- demersal commercial fisheries resources;
- nursery & spawning areas;
- pelagic commercial fisheries resources; and
- Fish Culture Zones;

Marine ecological sensitive receivers other than fisheries are discussed in *Section 5*.

4.5 TYPES OF IMPACT

Potential impacts to commercial fisheries resources arising from backfilling are as follows:

- direct disturbance to benthic habitats causing a loss of food supply;
- changes in water quality; and
- uptake of contaminants into the food chain.

A description of the effects these changes may have on commercial fisheries resources within the study area is given below.

4.5.1 *Disturbance to Benthic Habitat*

Demersal fisheries species utilise different elements of the benthos as food resources. Epibenthic predators (eg crabs, mantis shrimps and the majority of fish) feed on benthic infauna (eg polychaetes, nemertines and bivalves). Any changes in the biomass of benthic infaunal organisms will thus directly affect the numbers of predators that can be supported by them, either immediately or after a period of time. Another important component of the demersal fishery are prawns and molluscs which generally feed on benthic sediments and any organic material associated with them (eg carrion). Deposit feeders are known to aggregate in areas where the organic content of sediments is high[11].

Originally it was intended to establish relationships between demersal fisheries resources and their benthic prey through a literature search. Recently collected information on the benthic organisms present in the CMP IV area (*Section 5*), however, has indicated that faunal abundances are low throughout the area. As detailed in *Section 4.2.1*, abundances of demersal fisheries in the ESC area are also very low. This has prevented the establishment and rigorous testing of any trophic relationships applicable to the ESC area.

As an alternative, the table below (*Table 4.5a*) details the feeding habits of a selection of benthic feeding fish, some from ESC region, others from elsewhere in Hong Kong. As expected, plankton feeders, *Leiognathus, Collichthys* and *Thrissa,* which do not depend on benthic infauna as prey, appear in high numbers in the region. Typical benthic feeders, however, eg *Nemipterus, Chrysophrys* and *Cynoglossus* are rare in the ESC area as are their main food items (bivalves, brittle stars, crabs and fish).

Neither benthic feeders, nor plankton feeders are likely to be affected by any increased sedimentation in the area for two reasons;

- the prey for the plankton feeders will be unaffected by increased sediment deposition therefore their abundance is not expected to be affected by sedimentation; and

- since the ESC area ranks as the lowest in terms of abundance of commercially important benthic feeders in Hong Kong, increases in sedimentation may possibly impact the present population but will not alter this ranking.

Sediment plumes arising from backfilling operations, however, will lower light penetration in the water column and hence impact the abundance of phytoplankton. Plumes, therefore, may cause short term impacts to pelagic fishes which consume the phyto- and zooplankton. This is likely to result in short term migrations of pelagic fishes away from the area as they search for food.

One species that may be affected by increased sedimentation is the croaker, *Johnius belengeri.* This fish feeds solely on benthic organisms that live in soft sediment (mainly crabs, brittle stars and foraminiferans). The abundances of crabs and brittle stars are very low at ESC, however, the Foraminifera (25% of the diet), are abundant. Increased sediment deposition could affect the abundance of Foraminifera and consequently the abundance of the croakers.

Sediment may be deposited on the seabed outside the CMP through natural dispersion of the sediment plume and the processes of near-bed transport, erosion and wave-induced re-suspension (see *Section 2*). Sediment deposition, however, is expected to be small (a worst case maximum of 0.5 - 1.0 kg m^{-2} confined to a small area on CMPs IIA, IIIA, IIIB; see modelling *Scenario 4 in Section 3*) so impacts to commercial fisheries outside of the CMPs are expected to be minimal, especially as the more abundant species are pelagic and therefore less affected by sedimentation.

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[11] Britton JC & Morton B (1992) The ecology and feeding behaviour of *Nassarius festivus* (Prosobranchia: Nassariidae) from two Hong Kong bays. Proceedings of the 4th International Marine Biological Workshop: The Marine Flora & Fauna of Hong Kong and Southern China III. Hong Kong University Press

Table 4.5a *Selected commercial fisheries resources and their relationships with benthic fauna*[12][13]

Species	Food Items	Abundance of food type at ESC	Abundance at ESC
Plankton Feeders			
Leiognathus brevirostris Ponyfish	21% Benthic food items 68 % Planktonic items including Copepods, Amphipods, Chaetognatha	Low abundance of benthic foods. Plankton abundance unknown but thought to be high due to water mixing with the estuary.	Very high, though twice as many were collected from South Lantau.
Collichthys lucida Lionhead	36% Benthic food items including benthic amphipods and cumaceans 64% Planktonic	As above, though greater reliance on benthic prey in the diet.	Although the fish dominates at ESC its abundance is very low when compared with South Cheung Chau or the Soko Islands
Thrissa kammalensis Herring	91% Planktonic items Copepods, Crustacean larvae, Chaetognath, Phytoplankton	Thought to be high due to current mixing between estuary and oceanic waters	Highest abundances in Hong Kong are in the East Sha Chau region
Benthic feeders			
Nemipterus japonicus Goldenthread	75% Benthic food items including Bivalves, Ophiuroids, Worms, Crabs	Low abundances, especially bivalves and ophiuroids	Low abundances, mainly found around Lamma Island and Tai Tam
Chrysophrys major Red Pargo	80% Benthic food items including Bivalves, Crabs, Worms	Low abundances especially bivalves	Never found in ESC region, mainly found in NE Waters
Cynoglossus spp. Sole	100% Benthic food items, mainly juvenile benthic fish	Low abundances	Moderate abundances in ESC region, mainly found in Deep Bay, South Cheung Chau and Soko Islands
Johnius belengeri Croaker	100% Benthic food items including Ophiuroids, Crabs, Foraminifera	Low abundances of Ophiuroids and crabs, Foraminifera abundant.	Moderate abundance in ESC region, higher numbers found at South Lantau, South Cheung Chau and Waglan.

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[12] Xu *et al.* 1994. Atlas of the fishes and their biology in Daya Bay

[13] ERM-Hong Kong Ltd 1996. Seabed Ecology: East Sha Chau. Draft Report GEO, CED.

4.5.2 *Changes in Water Quality*

The backfilling operations will cause an increase in suspended solid concentrations in the water column and hence turbidity of the sea water. This may cause damage through clogging the gills of fish.

Direct physical impacts from high SS concentrations upon fish are well documented and include:

- "coughing" as fish attempt to expel sediment from their gills;
- abrasion on scales and gills, making fish more susceptible to infection; and
- avoidance behaviour.

Increased suspended solid (SS) concentrations are also associated with various indirect effects. High levels of SS often cause an associated oxygen depletion, particularly at the bottom of the water column and in sediments. This can result in hypoxia in benthic species, epifauna and demersal fish. Water quality impacts have a greater effect on sessile organisms than on mobile species, which when exposed to poor water quality will generally avoid the area and move to a more preferable habitat.

As discussed in *Section* 3.0, water quality impacts arising from backfilling operations are expected to be negligible. A discussion of fish tolerances to water quality impacts predicted by this Study is presented in *Section* 4.6.3.

4.5.3 *Uptake of Contaminants into the Food Chain*

Contaminant impacts to fisheries may arise as a result of:

- accumulation of contaminants in the tissue of fish and invertebrates resulting sublethal effects which may affect behaviour, reproduction and increasing susceptibility to disease; and

- increased mortality, and sub lethal effects to, eggs, larvae and juvenile species, as these are particularly sensitive to elevated contaminant concentrations.

Contaminants which accumulate in commercially important fish species may ultimately impact human health. Despite these potential impacts, concentrations of metals in muscle tissue of 13 species of commercially valuable fish and prawns caught at ESC were near background levels for Hong Kong waters(14). In addition, an independent review of the current disposal activities at ESC concluded that for most metals the tissue concentrations in fish were variable and no trends were apparent. It was concluded that the fish captured in the vicinity of the ESC did not show a significant elevation in heavy metals relative to fish in other Hong Kong waters(15). A full discussion of risk assessment in the food chain is detailed in *Section 5.6*.

Concern has been expressed that contaminants may be released from the capped pits by bioturbation. A full discussion of this is presented in an assessment of impacts to Marine Ecology (*Section 5.5.4*).

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(14) *op cit* (CES and Binnie Consultants Ltd. 1994).
(15) *op cit* (EVS Environment Consultants 1996)

4.6 EVALUATION OF IMPACTS

This section will evaluate impacts arising from sediment deposition, SS concentrations and the fate of contaminants. In addition to potentially adverse environmental impacts there are several environmental benefits associated with backfilling which are also discussed.

4.6.1 *Potential Adverse Impacts of Backfilling*

The rate and duration of suspended solids elevations predicted to result from mud disposal, and the season at which they occur will influence the type and extent of impact upon commercial fisheries resources. Modelling results given in *Section 3* predict that elevated concentrations of suspended sediment (approximately 5 $mg\ l^{-1}$) will occur within the CMPs and that small plumes will extend to the north during flood tide, and east and west during ebb tide (*Annex G* Scenario 4). These elevations in SS may locally impact fish, fry and larvae. However, given the proximity of the area to the Pearl River Delta, which frequently carries high SS loads, it is expected that organisms living in the area would be adapted to, and tolerant of, high and fluctuating suspended solid loads. The ambient ranges in SS levels measured in the area are much greater than the predicted elevations due to backfilling. Adverse impacts to fisheries in the region of the ESC CMP IV are not, therefore, expected to arise.

As a result of the backfilling activities more vessels will be using the area. Impacts of these activities to existing vessel usage of the area, ie fishing operations, are not expected to occur (see *Section 2.8*).

4.6.2 *Beneficial Impacts of Backfilling*

Once backfilling and capping operations have been completed, and the seabed has been restored to its original condition, a beneficial effect associated with recolonization by the natural fauna is expected to occur. After a period of recolonisation, during which it would be expected that the benthic assemblage would be restored, the original trawl fisheries resources, and any spawning and nursery functions of the habitat are expected to be replaced. Studies of recolonization at ESC indicated that the process had started within 4 months of the completion of backfilling, but that the recolonizing assemblage had not yet attained the species composition of undisturbed areas,(see *Section 5.3.3*(16)(17)). Deposits of granular or mixed material (heterogeneous substrate) on the seabed have been shown to enhance ecological diversity in the eastern waters of Hong Kong and placing this material on the capped pit has been suggested as a means of enhancing the ecological value of the area(18). This could, therefore, result in an increase in abundance of demersal fish species.

Fishing operations are presently restricted at CMP IV due to inconducive bathymetry. However, after the backfilling operations are complete in mid 2003 (*Figure 2.5a*), the natural seabed will be restored and fishing operations can be resumed. The potential gain in fisheries production associated with restoration of the natural seabed at CMP IV can be estimated using the following equation:

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(16) *op cit* (Binnie Consultants Ltd 1995)

(17) *op cit* (ERM-Hong Kong Ltd, November 1996)

(18) Binnie Consultants Ltd (March 1996) Investigation of Benthic Recolonisation at the Mirs Bay Disposal Site. Draft Report.

- Potential gain in production = Area restored for production × Production estimate for the area

Production estimates from the present AFD Study for stations T16 & T17 (The Brothers & Lung Kwu-Sha Chau) during the period March to September 1996 are used to estimate theoretical fisheries production values during the sequence of CMP IV backfilling (*Table 4.6a*).

It should be noted that this method provides a theoretical estimate, based on the assumptions that the yield from the pit areas would be similar to the nearby trawl stations, that the whole area would be fished and that the Mean Yield calculated for T16 and T17 from the present dataset is representative of the true mean yield for these stations. In this example, data from T16 & T17 are used, allowing the calculation of more than one estimate for comparison. This also allows means to be calculated and hence an estimate of variability to be derived (eg, Mean for all pits = 330,280g ± 5,077g SE).

Table 4.6a ***Theoretical estimates of potential production gains at East Sha Chau CMP IV based on data from AFD Study of Fisheries Resources & Fishing Operations in Hong Kong Waters***

Mean Yield (Mar-Sep 96) (g)	Area Surveyed (m^2)	Productivity (g m^{-2})	Backfilling sequence	Area restored (m^2)	Potential Production Gain (g)
The Brothers					
4866.5	53550	0.091	Pit A	1.28M	116,480
			Pit B	1.30M	118,300
			Pit C	1.01M	91,910
			Pits A + B	2.58M	234,780
			All Pits	3.59M	326,690
Lung Kwu-Sha Chau					
4969.9	53350	0.093	Pit A	1.28M	119,040
			Pit B	1.30M	120,900
			Pit C	1.01M	93,930
			Pits A + B	2.58M	239,940
			All Pits	3.59M	333,870

4.6.3 *Critical Concentration Thresholds*

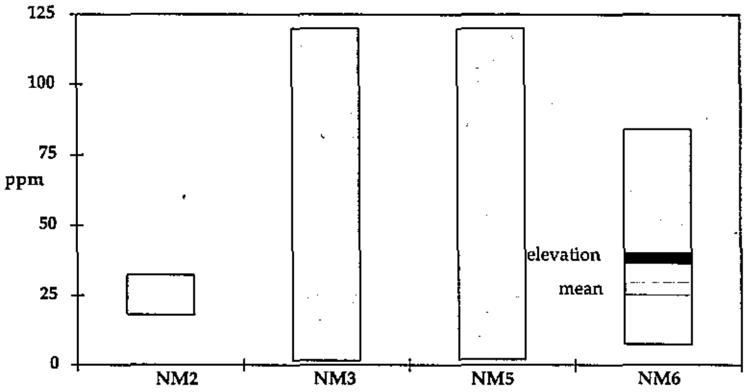
The development of critical concentration thresholds for benthic marine organisms can provide a tool to assess whether backfilling operations may impact the ecological community. For example, acute and/or chronic effects to marine organisms may become manifest only at certain levels of contaminant concentration, and these levels may then be specified as tolerance thresholds. However, this approach is not practical for Hong Kong waters due to the lack of species threshold data specific to Hong Kong. Although literature surveys have been used in the past to fill such data gaps, many of the examples cited in these reports are derived from temperate habitats and species and their relevance to Hong Kong's marine environment is as yet undetermined.

As an alternative approach, species tolerances to the natural variations in the marine environment near CMP IV may be estimated using the maximum and minimum values recorded from baseline monitoring programmes. In the absence of more precise impact triggers, these ranges may be considered critical concentration thresholds, and impacts could be presumed to occur only at levels lying beyond the range of natural variation.

This approach was followed as regards elevations above ambient levels for the following water quality parameters: Suspended Sediments (SS), Dissolved Oxygen (DO) and Nutrient Concentration. Released concentrations based on the contaminant modelling are minimal (*Annex O*) and are addressed through rick assessment in *Section 5.5.4*. This indicates, therefore, that the predicted increases in contaminant levels will be within the range that commercial fisheries resources are tolerant of, and adapted to (assessed further in *Section 5.5.4*). Plumes associated with the backfilling are predicted to reach EPD water quality stations (NM2, NM3, NM5, NM6). *Figure 4.6a* illustrates the ambient variations in SS, DO and Nutrient levels at these stations.

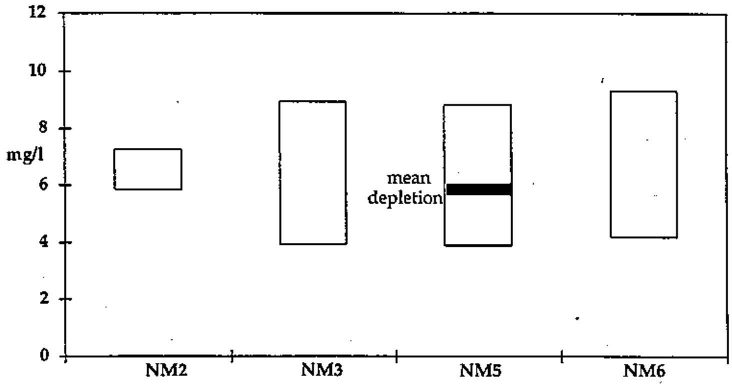
Figure 4.6a. ***Maximum and minimum ranges for water quality parameters at EPD monitoring stations near to CMP IV. Mean values and elevations are shown for stations where there is a detectable increase in the parameter concerned.***

i. Suspended Solids



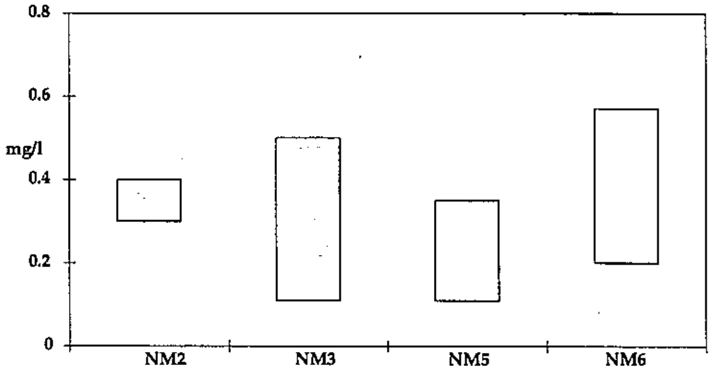
Detectable changes in SS (based on *Scenario 4*) were only observed at the monitoring station located to the west of the CMPs (NM6). The elevations are not likely to impact fish in the area as the increases fall within the ambient range (*Figure 4.6a.i*). Dissolved oxygen depletions as a result of backfilling occur only at the station close to Lung Kwu Chau (NM5). Again, as with SS levels, the depletion is within the ambient range thus no impacts are expected as the species present are likely to be adapted to concentrations within this range (*Figure 4.6aii*).

ii. Dissolved Oxygen Depletion



There were no predicted elevations in nutrient levels at any of the EPD water quality stations since elevations were largely confined to CMP IV. No impacts to commercial fisheries as a result of increased nutrient levels are predicted to occur outside the confines of CMP IV (*Figure 4.6a.iii*).

iii. Nutrient Levels



4.7 CUMULATIVE IMPACTS

Cumulative impacts to commercial fisheries resources may arise from concurrent dredging, backfilling or development projects in the area.

Types of impacts may include physical effects (eg increased suspended sediments concentrations), water quality effects (eg changes in dissolved oxygen, nutrients or contaminant concentrations), and ecosystem effects (eg benthic or water column habitat disturbance). Activities may result in the following impacts to commercial fisheries resources:

- prolonging the period of impact;
- increasing the intensity of the impact; and

- causing different effects in combination than any one impact would cause independently (synergy).

A full discussion of cumulative impacts is presented in *Section 5.8*.

4.8 *MITIGATION MEASURES*

Impacts to commercial fisheries resources, either through changes in water quality or changes in habitat, are not predicted based on the modelled operational scenarios. Mitigation measures designed to control impacts to water quality, are described in *Section 3.9* and developed in conjunction with the Operations Manual and EM&A Manual, will also mitigate any impacts to commercial fisheries. Based on the findings of this assessment, no special mitigation measures to protect commercial fisheries sensitive receivers are necessary.

4.9 *CONCLUSIONS*

A review of existing information on commercial fisheries resources located within and around the ESC CMP IV has identified the area as supporting low abundances of demersal fisheries resources and high abundances of pelagic fisheries resources. While earlier studies have indicated that the East Sha Chau area is an important nursery and spawning ground, initial results of the ongoing Study of Fisheries Resources and Fishing Operations in Hong Kong Waters have indicated that the area supports a low abundance of juvenile fisheries resources in comparison to other areas in Hong Kong.

Potential impacts to fisheries resources may arise from disturbances to benthic habitats, changes in water quality and contaminant release. Disturbances to benthic habitats are predicted to be confined within the CMP, and as recolonisation of sediments is expected to occur following completion of works, the project will be of long term benefit in restoring benthic fauna, epifauna and demersal fisheries resources to the area. As changes in water quality are minimal and transient, adverse impacts to fisheries resources are not predicted to arise. Assessment of contaminant release has indicated minimal concentrations will be released; the potential effects of these concentrations are assessed through risk assessment as described in *Section 5.5.4*.

Impacts arising from the proposed backfilling operations are predicted to be largely confined to the CMP IV, and will not cause adverse effects to any habitats or species of commercial or conservation importance. While no special mitigation measures are required for fisheries resources, mitigation measures recommended to reduce impacts to water quality to acceptable levels are also expected to mitigate impacts to fisheries resources.

5 MARINE ECOLOGY

5.1 INTRODUCTION

This section presents an assessment of the potential impacts to marine biota which may arise as a result of the proposed contaminated mud disposal at the ESC CMP IV. This section supplements *Section 4* on Commercial Fisheries by concentrating on potential impacts to benthic fauna, the Chinese Horseshoe Crab, corals and marine mammals.

The objectives of the assessment are as follows:

- to identify ecological sensitive receivers;
- to assess the scale of possible ecological impacts from backfilling;
- to highlight any insurmountable impacts to marine ecological resources arising from backfilling of the ESC CMP IV; and
- to identify the key issues for detailed assessment and further ecological studies.

A review of existing ecological data for the study site has been conducted to collate information on baseline ecological conditions. Particular emphasis has been placed on benthic invertebrate communities and marine mammals. Potential impacts have been discussed and, where appropriate, mitigation measures suggested.

5.2 STATUTORY REQUIREMENTS AND EVALUATION CRITERIA

Legislative and regulatory controls which apply to marine species include:

- The Animals and Plants (Protection of Endangered Species) Ordinance (Cap.187) 1988, which for the marine environment of Hong Kong would include the protection of all cetaceans and sea turtles;
- The Wild Animals Protection Ordinance (Cap. 170) 1980 which protects all cetaceans;
- The Fisheries Protection Ordinance (Cap.171) 1987 which provides for the conservation of fish and other aquatic life and regulates fishing practices;
- The Convention on the International Trade in Endangered Species of Flora and Fauna (CITES) which lists the Chinese White Dolphin (*Sousa chinensis*) on Appendix One.

There are no regulatory criteria to evaluate the impact of development upon ecological resources. However, consideration of conservation significance can be applied to both species and communities, based on a number of factors including rarity, ecological importance and, in the case of communities, diversity.

5.3 *EXISTING ECOLOGICAL ENVIRONMENT*

5.3.1 *Introduction*

The ESC CMP IV is situated in the western waters of Hong Kong to the north of the Chek Lap Kok Airport platform. As described in *Section 3*, the study area is located within the Pearl River Estuary and is strongly influenced by discharges from this river, which fluctuate seasonally. These conditions contrast with those in the eastern waters of Hong Kong, which are predominantly influenced by oceanic waters.

Studies conducted for the Civil Engineering Department (CED), have investigated the ecology of Marine Borrow Areas (MBAs) in Hong Kong. Several of these studies provide baseline ecological information of direct relevance to this study. The reports reviewed are listed in *Box 5.3a* below.

Box 5.3a *List of Reports Reviewed as part of Baseline Ecological Review*

- ERM-Hong Kong Ltd. Seabed Ecology: East Sha Chau. Draft Report, November 1996;
- EVS Environment Consultants. Review of Contaminated Mud Disposal Strategy and Status Report on Contaminated Mud Disposal Facility at East Sha Chau, 1996;
- Binnie Consultants Ltd and CES. Environmental Monitoring Programme East Sha Chau - Phase 2. Monthly Progress Reports from January to November 1995.
- CES and Binnie Consultants Ltd. An Assessment of the Impact of Contaminated Dredged Material Disposal at Contained Disposal Facilities with Reference to East Sha Chau, 1993;
- Binnie Consultants Ltd and CES. East Sha Chau Monitoring Programme (November 1992-December 1993) Final Report, 1994;
- Binnie Consultants Ltd. REMOTS Survey of Soft-Bottom Environments in Coastal Waters of Hong Kong, 1993;
- Binnie Consultants Ltd. REMOTS and Grab Survey to Assess Benthic Recolonisation following Backfilling at East Sha Chau (East) Marine Borrow Pit, 1995;
- Binnie Consultants Ltd. Fisheries Survey of Hong Kong Waters: Gill-Net, Trawl, Ichthyoplankton and Reproductive Assessment Report, 1995;
- Binnie Consultants Ltd. Fisheries Survey of Hong Kong Waters: Ichthyoplankton Assessment Report, 1995; and
- Mouchel Asia Ltd. Environmental Monitoring & Audit for Contaminated Mud Pits II & III at East of Sha Chau. Monthly Reports
- ERM-Hong Kong Ltd (March 1996) Aviation Fuel Receiving Facility at Sha Chau: Detailed Design Basis Supplementary EIA.

The findings from these ecological studies have been used as the basis for the following discussions which make particular reference to the identification of any species or habitats of key ecological or conservation importance which may be affected by the proposed works. *Figure 5.3a* shows the locations of previous surveys in the study area.

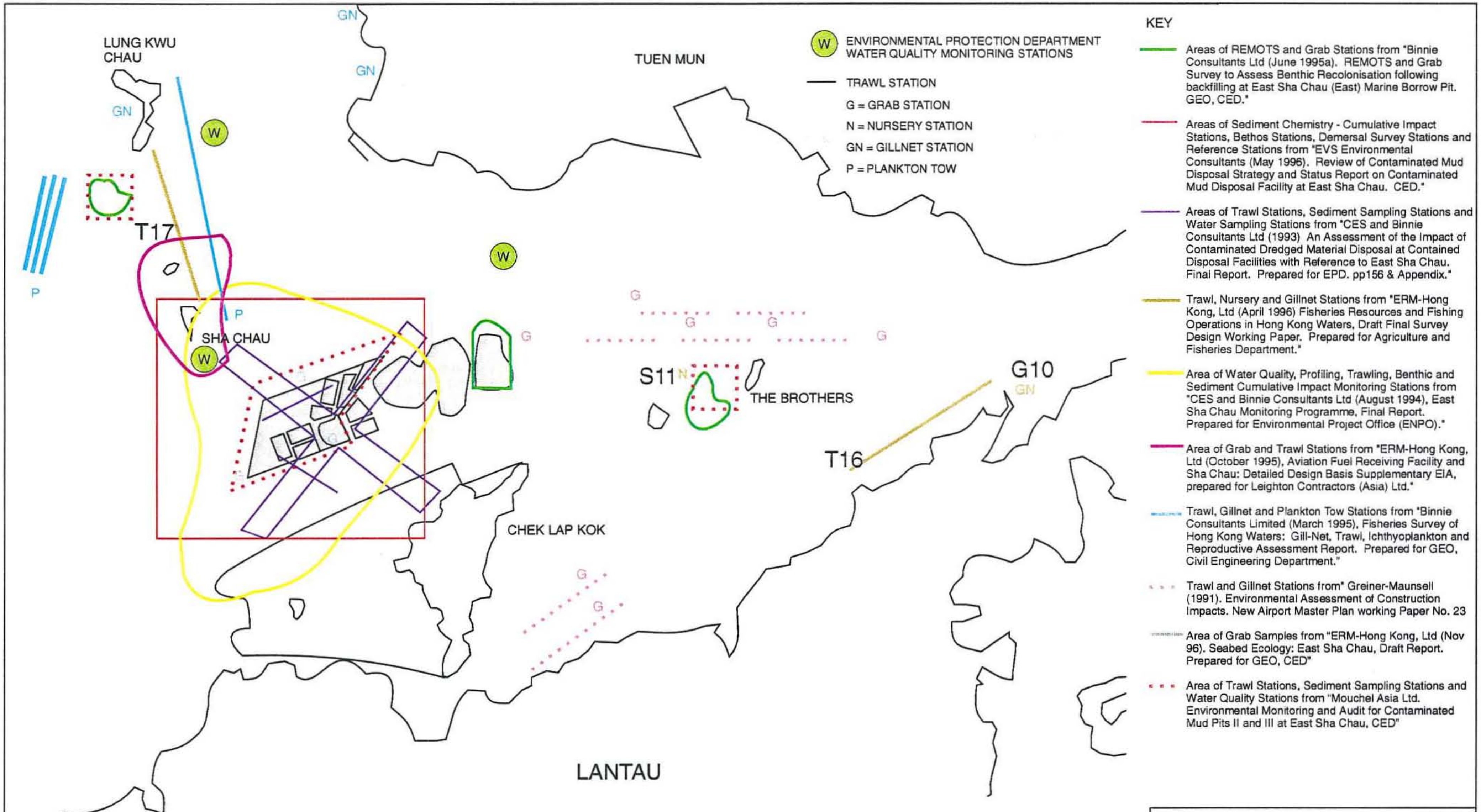


FIGURE 5.3a - PREVIOUS SAMPLING STUDIES IN THE VICINITY OF EAST SHA CHAU CONTAMINATED MUD PITS

ERM Hong Kong, Ltd
6th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

5.3.2 *Physical Characteristics of the ESC CMP IV*

As described in *Section* 2, the ESC CMP IV consists of three adjacent borrow areas situated to the east of the existing CMPs. The pits were dredged to a depth of -35 mPD, however Pit C has been backfilled with uncontaminated material to -14 mPD. It is proposed to backfill the pits with contaminated dredged material and then cap this with clean material to reinstate the pit to the level of the existing seabed. The backfill mud used for capping is of a similar substrate type to that which already exists in the area, ie soft marine mud, and after anthropogenic disturbance has ceased, soft bottom benthic communities similar to those which are present in the surrounding areas near the CMPs are expected to colonise the newly created substrate.

5.3.3 *Benthic Communities: Infauna*

Literature Review

The benthic environment at ESC is characterised by soft sediments, composed largely of silts and clays, in a homogeneous layer on the seabed or as loosely packed mud clasts bound in a 'puzzle fabric'(1). The sediment is well oxidised in the surface layer and total organic carbon (TOC) values of approximately 1% have been reported(2). Information on the benthic community inhabiting the sediments in the vicinity of ESC is available from a variety of sources, including an early, territory-wide survey in which benthic community structure was examined at 200 sampling stations in Hong Kong waters(3), and the recent CED-sponsored monitoring surveys at ESC(4)(5)(6)(7). Although limited sampling has been conducted within CMP IV (*Figure 5.3c*), the studies have indicated that the benthic community in this site is similar to that recorded in other parts of the western waters of Hong Kong, and is characterised by generally high diversity but low abundance and biomass. Polychaetes are numerically dominant, comprising between 44% (8) and 71%(9) of individuals. Molluscs, crustaceans, and echinoderms are also well represented components of the soft-bottom benthic community. These groups, when combined with the polychaetes, generally account for 95% of the benthic assemblage.

Benthic community structure reflects the impacts of various dredging and backfilling operations at ESC(10). 'Near-field' stations (those in or near CMP IV) show lower faunal abundances and species richness than 'far field' stations (those

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(1) Binnie Consultants Ltd (June 1995). REMOTS and Grab Survey to Assess Benthic Recolonisation following backfilling at East Sha Chau (East) Marine Borrow Pit. GEO, CED.

(2) EVS Environmental Consultants (1996a). Review of Contaminated Mud Disposal Strategy and Status Report on Contaminated Mud Disposal Facility at East Sha Chau. CED.

(3) Shin P K S and Thompson G B (1982). Spatial Distribution of Infaunal Benthos of Hong Kong. Marine Ecology Progress Series 10:37-47.

(4) CES and Binnie Consultants Ltd (1993) An Assessment of the Impact of Contaminated Dredged Material Disposal at Contained Disposal Facilities with Reference to East Sha Chau. Final Report. Prepared for EPD. pp 156 & Appendix.

(5) Binnie Consultants Ltd and CES (1994). Environmental Monitoring Programme East Sha Chau - Phase 2. Monthly Progress reports from January to December 1994.

(6) Binnie Consultants Ltd and CES (1995) Environmental Monitoring Programme East Sha Chau - Phase 2. Monthly Progress Reports from January to November 1995.

(7) Mouchel Asia Ltd. Environmental Monitoring and Audit for Contaminated Mud Pits II & III at East Sha Chau. Monthly Reports. 1995-6

(8) *op cit* (Binnie Consultants Ltd 1995).

(9) Wu R S S and Richards J (1981). Variations in Benthic Community Structure in a Sub-tropical Estuary. Marine Biology 64: 191-918

(10) *op cit* (Binnie Consultants Ltd June 1995)

located at reference sampling areas adjacent to Lung Kwu Chau and the Brothers Islands, approximately 3-5 km from CMP IV).

Samples taken in April 1995 from the CMP IV Pit C[11] recorded similar population densities but only 50% of the species (16) of 'far field' reference stations (32-35 species). A large proportion of the overall abundance at CMP IV stations was due to the opportunistic spionid polychaete *Polydora tentaculata.* Densities in three areas sampled in the vicinity of ESC averaged between 127 and 181 individuals m^{-2}. It was noted that many of the individuals collected were small and considered to be juveniles. A summary of the benthic grab data from these three locations is presented below in *Table 5.3a.*

Table 5.3a ***Summary of Benthic Grab Data obtained from surveys at ESC***[12]

Description	*Borrow Pit Stations (CMP IV)*	*Lung Kwu Chau Reference Stations*	*The Brothers Reference Stations*
Total number of taxa (all stations combined)	16	35	32
Mean Abundance per m^2 (± SD)	181 ± 337	157 ± 65	127 ± 153
Percentage of taxa:			
Polychaetes	44%	60%	62%
Crustaceans	38%	34%	22%
Other	18%	6%	16%
Percentage of individuals:			
Polychaetes	79%	57%	69%
Crustaceans	17%	34%	22%
Other	4%	9%	9%

Note: Other = Individuals from the phyla Mollusca, Echinodermata, Coelenterata, Sipunculida, and Nemertina

An independent review of benthic invertebrate surveys carried out at ESC was undertaken by EVS Environment Consultants at active and capped pits[13] and the following conclusions drawn:

- richness and abundance of benthic invertebrates in the study area has increased since mid-1994, with recovery from natural disturbances (eg typhoons) identified as the most plausible reason for the increase; and
- richness and abundance of benthic invertebrates in capped pits and most 'near field' areas has been consistently lower than in 'far field' areas. Contaminant concentrations in the areas near the disposal pits can be excluded as a cause of the differences because the areas near the pits are less contaminated than those further away. Other possible explanations for the

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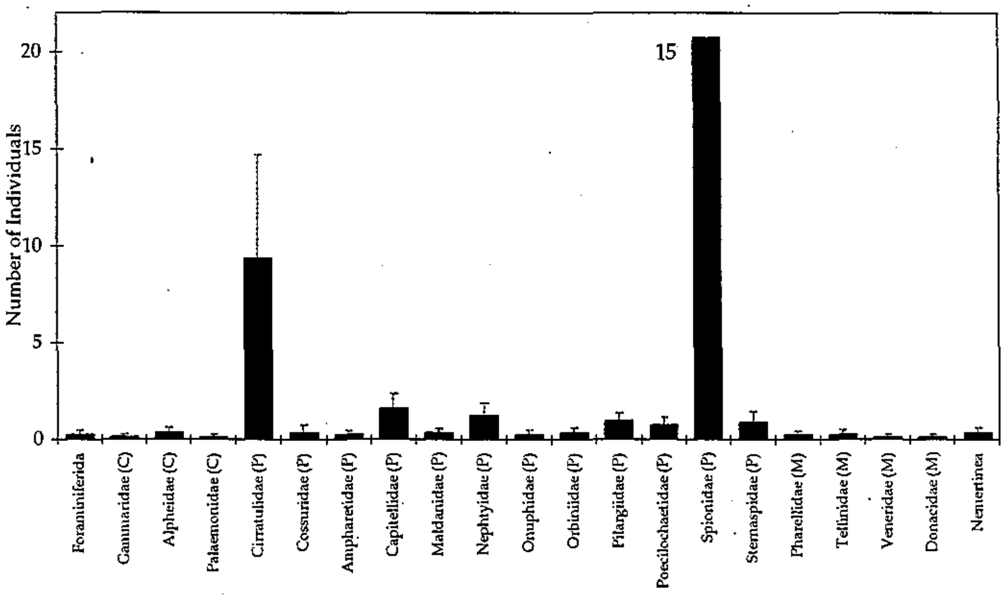
[11] *op cit* (Binnie Consultant Ltd, June 1995)
[12] *op cit* (Binnie Consultant Ltd, June 1995)
[13] *op cit* (EVS Environment Consultants, 1996a)

differences include a stimulatory effect of higher organic carbon at the far field sites, a sampling artifact, or disturbance effects at the near-field sites.

Recent data on Benthic Communities

Recent information on the benthic fauna of the ESC region has been obtained from grab samples taken in August 1996[14]. Grab samples were taken from a station located on the northern edge (or Pit Lip) of CMP IV. The mean number of individuals collected from each grab was 39 (± 54 SD) and this consisted mainly of polychaetes (in the families Spionidae and Cirratulidae). Few molluscs and crustaceans were present in the grabs (*Figure 5.3b*).

Figure 5.3b ***Abundance of benthic fauna in Pit Lip sediments at CMP IV (mean number per grab + SE). M = Mollusc, P = Polychaete, C = Crustacean***



Despite their low abundances bivalve molluscs formed the largest portion (83%) of the biomass of the grab samples. The bivalves were patchily distributed amongst the grabs, causing high variation in biomass values. The polychaete worms, as mentioned above, were found in high numbers but low biomass (16% of total biomass). The mean biomass of grabs taken from the Pit Lip of 493 mg grab^{-1} (± 1072 SD), was higher than stations located near CMP I but lower than stations located in a far field reference area near Sha Chau (RW). Similarly Pit Lip samples had significantly more individuals than the samples from CMP I, though significantly less than the samples from a far field reference area (RW). Comparisons between Pit Lip and another far field reference area which showed signs of recent disturbance (RN), indicated that Pit Lip samples had greater biomass and number of individuals than the reference area. These differences, however, were not significant due to the high levels of intersample variation.

This study used a method for examining changes in the structure of marine communities due to impacts called abundance/biomass comparison plots. Known as the ABC method, taxa are ranked in order of abundance or biomass on the *x* axis with percentage dominance on the *y* axis.

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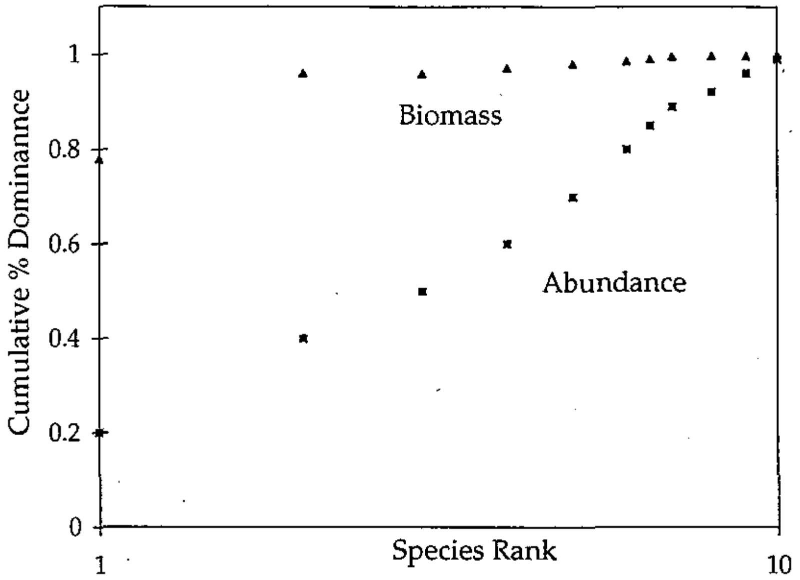
[14] ERM-Hong Kong Ltd. (November 1996). Seabed Ecology: East Sha Chau. Draft Report, GEO, CED.

Under stressed conditions benthic communities become increasingly dominated by one or a few small-sized species and the abundance curve lies above the biomass curve throughout its length. In undisturbed communities, the biomass curve lies above the curve for abundance for its entire length. In moderately disturbed conditions the biomass and abundance curves are closely coincident. *Figure 5.3c* illustrates the relationship for a representative grab sample from the Pit Lip. As the biomass curve remains above the abundance curve for its entire length this technique indicates that the Pit Lip area is undisturbed.

Figure 5.3c *ABC plot for station (E 53) on the Pit Lip of CMP IV*



Analysis of the sediments from grab samples and SPI images at the Pit Lip indicated that the sediments were more heterogeneous than sediments analysed from CMP I and from far field reference areas. The grain size of the sediments was comparatively large with over 15% greater than 63μm. As a consequence of the larger grain size, penetration depth for an SPI camera was low (10-20cm). Total Organic Content was comparatively low (<0.71%).

5.3.4 *Benthic Communities: Epifauna*

Trawl surveys were conducted at Sha Chau Island as part of the EIA for the Aviation Fuel Receiving Facility (AFRF) during September 1994 and again each month from January - December 1995(15). Sixty nine invertebrate species, including 19 species of crab and 13 species of shrimp, were recorded during trawl surveys conducted in the vicinity of Sha Chau Island. The species collected are listed below in *Table 5.3b*.

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(15) ERM-Hong Kong Ltd (March 1996) Aviation Fuel Receiving Facility at Sha Chau: Detailed Design Basis Supplementary EIA.

Table 5.3b *Summary of Results of Trawl Survey in the vicinity of Sha Chau (January to December 1995*

Phylum	Class	Subclass	Common Name	Number of Species
Cnidaria	Anthozoa	Alcyonaria	Sea Pens	4
			Gorgonian Coral	1
		Zoantharia	Sea Anemones	1
	Hydrozoa		Hydroid	1
Platyhelminthes	Turbellaria		Flatworm	1
Mollusca	Gastropoda	Pulmonata	Snails	9
		Opisthobranchia	Sea Slugs	1
	Bivalvia	Lamellibranchia	Bivalves	8
	Cephalopoda	Coleoidea	Octopus	1
			Cuttlefish	2
			Squid	1
Arthropoda	Crustacea	Malacostraca	Shrimps	13
			Mantis Shrimp	1
			Crabs	19
	Echinodermata	Echinoidea	Sea Urchin	1
		Asteroidea	Starfish	1
		Ophiuroidea	Brittle Star	1
		Holothuroidea	Sea Cucumber	1

None of the monitoring studies in this region has identified any soft bottom species or communities of conservation importance. However, infauna are often a key component of the food web, as they are prey for other species, eg some epifaunal gastropods(16) and demersal fish, some of which have commercial value. An assessment of infauna as prey organisms for commercial fisheries resources is provided in *Section 4.5.1*.

5.3.5 *Chinese Horseshoe Crab*

Concern has been expressed as to the potential impacts of the backfilling operations on the Chinese horseshoe crab, *Tachypleus gigas*. In comments on the IAR, AFD indicated that horseshoe crabs are found within the study area.

Specimens of *Tachypleus gigas* were collected at various stations in Hong Kong during shrimp trawling operations (Mar -Sep) for the AFD ERM Fisheries Resources and Fishing Operations in Hong Kong Waters Study (*Table 5.3c*). Of

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(16) Taylor, JD. (1994). *Sublittoral benthic gastropods from the southern waters of Hong Kong*. p 475 - 495. In: B Morton (ed) The Malacofauna of Hong Kong and Southern China III. Proceedings of the Third International Workshop on the Malacofauna of Hong Kong and Southern China, Hong Kong 13 April - 1 May 1992. Hong Kong: Hong Kong University Press.

the 17 crabs collected during the period March - September, seven were obtained in the ESC area. All but one of the other individuals collected were from the nearby sampling station in Deep Bay. This result is in contrast to the findings of trawl sampling for the EIA of the AFRF. There were no records of *Tachypleus* in any catches at any time during the study. Two other studies in the area also reported no records of *Tachypleus* in any trawl catches(17)(18). Abundance of the crabs is variable, and while they occur in the Study area, they have not been found in the monthly monitoring directly around the pits. The pits themselves, therefore, do not appear to be within the preferred range for this species.

Table 5.3c *Landings of Horseshoe Crabs* Tachypleus gigas *in Hong Kong*

Station	Month	Number of Individuals	Total Weight (g)
ESC Region			
The Brothers	June 1996	1 1 1 1 1	1667 1667 3636 3030 227
Lung Kwu-Sha Chau	June 1996	1	380
	August 1996	1	325
Other Areas of HK			
South Lamma	June 1996	1	1515
Deep Bay	August 1996	2 3 1 1	496 864 244 292
	September 1996	1 1	210 400

5.3.6 *Corals*

Reports have been made of solitary corals (non colonial corals) occurring in the region around ESC, and hence concerns over the potential impacts of backfilling operations have been raised. Surveys undertaken in the area found few species of hermatypic corals. Hermatypic corals have vast numbers of symbiotic unicellular algae (zooxanthellae) within their endodermal lining. These algae are responsible for the well being and vigorous growth of the corals, aiding both calcium binding and the removal of wastes. Other members of the Anthozoa (soft corals, sea pens and gorgonians) are, however, present in the area. The results of trawl surveys carried out along transects around Sha Chau *(Figure 5.3c)* as part of the EIA for the Aviation Fuel Receiving Facility are presented in *Table 5.3d*.

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(17) *op cit* (Binnie Consultants Ltd & CES Jan-Nov 1995)

(18) Mouchel Asia Ltd (1996) Environmental Monitoring & Audit for Contaminated Mud Pits II & III at East Sha Chau (Monthly Reports)

Table 5.3d *Anemones, Sea Pens and Gorgonians (sea fans) collected from trawls at Sha Cha*

Date	Anemones	Sea Pens	Gorgonians
September 1994	14	66	2
January 1995	9	106	60
February	46	82	22
March	10	97	20
April	3	123	18
May	2	58	35
June	6	28	21
July	4	51	28
August	2	17	10
September	1	21	31
October	10	63	14
November	10	44	16
December	2	35	65

The table above indicates that sea pens, sea anemones and some gorgonians do occur in the ESC area. It is unlikely that there are any large hermatypic coral colonies in the ESC area due to the ambient conditions of high SS levels, low light penetration and the influence of the low salinity waters of the Pearl River. The absence of hermatypic corals in the trawl samples from the area supports this hypothesis.

5.3.7 *Marine Mammals*

The Chinese White Dolphin (*Sousa chinensis*) and the Finless Porpoise (*Neophocaena phocaenoides*) are the only species of marine mammal regularly sighted in Hong Kong waters[19]. In the ESC area the most regularly recorded species is the Chinese White Dolphin (*Figure 5.3d*). This species lives mostly in estuarine waters and are found throughout the Pearl River Estuary and other estuaries from Gulf of Tonkin to Shanghai. Research on dolphins in Hong Kong waters is currently being carried out on this species under the auspices of AFD by researchers at the Swire Institute of Marine Science and by Dr T Jefferson of the Ocean Park Conservation Foundation. Other studies are being conducted as a component of the EM&A for the AFRF at Sha Chau.

Photo-identification Method

An ongoing photo-identification catalogue is being kept by Lindsay Porter (funded by AFD) of the Swire Institute of Marine Science . An identifiable individual is one which bears a recognisable and consistent marking on the body, eg a nick in the dorsal fin, scars and distinctive colour patterns. An abundance estimate, based on sighting the same individual at least twice, has indicated that 112 individuals occur in Hong Kong waters. This estimate can be considered as conservative since standard photo-identification methods base estimates on only

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[19] E.C.M. Parsons, Mary Felley and Lindsay J Porter (1995). An Annotated Checklist of Cetaceans Recorded from Hong Kong's Territorial Waters. Asian Marine Biology 12 (1995): 79-100.

one sighting of each individual unlike the two sightings used here. Another photo-identification catalogue compiled by Dr Thomas Jefferson (also funded by AFD) of the Ocean Park Conservation Foundation has identified approximately 80 individuals (using standard methods). The differences between the two abundance estimates may be partially explained by the different timescales involved; Jefferson's surveys commenced in October 1995 whereas those of Porter have been conducted since 1993. These two estimates are often regarded as minimum estimates since only identifiable individuals can be counted.

Line-transect Method

The second method of estimating abundance involves counting individuals seen from line transect surveys. The resulting estimate is regarded as a maximum since it may include repeated sightings of the same individual. The present abundance estimate for surveys carried out in waters around ESC is 126 individuals(20). This estimate is still provisional as the surveys are due to continue until April 1998.

The area around Sha Chau and Lung Kwu Chau has been designated as a marine park due to its role as key feeding, breeding and nursery habitat for *Sousa chinensis*. Part of the North Lantau area has also been identified as being of particular importance to *Sousa chinensis*. Records of dolphin sightings(21) (*Figure 5.3d*) indicate that dolphins are often seen in close proximity to the current CMPs, including the MBAs for CMP IV, though they appear to favour the marine park and the area to the north east of the Chek Lap Kok airport platform. In the Autumn sampling (Aug-Oct 1996), 37 % of the dolphins sighted were within the marine park. In general there appears to be little seasonal difference in the distribution of the dolphins within the most frequently surveyed part of the north Lantau area. However, the range of *Sousa chinensis* is thought to extend further east, towards the Brothers, during the summer months (*Figure 5.3d*).

The dietary preference of *Sousa chinensis* has not been extensively studied but was assumed to comprise 50% fish and 50% shrimp in a recent risk assessment study of the East Sha Chau area(22). The importance of this area for the survival of the species is not known. Hong Kong waters comprise only part of the potential range of this species within the Pearl River delta, however, the apparent rarity of this species confers a high level of conservation importance to its presence in the area.

5.4 SENSITIVE RECEIVERS

Based on the preceding review of baseline ecological conditions in the study area, ecologically sensitive receivers which may be affected by the proposed backfilling operations have been identified, as shown in *Figure 5.4a*, and are listed below:

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(20) Thomas Jefferson (October 1996) Multi-disciplinary research program on the Indo-Pacific Hump-Backed Dolphin Population. 2nd Quarterly Progress Report, submitted to AFD.

(21) Thomas Jefferson (1996). Unpublished data. Ocean Park Conservation Foundation.

(22) EVS 1996. Review of Contaminated Mud Disposal Strategy and Status Report on Contaminated Mud Disposal Facility at East Sha Chau, Prepared for the Civil Engineering Department, Government of Hong Kong. May 1996.

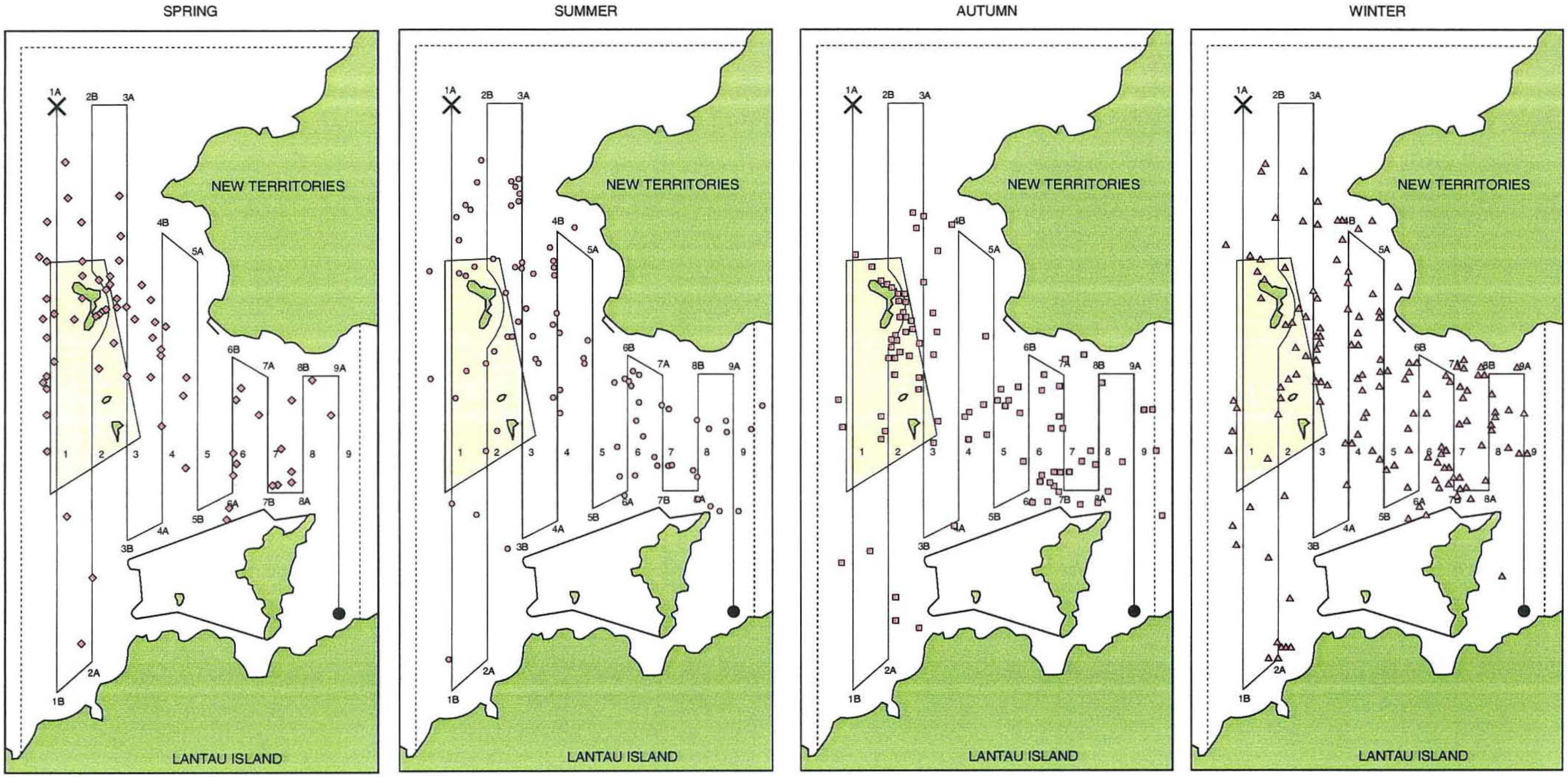

FIGURE 5.3d - SEASONAL DISTRIBUTION OF INDO-PACIFIC HUMP-BACKED DOLPHIN SIGHTINGS IN THE NORTH LANTAU WATERS OF HONG KONG, 1 SEPTEMBER 1995 - 15 OCTOBER 1996

ERM-Hong Kong, Ltd
6th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong
ERM

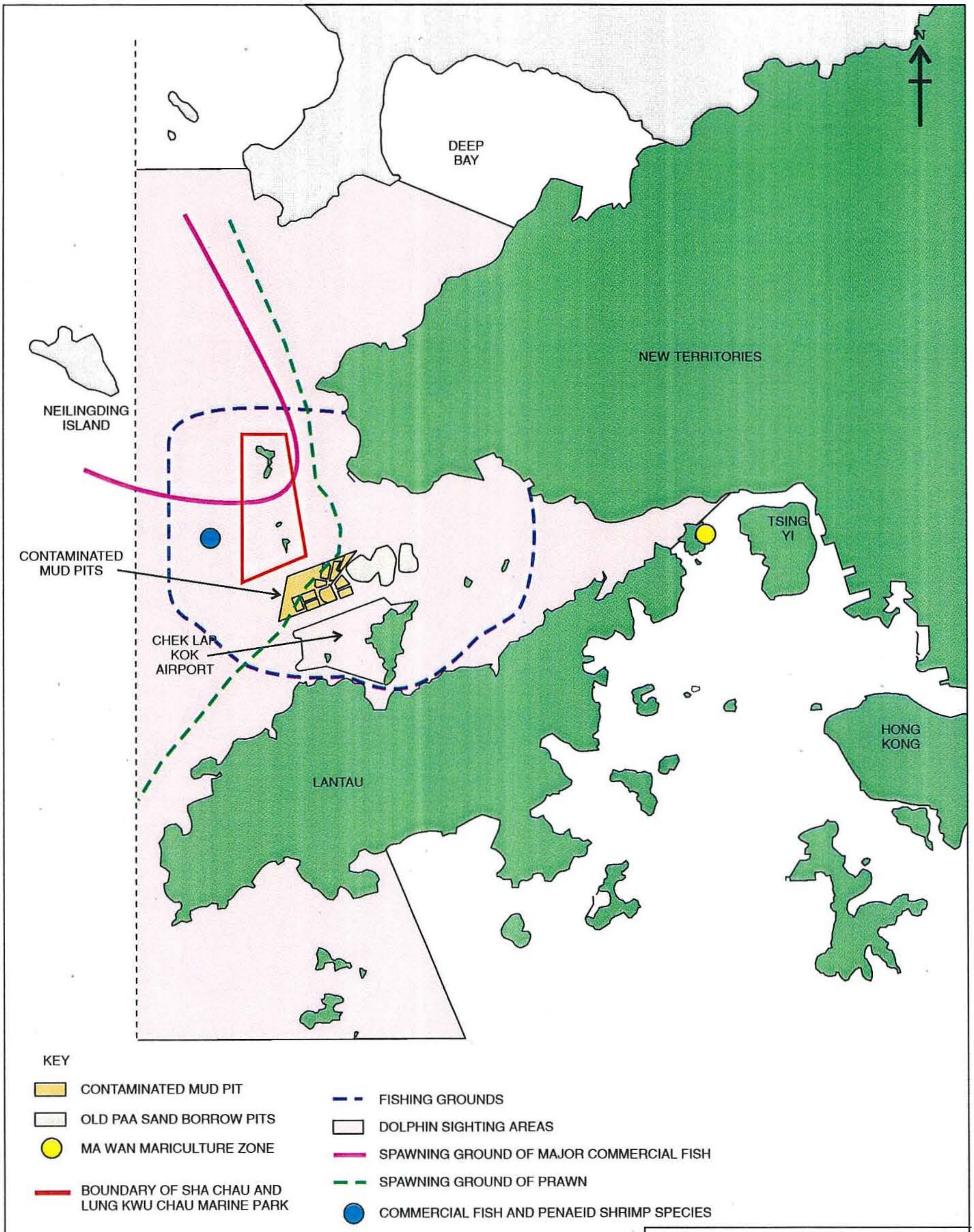

FIGURE 5.4a - IDENTIFIED ECOLOGICAL SENSITIVE RECEIVERS, LOCATED WITHIN THE VICINITY OF CMP IV

ERM Hong Kong, Ltd
6th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong
ERM

- benthic habitat;
- *Tachypleus gigas* (Chinese Horseshoe Crab);
- Gorgonian corals;
- *Sousa chinensis* (Chinese White Dolphin) and its habitat outside the marine park; and
- the Sha Chau and Lung Kwu Chau marine park.

The exact location of many of these sensitive receivers may not be clearly defined as they exist as continuous and/or variable habitats or mobile populations. Intertidal habitats have not been specifically referenced in this assessment as the coastline adjacent to CMP IV comprises the reclaimed airport platform, which is not considered to be of ecological importance. Other stretches of intertidal habitat are included as part of the marine park. Fishery sensitive receivers have been discussed in *Section 4*.

5.5 *TYPES OF IMPACTS*

Impacts on ecological resources potentially arising from backfilling are as follows:

- direct disturbance to benthic habitats (*Section 5.5.1*);
- changes in water quality (*Section 5.5.2*);
- habitat disturbance through increased traffic and noise (*Section 5.5.3*); and,
- uptake of contaminants through processes such as bioturbation (*Section 5.5.4*) and food chain bioaccumulation (*Section 5.6*).

A description of the effects these impacts may have on ecologically sensitive receivers within the study area is given below.

5.5.1 ***Disturbance to Benthic Habitats***

Potential Impacts Within CMP IV

Within the CMP, sediment deposition will lead to direct disturbance and modification of the seabed and will impact the benthic and epifaunal communities which have colonised the CMPs since dredging ceased. The primary impacts to benthic communities will be the smothering and burial of infauna and epifauna in the pits, and habitat modification. As these impacts will necessarily occur during backfilling operations, it is important to determine whether the CMPs contain unique or otherwise noteworthy benthic assemblages which will be lost.

As noted above in *Section 5.3*, a study comparing the ESC CMP IV with the surrounding area suggested that the benthic fauna within the CMP comprised a lower species diversity and density of individuals than adjacent areas(23). The study did not identify any species of conservation importance in or around the CMP, although it should be noted that sampling effort was limited. Recent information on the state of the benthic community at CMP IV gained from the CED-sponsored Seabed Ecology Studies(24) indicates that there are no species present of high conservation value. The results of this study indicate that CMP IV has higher number of individuals and biomass than CMP I, though less than a far field reference area.

(23) *op cit* (Binnie Consultants Ltd, June 1995)
(24) op cit (ERM-Hong Kong Ltd, November 1996)

Once the operations have ceased, the backfilled area will be initially colonised by opportunists and during the early stages of recovery, diversity is expected to be low. As more competitive species begin to colonise, the diversity of the community will increase until it returns to, or near to, the original conditions. If granular or mixed material is included in the material disposed, there will be a greater diversity of habitat available for colonisation which may result in an increase in ecological diversity.

Potential Impacts Outside CMP IV

Sediment may be deposited on the seabed outside the CMP during placement and capping (through dispersion of sediment plumes) and post-placement (through erosion and wave-induced re-suspension). The effects of sediment deposition outside the CMP on benthic habitat will clearly be less than those within the CMP due to the dramatically lower rates of deposition outside the backfilling area. The extent of effects outside the pits will depend on rate of sediment deposition and the ability of the natural benthic assemblage to adapt to that rate.

The results of a representative modelling scenario (Scenario 4) indicate that maximum deposition rates outside CMP IV will be on the order of 1 kg m^{-2} day^{-1}. The area impacted at this rate is located very near the pit and is extremely small (approximately 300m by 300m --see *Annex G*). Furthermore, it is expected that wave action will lead to erosion and transport of the deposited material by tidal currents within a few tidal cycles. As discussed in *Section 3.10*, material placed in CMP IV is expected to remain within the pit and not be eroded by tidal current or wave action except under extreme (>1:10 year) storm events. Erosion of material from the pits, therefore, is expected to contribute to sediment deposition outside CMP IV only in rare cases. Based on these analyses and the fact that naturally-occurring benthic assemblages are likely to be adapted to somewhat fluid seabed conditions, unacceptable disturbance to the benthos outside CMP is not anticipated.

In summary, changes to the benthic assemblage within the pit will occur as a result of smothering with backfilling material but are not expected to impact any species of particular conservation significant. After capping, the substrate will be colonized by pioneering species and if the cap is constructed with granular or mixed materials, the benthic faunal diversity may be enhanced above previous levels. Based upon sediment deposition modelling results (*Section 3.7*) and erosion analyses (*Section 3.10*), disturbance to benthic communities outside the CMP is expected to be minimal.

5.5.2 *Changes in Water Quality*

The backfilling operations will cause an increase in suspended solid concentrations in the water column and hence turbidity of the sea water. This may clog the filter feeding mechanisms of invertebrates and cause damage through scouring and abrasion if concentrations are sufficiently high.

Increased suspended solid (SS) concentrations are also associated with various indirect effects. High levels of SS often cause an associated oxygen depletion, particularly at the bottom of the water column and in sediments. This can result in hypoxia in benthic infauna and epifauna. Water quality impacts have a greater effect on sessile organisms than on mobile species, which when exposed to poor water quality will generally avoid the area and move to a more preferable habitat.

In the ESC area, sessile organisms such as corals are particularly susceptible to SS and DO-related water quality impacts. Several factors, however, reduce the likelihood of unacceptable impacts to corals. As stated in *Section 5.3.6*, the corals in the ESC area are ahermatypic gorgonian corals which do not require high light levels due to their lack of zooxanthellae. If elevated SS levels did occur, sublethal effects such as clogging of filter feeding polyps or stimulation of mucous production may occur, but corals are likely to recover as the plumes disperse. Furthermore, water quality modelling has shown that plumes resulting from disposal at CMP IV are of low concentrations and will not cause exceedance of WQOs. As WQOs within the marine park at Sha Chau and Lung Kwu Chau are not exceeded, no unacceptable impacts to the marine park are predicted. A discussion of predicted impacts in suspended sediment, dissolved oxygen and nutrient concentrations is provided in *Section 3.7*. An assessment of these predicted impacts in the context of ambient levels recorded at four water quality monitoring stations in the study area is given in *Section 4.6.3* and concludes that all predicted elevations are well within naturally-occurring ranges. Therefore, no unacceptable impacts to marine ecology sensitive receivers as a result of changes in water quality are expected.

5.5.3 *Habitat Disturbance Due to Traffic and Noise*

Disposal of contaminated mud could potentially result in an increase in marine traffic and underwater noise affecting *Sousa chinensis*. Studies have shown that because of the efficient transfer of sound in water, dolphins can detect noises associated with vessels similar to dredgers at distances up to approximately 5 km. Noise disturbance interferes with communication and echolocation pulses which are used for navigation and feeding, leading to behavioural changes. There is evidence suggesting that some cetacean species will minimize their use of areas affected by underwater noise. Spinner dolphins, for example, reportedly reduced their use of a Hawaiian bay after the commencement of construction of a water pipeline.(25) In addition, underwater noise and increases in marine traffic may disturb normal cetacean movement patterns through potential collision with vessels, increased turbidity generated by propellers and submerged equipment.

When considering potential impacts to *Sousa chinensis*, this assessment must address whether *Sousa chinensis* are found in the area of the CMP IV and whether the proposed operations are likely to adversely affect the dolphins. The review of existing information suggests that the North Lantau area is used extensively by *Sousa chinensis*. This species is regularly sighted in the waters around Sha Chau and Lung Kwu Chau, and often sighted in the vicinity of the CMP IV, perhaps due to the location of a sewage outfall in this area. Therefore it is established that dolphins use the area in and around the CMP IV.

As there is little available information on the behaviour and response of dolphins to underwater disturbances, impacts associated with disposal and dredging at CMP IV are difficult to predict. The proposed activities, however, are likely to be minor in the context of recent construction activities in the North Lantau area and do not involve blasting, jetting or other high noise level activities. The North Lantau area is heavily utilized by slow and high speed vessels and, as discussed in *Section 2.8*, the increased traffic associated with

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(25) Richardson W.J. *et al* (1991) Effects of noise on marine mammals. OCS study MMS 90.0093 Rep from LGL Ecological Research Association Inc. Bryan TX for Minerals Service. Atlantic OCS Reg. Herndon VA 462 p.NTIS PB91-168914

operations at CMP IV is small. These findings, in conjunction with the limiting of operations to within the boundaries of CMP IV, indicate that impacts to *Sousa chinensis* from increased noise and marine traffic associated with CMP IV are not expected to have an adverse impact on the species.

5.5.4 *Uptake of Contaminants Through Bioturbation and Bioaccumulation*

This section provides a general introduction to the effects of contaminants in the marine environment and discusses the potential for contaminant release from the pits through processes such as bioturbation of benthic organisms. Food chain bioaccumulation is addressed through a review of recent, local risk assessments performed to assess the impacts of contaminants on fish, dolphins and humans in *Section 5.6*.

Impacts of Contaminant Release

Research has shown that the majority of metals in dredged materials are likely to remain within the particulate material as they bind strongly to sediment particles (adsorption), organic materials (chelation), and may co-precipitate with either manganese or iron oxides(26). However, it is possible for metals to enter the body of benthic invertebrates through diffusion from pore water across respiratory surfaces or as a result of sediment ingestion which exposes the metals to a digestive enzymes which can facilitate absorption into the body. Cadmium has been shown to be less inert than other sediment bound metals and dissociates in sea water from sediment particles into the aqueous phase. Exposure through this pathway has been cited as the principle route of uptake for this metal in certain invertebrate species(27).

Organic contaminants, such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs), are also of concern in marine sediments. This group contains contaminants with widely varying physical, chemical and biological properties. They may arise in the environment either as a result of industrial synthesis and use (eg pesticides) or as a by-product of everyday processes such as combustion of fossil fuels (eg PAHs). Although some organic contaminants may have acute effects, it is unlikely that these will be manifest at concentrations present in Hong Kong sediments. Many of these compounds are lipophilic and hence tend to accumulate in fatty tissues of organisms such as marine mammals and people. Thus the principal source of concern for this group of chemicals arises from their persistence and potential for bioaccumulation, leading to long-term or chronic effects.

Contaminant impacts to marine organisms may arise as a result of:

- accumulation of contaminants in the tissue of invertebrates resulting in sublethal effects which may affect behaviour, reproduction and increasing susceptibility to disease; and

- increased mortality, and sub lethal effects to, eggs, larvae and juvenile species, as these are particularly sensitive to elevated contaminant concentrations.

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(26) *op cit*

(27) Luoma S M and Jenne E A. (1975). The Availability of Sediment Bound Cobalt, Silver and Zinc to a Deposit Feeding Clam. US. Geological Survey, Menlo Park, California 34.

Contaminants may accumulate in invertebrate species which are prey items for commercially important fish species and by this route can ultimately impact human health. *S. chinensis* is also vulnerable to contaminant impacts due to its position near the top of the food chain. Marine mammals have been shown to be vulnerable to metal and organics contamination and studies of seals, porpoises and dolphins have shown that elevated mercury concentrations in the liver may have weakened their resistance to disease(28). In Dall's Porpoise elevated levels of the contaminant DDE significantly reduced levels of testosterone in the blood thereby affecting reproductive performance(29). Other impacts of organic contaminants (PCBs) on reproduction, causing premature births, have been discovered in ringed seals(30).

Bioturbation

Bioturbational effects are an important consideration in assessing the ultimate effectiveness of any confined aquatic disposal project because the thickness of the cap layer required to biologically isolate contaminated sediments is typically greater than that needed to chemically isolate them(31). If the cap is of insufficient thickness it is possible that deep burrowing animals can take up contaminated sediments, thereby providing a route for contaminants to potentially enter the food chain.

Bioturbation is defined as the physical re-working of sediments by animals. There are two important components of bioturbation: fluid advection or pumping; and vertical particle transport. Some organisms invoke both processes each of which affects sediment geotechnical properties by increasing the water-content and lowering the sediment shear strength. Other organisms merely build burrows and pump fluid in order to ventilate the burrows and obtain oxygen and food particles suspended in the water column. The type of bioturbation is thus dependent on the suite of organisms present in the benthos.

The effect of bioturbation on contaminant laden particles and pore water is relatively well known for clams, worms and small crustaceans(32). The depth of macrofaunal mixing rarely exceeds 30 cm, however, at adult densities of 100 m^{-2} the polychaete *Nereis virens*, required a cap thickness of 50 cm to effectively isolate buried contaminants(33).

Species that could potentially penetrate caps and cycle contaminants back into the food chain are those that burrow deeply into the benthos, consume or otherwise manipulate sedimentary particles, and directly contact contaminated pore waters. These high risk species include burrowing macrofaunal deposit-feeders, deep burrowing megafauna greater than 5 cm body length (eg, mantis shrimps, crabs and lobsters), and burrowing demersal fish (eg the goby, *Trypauchen vagina).* These species can have burrow depths exceeding 50 cm to over a metre or more(34) (35) (36) (37) (38).

(28) Law R J *et al.* (1991) Concentrations of Trace Metals in the Livers of Marine Mammals (Seals, Porpoises and Dolphins) from Waters around the British Isles. Marine Pollution Bulletin. Volume 22. No4. pp.183-191. 1991.

(29) Subramanian AN etal. (1987) Reduction in the testosterone levels by PCBs and DDE in Dall's Porpoises of Northwestern North Pacific. Mar Poll Bull Vol 18:12:643-646

(30) Helle E et al (1976) DDT and PCB levels and reproduction in ringed seal from the Bothnian Bay. Ambio. 188-189

(31) Brannon JM *et al.* (1985) Effectiveness of capping in isolating contaminated dredged material from biota and the overlying water. Waterways Experiment Station, Technical Report D-85-10

(32) Aller RC (1982) The effects of macrobenthos on chemical properties of marine sediment and overlying water. Chapter 2. In: PL McCall and MJS Tevesz (eds.) Animal-Sediment Relations; The Biogenic Alteration o f Sediments. Plenum Press.

(33) *op cit* (Brannn *et al.* 1985)

(34) Atkinson, RJA and RSV Pullin. (1976). The red band fish, *Cepola rubescens* L. at Lundy. Report Lundy Field Society 27: 1-6.

Infaunal crustaceans represent some of the deepest burrowing organisms, with the shrimp *Axius* having the deepest documented burrowing depth (between 2 to 3 meters in Nova Scotia(39)). Relatively little is known about the burrowing depth or densities of mantis shrimp at ESC, though trawl samples in the area indicate that they are one of the most abundant components of the demersal fishery (see *Figure 4.3a*). The presence of mantis shrimp in the sediments of ESC has the potential to affect cap integrity only if it has:

- penetrated the cap;
- is effective at both fluid advection and vertical particle movement; and
- is present in densities high enough to have an effect on the total mound area.

The macrofauna at ESC are present at extremely low densities(40)(41), and biomass(42) and the depth of reworking in this area, as evidenced from sediment profile images taken, is confined for the most part to the upper 10 cm of sediment and rarely exceed 15 cm(43). The depth of burrowing for most nearshore estuarine macrofauna averages from 2 to 15 cm with extremes of 60 cm(44) (45). The 10 cm value is commonly accepted as being representative, and the results of sediment profile imaging surveys in Hong Kong territorial waters support this use of this representative value.

Based on the international and local literature review discussed above, a one metre cap is considered to be sufficiently thick to act as an effective barrier to macrofauna in the ESC area. However, there is no definitive evidence on the most effective cap thickness for deep-burrowing megafauna and demersal fishes Since the deepest recorded value for burrowing shrimp worldwide is on the order of 3 metres(46), a highly conservative cap design would require placement of at least 3 metres of uncontaminated material. As the cap design for CMP IV is 6 metres (see *Figure 2.4a*), there is considered to be no appreciable risk of cap penetration by bioturbating organisms.

5.6 *RISK ASSESSMENT*

Assessment methodologies have been developed to quantitatively express the risk of inducing a toxic effect when an organism is exposed to a given concentration or dose of a contaminant. The approach involves evaluating the magnitude of risk of adverse effects as a function of the degree of exposure to contamination. Many risk assessment parameters, such as reference doses,

(35) Cool, DO (1971). Depressions in shallow marine sediments made by benthic fishes. Journal of Sedimentary Petrology 41: 577-578.

(36) Myers, AC (1979). Summer and winter burrows of a mantis shrimp, *Squilla empusa*, in Narragansett Bay, Rhode Island (USA). Estuarine Coastal Marine Science 8: 87-98.

(37) Pemberton, GS, MJ Risk, and DE Buckley. (1976). Supershrimp: Deep bioturbation in the Strait of Canso, Nova Scotia. Science 192: 790-791.

(38) Twichell, DC.*et al*. (1985). The role of erosion by fish in shaping topography around Hudson Submarine Canyon. Journal of Sedimentary Petrology 55: 712-719.

(39) *op cit* (Pemberton et al 1976)

(40) Shin, PKS and GB Thompson. (1982) Spatial distribution of infaunal benthos of Hong Kong. Marine Ecology Progress Series 10:37-47

(41) *op cit* (EVS Environment Consultants 1996)

(42) ERM-Hong Kong Ltd (1996). Seabed Ecology: East Sha Chau. Draft Report GEO, CED.

(43) *op cit* (Binnie Consultants Ltd. 1995)

(44) Matisoff, G. (1982). Mathematical models of bioturbation. In: P.L. McCall and M.J.S. Tevesz, (eds).Animal-Sediment Relations; The Biogenic Alteration of Sediments. Plenum Press Topics in Geobiology, New York. pp 289-330.

(45) Boudreau, B.L. (1994). Is burial velocity a master parameter for bioturbation? Geochimica et Cosmochemica Acta, 58: 1243-1249.

(46) *op cit* (Pemberton *et al* 1976)

reference concentrations and dose response relationships, are frequently based on empirical data and may not necessarily hold for the case under consideration, hence a degree of uncertainty is introduced into the assessment process. In addition, as sources other than disposal of contaminated dredged materials contribute to ambient contaminant concentrations in biota in the ESC area, risk assessment results should not be directly attributed to disposal operations. Instead, they should be considered as a tool for interpreting potential cumulative effects and for identifying issues of concern for potential mitigation in individual projects.

This discussion summarizes the results of several recent risk assessment studies focusing on contaminant impacts in the ESC area. These studies address whether human consumption of seafood from the ESC area is predicted to result in exposures to heavy metals that would give rise to concern for the general public and sensitive subpopulations. They also assess whether the levels of heavy metals present in prey species in the ESC area are likely to pose unacceptable risks to predator species such as *Sousa chinensis*. To place the ESC area in context, another study was conducted to compare risks between three areas of Hong Kong waters. Finally, recently-released data on metals and organics concentrations in the blubber of stranded (dead) *Sousa chinensis* are reviewed for insight into the causes and effects of dolphin body burdens.

5.6.1 *Human Health Risk Assessment*

Two previous assessments concerning risks associated with consuming seafood from the ESC area have been conducted using local monitoring data. One study performed both preliminary and more in-depth calculations as a demonstration of the risk assessment technique(47). This study used environmental monitoring and audit data from the ESC CMPs to estimate exposure scenarios, based on consumption patterns, for the general public (assumed to be the 50th percentile of the consumption value), the reasonable maximum (the 90-95th percentile) and for subsistence populations which were assumed to derive their primary food source from seafood at ESC (ie the maximum).

Heavy metals examined in the study included cadmium, chromium, copper, lead, mercury, nickel and zinc. Estimated non-carcinogenic risks from consumption of fish and prawns were below levels of concern for all groups except the subsistence group (prawns only). The most notable risks were predicted to be associated with copper, which was expected due to its natural occurrence in the circulatory system of prawns. When the assessment was recalculated, however, after a revision in the recommended reference dose was issued by the US EPA, none of the exposure groups were found to be exposed to undue risks (ie Hazard Quotients were always less than one). In a continuation to this study, sample risk calculations for human consumption based on updated exposure assumptions showed that none of the examined subpopulations were at risk from cadmium, copper and mercury associated with consumption of fish from the ESC area(48).

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(47) EVS 1994, Overview of Contaminated Mud Disposal at ESC. A Brief to the Hong Kong Advisory Council on the Environment. Prepared for the Civil Engineering Department, Government of Hong Kong. October 1994.

(48) EVS 1996. Review of Contaminated Mud Disposal Strategy and Status Report on Contaminated Mud Disposal Facility at East Sha Chau, Prepared for the Civil Engineering Department, Government of Hong Kong. May 1996.

A separate risk assessment study⁽⁴⁹⁾ also used ESC monitoring data on the levels of metals in fish and prawn tissues. Risks associated with ingestion of cadmium and chromium were considered. This study found that neither metal posed significant increased health risks to average (50th percentile) or high-end (90-95th percentile) consumers of seafood from the ESC area.

5.6.2 *Ecological Risk Assessment for* Sousa chinensis

One of the studies cited above (EVS 1994) also considered risks through the food chain to *Sousa chinensis* from chromium, copper, lead, mercury, nickel and zinc. The study used conservative assumptions, including the assumption that *S. chinensis* was feeding exclusively on fish and prawns from the ESC area. In the screening level phase, the risk assessment calculations showed that *S. chinensis* may be at risk from consumption of contaminated seafood due to high (ie greater than one) calculated Hazard Quotients for chromium, copper, mercury and zinc. More detailed calculations⁽⁵⁰⁾, however, estimated only a marginal (0.99) Hazard Quotient (HQ) for mercury and minimal risk for other metals.

While not following a traditional risk assessment approach, a recently-released paper on metals concentrations in fish tissue in the North Lantau area draws conclusions about the potential effects on *Sousa chinensis*⁽⁵¹⁾. The paper suggests that the observed elevated metals levels in fish tissue are high enough to have severe health implications for *Sousa chinensis*. This conclusion was based on calculating the daily level of trace metal intake for dolphins and comparing it to the World Health Organisation limits for human health tolerable daily intake. As this study was based on a different dataset of fish tissue concentrations (ie independently collected and analysed tissue samples rather than the ESC monitoring programme) and used different techniques (eg selection of contaminant intake rates and tissue types varied), it is not possible to contrast its findings with EVS's assessment without further calculation.

EVS recently undertook such a comparative exercise to explore differences in conclusions between the two studies⁽⁵²⁾. By modifying earlier assumptions about dolphin diet (ie that dolphins consume 50% fish and 50% prawns) to Parsons assumption of 100% fish-based diet, and utilizing the EVS intake models and toxicity reference values, a consistent approach was applied to both data sets. The results of the comparative exercise are presented in (*Table 5.6a*).

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(49) Shaw 1995 Evaluation of Risks to Human Health in Hong Kong from Consumption of Chemically Contaminated Seafood: A Risk Assessment Approach, MSc Thesis, University of Hong Kong.

(50) *op cit.* (EVS 1996)

(51) Parsons ECM (1996) Trace metal levels in North Lantau fishes: implications for the health of Hong Kong's Indo-Pacific hump-backed dolphin (*Sousa chinensis*) population. In preparation.

(52) EVS Environment Consultants (1996b) Implications of fish and dolphins contaminant studies for management of the East Sha Chau contaminated mud disposal facility. Report to the Civil Engineering Department.

Table 5.6a *Comparison of Parsons (1996) and EVS (1996b) Hazard Quotients for Dolphins Consuming Fish at North Lantau*

	Metal Concentration in Fish (mg kg^{-1} wet weight)		**Hazard Quotient (no units)**	
Metal	**Parsons (1996)**	**EVS (1996b)**	**Parsons (1996)**	**EVS (1996b)**
Cadmium	1.3	0.0070	99	0.55
Chromium	0.45	0.092	0.084	0.017
Copper	0.98	0.27	0.039	0.11
Lead	13	0.063	0.98	0.0048
Mercury	1.8	0.035	56	1.1
Nickel	0.72	0.094	0.011	0.0014
Zinc	7.2	7.1	0.027	0.027

It is interesting to note that the consistent risk assessment methodology did not cause the conclusions from the two data sets to converge due to the large differences in fish tissue concentrations between the two studies. According to the Parsons (1996) dataset dolphins are at an elevated level of risk from mercury and cadmium exposure, whereas EVS (1996b) predicts moderate levels of concern for mercury only. A further discussion of possible explanations for the differences in conclusions is provided in EVS (1996b).

5.6.3 *Comparative Risk Assessment*

Another aspect of recent risk assessment work has involved comparative assessments for fishes, dolphins and humans for three sites in Hong Kong waters.(53) The flatfish, *Cynoglossus* sp, was selected as the indicator species because it is a benthic species with potential exposure to contaminated sediments through both direct contact and/or through consumption of contaminated prey. A comparison of fish tissue concentrations for seven metals (cadmium, chromium, copper, lead, mercury, nickel and zinc) showed no significant differences between the ESC area, Victoria Harbour and Tai Mun Wan (north of Tung Lung Chau and assumed to be uncontaminated). In addition, observed tissue concentrations were compared to concentrations gathered through an international literature search and it was determined that none of the tissue concentrations exceeded the range of concentrations found in uncontaminated areas worldwide.

The comparative risk assessment for *Sousa chinensis* indicated HQs below one (ie very low risk) for all contaminants except cadmium for which the HQ was 1.1. Victoria Harbour and Tai Mun Wan data resulted in HQ of 1.1 and 0.92, respectively. The similarity between HQ for the three areas was thought to indicate that either low-level cadmium is affecting dolphins throughout Hong Kong waters or that the risk assessment may be overly conservative in calculating risks due to cadmium(54).

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(53) EVS Environment Consultants (1996c). Contaminated Mud Disposal at East Sha Chau: Comparative Integrated Risk Assessment. Report to Civil Engineering Department.

(54) *op cit* (EVS 1996c)

Human health risks were compared between the three sites for three sectors of the population: the general population as represented by the 50th percentile seafood consumer, the reasonable maximum exposure, and the subsistence fishing population. For the first two sectors, none of the HQs for any contaminant at any of the three sites approached one. This was interpreted to indicate that the vast majority of the population is not at risk from consumption of seafood. The report noted this conclusion is supported by the fact that the mean fish tissue concentrations were all well below Hong Kong's Food Adulteration Limits. However, for the subsistence fishing population, which was assumed to consume 700-800 times the contaminant intake of the general population, HQs exceeded one for both lead and mercury at ESC. HQs also exceeded one for lead at Tai Mun Wan but were below one for all contaminants in Victoria Harbour. The study concluded that as the assessment procedures were highly conservative, it is unlikely that consumption of fish from ESC is posing significant health risks to fishermen and their families.(53)

5.6.4 *Review of* Sousa chinensis *Body Burden Data*

Numerous risk assessment studies have assessed the impacts to fish, dolphins and humans from the seven metals presently used to classify dredged material as contaminated or uncontaminated. There is, however, a relative shortage of information on the potential effects of organic contaminants. Recent data on marine mammal blubber concentrations, obtained from stranded Chinese White Dolphins, Finless Porpoise and Bottlenose Dolphins specimens, however, includes measurement of PCBs, chlorobenzene, lindane, chlordane, dieldrin, mirex and DDT, as well as heavy metals(55).

In order to evaluate these observed concentrations, a comparison with literature-based effect/no effect ranges for marine mammals was undertaken. Organics concentrations were considered elevated to levels of potential concern if concentrations in blubber exceeded the "no apparent effect" concentration range or exceeded concentrations associated with direct or indirect effects (*Table 5.6b*).

Table 5.6b *Number (Percentage) of Marine Mammals with Elevated Body Burden of Organics*

Contaminant	**Chinese White Dolphin**	**Finless Porpoise**	**Bottlenose Dolphin**
Total PCBs	3 (37%))	2 (18%)	1 (33%)
Chlorobenzenes (HCB)	1 (12%)	0 (0%)	0 (0%)
Lindane (HCH)	2 (25%)	4 (36%)	1 (33%)
Chlordane	1 (12%)	0 (0%)	0 (0%)
Dieldrin	0 (0%)	0 (0%)	0 (0%)
Mirex	6 (75%)	3 (27%)	2 (66%)
Total DDT	4 (50%)	8 (72%)	2 (66%)

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(55) Parsons ECM (1996) cited in *op cit* (EVS 1996b)

Concentrations of metals were considered elevated to levels of potential concern if concentrations in blubber, kidney or liver exceeded the "no apparent effect" concentration range or exceeded concentrations associated with direct effects (*Table 5.6c*).

Table 5.6c ***Metals Elevated to Levels of Potential Concern in Liver, Kidney and Blubber of Chinese White Dolphin and Finless Porpoise***

Contaminant	Chinese White Dolphin	Finless Porpoise
Cadmium	Kidney	Kidney
Chromium	Not Elevated	Kidney
Copper	Blubber, Liver	Blubber, Liver and Kidney
Lead	Blubber, Liver and Kidney	Blubber, Liver and Kidney
Mercury	Liver	Not Elevated
Nickel	Blubber	Blubber
Selenium	Liver	Liver
Zinc	Not Elevated	Not Elevated

The review concluded that both organics and metals may have had the potential to affect the health of these species of marine mammals. Of the contaminants analysed, concentrations of DDT, copper, and lead are of greatest concern as they are elevated in several different species and tissues. However, the report goes on to state several reasons why the disposal of contaminated material at ESC is not likely to be the major contributor to the observed body burdens:

- Monitoring of metals in water, sediment and tissue at ESC has not provided any evidence of elevated concentrations due to disposal;

- Although measurement of organics in fish tissue is not presently being conducted, measurement of PCBs and PAHs in sediments typically show concentrations which are near or below analytical detection limits;

- HQs calculated for fish, dolphins and humans at three areas in Hong Kong waters show similar, minimal risk indicating that ESC is not contributing a relatively higher proportion of contamination; and,

- DDT, the contaminant of greatest concern in marine mammal blubber, was recently not detected in a sampling programme at 13 marine, estuarine and freshwater sites in Hong Kong. (DDD and DDE were detected at concentrations slightly above detection limits.) The study notes that DDT has been banned in Hong Kong since 1988 but that other potential sources exist within the dolphins home range.(56)

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(56) *op cit* (EVS 1996b)

5.6.5 *Discussion of Findings*

Previous studies applying risk assessment techniques to Hong Kong have used standard methods and conservative assumptions to derive conclusions regarding the level of risk associated with consuming seafood from the ESC area. In the majority of the risk assessments abstracted above, it was concluded that no unacceptable risks are posed to either humans or *S. chinensis* from the metals levels in fish and prawn tissue in the ESC area. One study (Parsons 1996) suggested unacceptable levels of risk are being posed to *Sousa chinensis* from metals concentrations in fish at North Lantau. However, when the data from this study are subjected to the same standardized methodology employed in the other studies, the resulting risk levels are considerably reduced. In addition to evidence from the ESC monitoring programmes, which show no detectable elevations in metals concentrations as a result of disposal operations, a comparative risk assessment found no substantive differences between risks from seafood consumption at ESC, Victoria Harbour and Tai Mun Wan.

Recent data on organics and metals levels in marine mammal tissue have indicated that, in comparison to literature-derived effect/no effect ranges, concentrations for several contaminants are at levels of concern. To date, no risk assessments for organics have been conducted due to the lack of data on contaminant levels in prey organism tissue. As no such data have been collected for the East Sha Chau area, any risk assessment for organics would have to rely on arbitrary, estimated values or attempt to predict values from sediment concentrations. Although organics have been measured in sediments under the ESC monitoring programme since late 1995, concentrations have been consistently at or near the detection limits. Prediction of resulting concentrations of organics in prey organism tissue from concentrations in sediment is problematic and even more difficult when sediment concentrations are extremely low. Due to the extremely low concentrations of organics predicted to be released during the operation of CMP IV (see *Section 3.9*), and a lack of empirical data on organics concentrations in tissue, a risk assessment for organics was not undertaken for this EIA. As of November 1996, metals and organics (PCBs and PAHs) concentrations in both muscle tissue and whole body specimens for fish are being measured as part of the ESC CMP Environmental Monitoring and Audit programme. Once a dataset is developed, these data will provide an adequate basis for a robust organics risk assessment which could be used to assist in managing CMP IV.

Based on the available information presented here, no unacceptable impacts to human health and *Sousa chinensis* are predicted to result from the disposal of contaminated mud at CMP IV.

5.7 *CUMULATIVE IMPACTS*

Cumulative impacts to marine ecological resources may arise from concurrent dredging, backfilling or development projects in the area. Types of impacts may include physical effects (eg increased suspended sediment concentrations), water quality effects (eg changes in dissolved oxygen, nutrients, or contaminant concentrations), and ecosystem effects (eg benthic or water column habitat disturbance). Concurrent activities which contribute to one or more of these types of impacts may result in the following cumulative effects on marine ecology:

- prolonging the period of impact;
- increasing the intensity of the impact; and
- causing different effects in combination than any one impact would cause independently (synergy).

As discussed above, impacts to marine ecology associated with the proposed backfilling of CMP IV are expected to be directly related to the levels of suspended sediment, dissolved oxygen, nutrients and contaminants released and the degree of habitat disturbance. Water quality modelling results presented in *Section 3.8* indicate that no sensitive receivers are predicted to be impacted at concentrations above the WQO for suspended sediments, dissolved oxygen and nutrients. Modelling of contaminants has shown that levels are very low and well below applicable water quality criteria (see *Section 3.9*). A number of risk assessment studies have concluded that risk levels at ESC are low in both absolute and relative senses. Since project-specific impacts are not expected to result in unacceptable impacts to water quality, no unacceptable impacts to marine ecology sensitive receivers are expected.

As discussed in *Section 5.5*, habitat disturbance is expected to be low-level and temporary with regard to water column disturbance but more prolonged with regard to benthic habitat disturbance within the CMP IV itself. Despite the on-going disturbance to the benthos within the pits during backfilling, the proposed project is expected to benefit marine habitat by reinstating the natural seabed and providing, where possible, opportunities to increase habitat diversity. This assessment has thus concluded that the proposed operations are not predicted to result in unacceptable impacts to marine habitat.

Given the findings above, any project-specific ecology impacts associated with CMP IV, in conjunction with concurrent projects, are not expected to result in impacts which are substantially different from impacts resulting from the concurrent projects in the absence of activities at CMP IV. Thus, based on this assessment, cumulative impacts are not predicted to be unacceptable.

5.8 *MITIGATION MEASURES*

Impacts to ecological resources, either through changes in water quality or changes in habitat, are not predicted based on the operational scenarios modelled for this Environmental Assessment Report. Mitigation measures designed to control impacts to water quality, which are summarised in *Section 3.9* and will be incorporated into the Environmental Monitoring & Audit Manual for the project, will also mitigate any impacts to marine ecology sensitive receivers. Based on the findings of this assessment, no special mitigation measures to protect marine ecological sensitive receivers are recommended.

5.9 *CONCLUSIONS*

A review of existing information on ecological resources located within and around the ESC CMP IV has identified the area as supporting soft bottom benthic fauna, fisheries resources and the Chinese white dolphin *Sousa chinensis*. Information on baseline ecological conditions suggests that no species of conservation importance have been recorded from the area, with the exception of *Sousa chinensis* and *Tachypleus gigas*. Sighting records of *Sousa chinensis* indicate that it is often located near the CMP IV, though it prefers habitat surrounding Sha Chau and Lung Kwu Chau, and ranges throughout the Pearl River Estuary. *Tachypleus gigas* has been recorded from trawl catches taken recently in the ESC region, though none have been taken directly from within CMP IV.

Potential impacts to ecological resources may arise from, disturbances to benthic habitats, changes in water quality, disturbances to other habitats and uptake of contaminants to the food chain. Disturbances to benthic habitats were predicted to be confined to within the CMP, and as colonization of sediments is expected to occur following the completion of works, the project will be of benefit in restoring benthic fauna and epifauna to the area. As changes in water quality are minimal and transient, adverse impacts to ecological resources were not predicted to arise. Although little information on the effects of disturbance to *Sousa chinensis* is available, impacts arising from noise and habitat disturbances were not predicted. Contaminant release was examined through a review of several detailed risk assessment studies which indicated that minimal risk to human health and *Sousa chinensis* arises from metals release from contaminated sediments, via the food chain. Using both monitoring data from ESC and an independently collected dataset of fish tissue, standardised risk assessment method predicted no risk from most metals and marginal risk for Mercury. However, a comparison of risk at ESC, Victoria Harbour and Tai Mun Wan showed no difference in risk levels for fish, dolphins and humans from any of the seven metals analysed. Although elevated levels of organics in marine mammal tissue are of concern, the application of risk assessment techniques for organics is constrained by a lack of empirically-derived input data. Based on the available information, no unacceptable impacts to human health and *Sousa chinensis* are predicted to result from the disposal of contaminated mud at CMP IV.

Impacts arising from the proposed backfilling operations are predicted to be largely confined to the CMP IV, and will not cause adverse effects to any habitats or species of conservation importance. There are no predicted impacts to water quality or ecological resources within the marine park at Sha Chau and Lung Kwu Chau. Mitigation measures recommended to reduce impacts to water quality to acceptable levels are expected to also mitigate for effects on ecology. Therefore, no special mitigation measures are recommended for ecological sensitive receivers. Cumulative impacts predicted to arise from the proposed CMP IV backfilling in conjunction with concurrent projects are not expected to result in greater adverse impacts to ecological sensitive receivers than impacts arising from the concurrent projects independently.

6 AIR QUALITY

6.1 INTRODUCTION

This section presents the potential air quality impacts for the disposal of contaminated mud in the East Sha Chau Marine Borrow Pit (CMP IV). An assessment has been conducted to determine if there is potential for insurmountable air quality impacts associated with proposed operations at CMP IV. This assessment has been based on the same scenarios as those assessed for water quality impacts in *Section* 3, involving disposal by one tug boat/barge combination or one trailer dredger during a given one-hour period. Cumulative air quality impacts arising from disposal in conjunction with other operations such as capping or dredging of the pits have also been assessed.

6.2 STATUTORY REQUIREMENTS AND EVALUATION CRITERIA

The principal legislation for the management of air quality in Hong Kong is the Air Pollution Control Ordinance (APCO) (Cap 311). The statutory limits of specific air pollutants and the maximum allowable number of exceedances over specific time periods are stipulated by APCO. These limits and conditions for ambient air quality are referred to as the Hong Kong Air Quality Objectives (AQOs). The AQOs relevant to this study are shown below in *Table 6.2a*.

Table 6.2a *Relevant Hong Kong Air Quality Objectives ($\mu g\ m^{-3}$)(i)*

Pollutant	Averaging Time			
	1 Hour(ii)	8 Hours(iii)	24 Hours(iii)	1 Year(iv)
Sulphur Dioxide (SO_2)	800		350	80
Total Suspended Particulates (TSP)			260	80
Respirable Suspended Particulates (RSP) (v)			180	55
Nitrogen Dioxide (NO_2)	300		150	80
Carbon Monoxide (CO)	30,000	10,000		

Note:
(i) Measured at 298K (25°C) and 101.325 kPa (one atmosphere).
(ii) Not to be exceeded more than three times per year.
(iii) Not to be exceeded more than once per year.
(iv) Arithmetic means.
(v) Suspended particles in air with a nominal aerodynamic diameter of 10 micrometres and smaller.

In addition to the above established statutory limits, it is generally accepted that an hourly average TSP concentration of 500 $\mu g\ m^{-3}$ should not be exceeded at the identified sensitive receivers.

6.3 BASELINE AND FUTURE CONDITIONS

6.3.1 *Existing Conditions*

The proposed CMP IV is located to the north of the Chek Lap Kok Airport site and to the south of Tuen Mun. The Brothers are located to the east of the study area. The site is used by vessels en route to and from Hong Kong. Marine vessels associated with the new Airport Projects also use the region frequently.

The ambient air quality of the site is primarily affected by industrial emissions from the Tuen Mun area and Castle Peak Power station, and vehicle emissions from Tuen Mun Road and Castle Peak Road. As they are located more than 3 km from the site, air quality of the study area is expected to be good and well within the AQOs.

6.3.2 *Future Conditions*

The new Chek Lap Kok Airport is the only major development near the site. It is understood from the New Airport Master Plan that major facilities such as an aviation fuel storage site, aircraft maintenance workshop and ground support equipment maintenance workshop will be located to the west of the airport and thus a separation of more than 3 km from CMP IV is expected. Due to the distance between these future sources and the study area, the existing air quality of the study area is not anticipated to change as these facilities come on-line.

6.4 AIR SENSITIVE RECEIVERS

Air Sensitive Receivers (ASRs), as defined by HKPSG and the APCO, have been identified with reference to survey sheets and development plans.

At the Chek Lap Kok Airport, the Passenger Terminus Complex and the commercial development to the northeast of the Airport have been identified as future ASRs. In Tuen Mun, ASRs along the coast include Butterfly Beach, Pillar Point Refugee Camp, the proposed River Trade Terminus and the China Cement Plant. The ASRs and their respective distances to the boundary of the CMP IV site are given below in *Table 6.4a* and illustrated in *Figure 6.4a*.

Table 6.4a *ASRs of East Sha Chau CMP IV*

ASR		Location	Distance (m)
A1	Commercial Development	Northeast of Chap Lap Kok Airport	1,000
A2	Passenger Terminal Complex	Northeast of Chap Lap Kok Airport	1,300
A3	Butterfly Beach	South coast of Tuen Mun	3,400
A4	Pillar Point Refugee Camp	South coast of Tuen Mun	2,700
A5	River Trade Terminus	South coast of Tuen Mun	3,000
A6	China Cement Plant	South coast of Tuen Mun	3,400

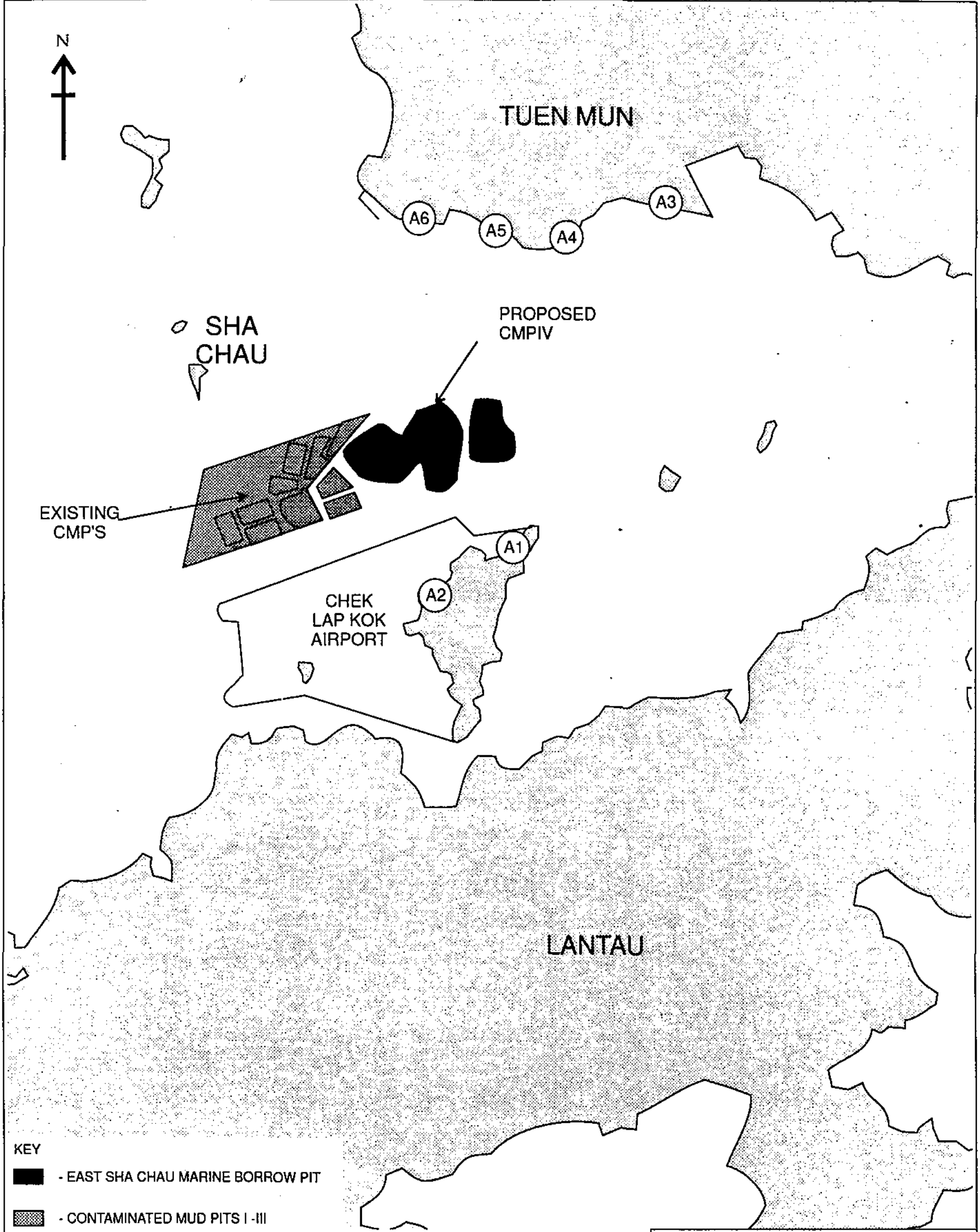


FIGURE 6.4a - LOCATIONS OF AIR SENSITIVE RECEIVERS

ERM Hong Kong
6th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

6.5 *POTENTIAL SOURCES OF IMPACT*

During the backfilling operations, contaminated mud (either grab-dredged or trailer-dredged material) will be delivered to the site by a barge/tug combination or trailer-dredger, respectively, and placed by bottom-dumping methods. Once backfilling is completed, pit caps will be constructed by hydraulic placement using a trailer dredger or cutter suction dredger. In addition to these activities, at some point prior to backfilling of Pit C, material presently in Pit C may be removed by trailer dredger for use in bund or cap construction or backfilling of access channels.

In order to account for single-source and cumulative air quality impacts, potential combinations of disposal, capping and dredging operations have been formulated into the following scenarios:

Scenario AN1-	Disposal by one barge/tug combination or one trailer dredger in Pit A, B or C.
Scenario AN2-	Dredging in Pit C and Trailer dredger disposal in Pit A or B.
Scenario AN3-	Trailer dredger placement of cap for Pit A and Trailer dredger disposal in Pit B.

Scenarios involving combinations of other activities were considered but not assessed in this EIA for the following reasons:

- Dredging in Pit C and simultaneous capping of Pit A was not assessed because it is likely that a single vessel will be performing both operations and thus will not be in both places at one time;
- Construction of bunds, and damming/backfilling of access channels (ie other dumping activities) in conjunction with disposal of contaminated mud or capping was not assessed because impacts are likely to be less than impacts associated with Scenarios AN2 and AN3; and
- Cumulative impacts associated with CMP IV operations in conjunction with other projects were not assessed because other projects are not expected to contribute to air and noise impacts in the East Sha Chau area.

As all materials will be dumped directly into the water below the water surface and will have a high moisture content, dust emission is expected to be low. Exhaust emissions from marine vessels used in the dredging, backfilling and placement of capping operations will be the main air pollution source. This assessment assumed a maximum of 2 trailer dredger disposal events per day, 20 barge/tug combination disposal events per day, and one trailer dredger operating continuously for dredging or placement of the cap.

6.5.1 *Emissions from Dredgers*

For trailer dredger disposal operations, this assessment has assumed that one trailer dredger will be allowed to dump at the CMP IV during each 1-hour period. It is expected that 8,000 m^3 trailer dredgers will be used. It has been assumed that the dredger, when dumping, would be moving slowly (2-3 knots) or drifting, and thus as a worst case, would be under minimal load. It is believed that engine output would be only a few hundred kilowatts which is similar to a single piece of heavy construction plant. Emission factors of dredger have been estimated in accordance with *US EPA - Compilation of Air Pollution Emission Factors (AP-42), 4th Edition, 1985* and are shown in *Table 6.5a*.

Table 6.5a *Emission Factors for dredger (g s^{-1} per dredger)*

Pollutant	Emission Factors
NO_2	0.3
RSP	0.092
CO	0.64

6.5.2 *Emission from Barges*

For disposal from barges, it has been assumed that the barge will be towed by tug boat. A maximum of one tug boat/barge combination disposing per 1-hour period has been assumed in this assessment. In Hong Kong, adequately-sized tug boats used for 800 m^3 barge towing are known to have an engine rating of approximately 500-600 kilowatts. Similarly to the trailer dredgers above, the tug boats would be moving slowly (2-3 knots) or drifting and thus under minimal load. Again output is assumed to be a few hundred kilowatts or roughly equivalent to a single bulldozer or truck under load. Therefore, emission factors will be similar to that of a dredger, the emission factors shown in *Table 6.5a*.

6.6 EVALUATION OF IMPACTS

The analysis above has indicated that dredgers and tug boats are the main sources of air quality impacts during disposal operations. Dredged materials will be disposed directly into water below the water surface and minimal fugitive dust impacts are expected. In addition, the disposal vessel (either trailer dredger or tug boat/barge combination) will be operated at minimal load. Each marine vessel's engine is expected to be operating at a comparable output to a piece of typical heavy construction plant (eg bulldozer or truck). A maximum of 2 dumps per day for trailer dredgers and 20 dumps per day for barge/tug combinations are expected during the operation of CMP IV. In light of the limited number of disposal events and distance separation, it is considered that air quality impacts on ASRs, arising from the CMP IV operations, should be negligible and the AQOs will not be exceeded.

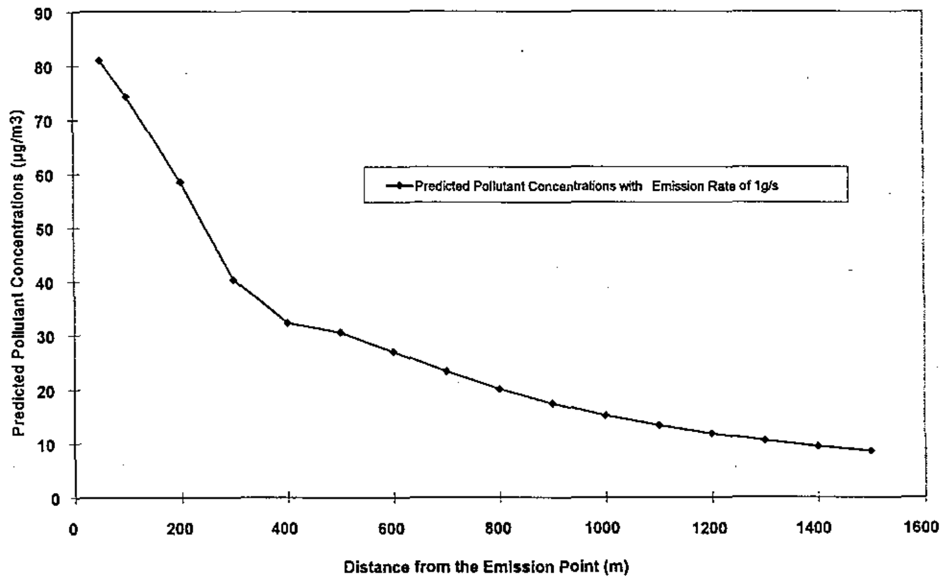
As indicated from Scenarios AN2 and AN3, dredging (in Pit C) or placement of the cap (for Pit A) by trailer dredger may take place concurrently with trailer dredger or barge/tug combination disposal. Therefore, cumulative air quality impacts arising from simultaneous operation of multiple plant may occur. As a worst case, there will be two vessels with air emissions operating at the same time (ie two trailer dredgers or one trailer dredger and one tug). Based on the emission factors listed in *Section 6.5a*, total emission rates for each scenario are calculated and summarised in *Table 6.6a*.

Table 6.6a *Total Emissions for Each Scenario (g s^{-1})*

Pollutant	Scenario		
	AN1	AN2	AN3
NO_2	0.3 × 1 = 0.3	0.3 × 2 = 0.6	0.3 × 2 = 0.6
RSP	0.092 × 1 = 0.092	0.092 × 2 = 0.184	0.092 × 2 = 0.184
CO	0.64 × 1 = 0.64	0.64 × 2 = 1.28	0.64 × 2 = 1.28

Ambient pollutant concentrations at downwind distances have been predicted using Industrial Sources Complex Short-term dispersion model (ISCST3) with emission rate of 1 g s^1 under different meterological conditions, i.e. stable and unstable conditions, stability class A-F and wind speeds of 1-10 m s^{-1}. The maximum predicted pollutant concentrations shown in *Figure 6.6a* decrease with distance from the source. The highest pollutant concentration at a downwind distance of 1 km is 15 μg m^{-3} under the neutral and calm weather conditions. Due to the low number of vessels required, the total pollutant emissions for each scenario is limited, less than 1 g s^{-1} for NO_2 and RSP for all scenario and marginally above 1 g s^{-1} for CO for Scenario 2 and 3, as shown in *Table 6.6a*. Therefore, the NO_2, RPS and CO concentrations at the nearest ASRs, over 1 km from the CMP IV will be within the AQOs.

Figure 6.6a *Predicted Ambient Pollutant Concentrations with Emission Rate of 1 g s^{-1}*



In practice, there may be several vessels at the site queueing to dump. The number of plant teams that could be used at the same time would be 25 for AN1, and 10 at each pit for AN2 and AN3 so as to meet the noise criteria. Based on these scenario, the total emission rates are calculated and shown in *Table 6.6b*.

Table 6.6b *Total Emissions for Each Scenario (g s^{-1})*

Pollutant	Scenario		
	AN1	AN2	AN3
NO_2	0.3 × 25 = 7.5	0.3 × 20 = 6	0.3 × 20 = 6
RSP	0.092 × 25 = 2.3	0.092 × 20 = 1.84	0.092 × 20 = 1.84
CO	0.64 × 25 = 16	0.64 × 20 = 12.8	0.64 × 20 = 12.8

The highest pollutant emissions are anticipated for Scenario AN1. In reference to the above modelling results, the predicted pollutant concentration at downwind distance of 1 km with emission rate of 1 g s^{-1} is 15 µg m^{-3}. Therefore, the NO_2, RSP and CO concentrations at downwind distance of 1 km for Scenario AN1 will be 112.5, 34.5 and 240 µg m^{-3} respectively. The predicted pollutant concentrations are well within the AQOs and the cumulative air quality impacts would be acceptable.

6.7 MITIGATION MEASURES

Considering that no major impact, in terms of any exceedances of AQOs, has been predicted for the local air quality from disposal operations, no air quality mitigation measures are recommended for these activities.

6.8 OUTLINE OF EM&A REQUIREMENTS

As no exceedances of the relevant AQOs have been predicted for the disposal operation, no air quality monitoring is recommended for the disposal operations.

6.9 CONCLUSIONS

The foregoing assessment has indicated that no exceedances of the AQOs have been anticipated and thus no major impacts to air quality are expected during the disposal, capping and dredging operations either singly, or in combination, at CMP IV. Therefore, no insurmountable air quality impacts associated with CMP IV operations are expected and mitigation measures and an air quality monitoring programme are not required for the disposal operations.

7 NOISE

7.1 INTRODUCTION

A noise assessment has been conducted for the proposed contaminated mud disposal in the East Sha Chau (ESC) Marine Borrow Pit (CMP IV) to determine the likelihood of any insurmountable noise impacts associated with the mud disposal operations. A methodology for assessing airborne noise impacts from the disposal activities has been developed based on the *Technical Memorandum on Noise From Construction Work Other Than Percussive Piling (TM).* Practical scenarios representing impacts associated with several stages of the proposed backfilling operation have been developed with respect to the operation design scheme described in *Section 2*. These scenarios form the basis of this noise study as part of the EIA.

7.2 STATUTORY REQUIREMENTS AND EVALUATION CRITERIA

In Hong Kong the control of construction noise outside of weekday daytime working hours (0700-1900, Monday through Saturday) is governed by the Noise Control Ordinance (NCO) and the subsidiary Technical Memoranda (*TM*) on :

- *Noise from Construction Work Other Than Percussive Piling* (*TM1*)
- *Noise from Percussive Piling* (*TM2*)
- *Noise from Construction Work in Designated Area* (*TM3*)

The execution of the proposed dumping activities falls within the control of *TM1*. *TM2* and *TM3* are irrelevant with respect to the nature of the proposed operations to the context of these *TM's*. The NCO noise criteria in *TM1* are for the control of noise from powered mechanical equipment (PME), and are dependent upon the designation of the area containing the Noise Sensitive Receivers (NSRs). The NCO requires that noise levels from construction at an affected NSR be less than a specified Acceptable Noise Level (ANL) which is set based on the Area Sensitivity Rating for the NSR. According to *TM1*, it depends on whether the NSR is located in urban or rural area, and affected by influencing factors such as major roads, industrial areas and airports.

The proposed disposal operations would be planned and controlled in accordance with the NCO, under the subsidiary *TM* on *Noise from Construction Noise Other Than Percussive Piling*. Operations requiring the use of PME during restricted hours (ie between the hours of 1900 and 0700 and during public holidays) and particularly at night, will require a Construction Noise Permit (CNP) and will need to achieve the applicable ANL. The ANL is derived from the Basic Noise Levels (BNL) determined in *TM1* by applying corrections for the duration of works and the presence of other nearby sites operating under a CNP. For this assessment, these corrections are not applicable and so have been set to zero, therefore the ANLs are equal to the BNLs. The ANL criteria are in terms of A-weighted continuous equivalent sound pressure level for a noise exposure duration of 5 minutes ($L_{Aeq,\,5\,min}$), and given in *Table 7.2a* below.

Table 7.2a *Acceptable Noise Levels (ANL, $L_{Aeq, 5 min}$ dB)*

Time Period	Area Sensitivity Rating		
	A	B	C
All days during the evening (1900-2300) and general holidays (including Sundays) during the day and evening (0700-2300)	60	65	70
All days during the night-time (2300-0700)	45	50	55

Although the NCO does not provide control for the construction noise during normal working hours, a limit of $L_{Aeq, 30 min}$ 75 dB is proposed in the *Practice Note For Professional Persons, PN2/93* which was issued by the Professional Persons Environmental Consultative Committee (ProPECC) in June 1993. This limit has been applied on major construction projects in Hong Kong, and is now generally accepted as a 'practical' limit for construction during daytime periods (0700-1900 hours). Accordingly, it also has been used as the assessment criterion for the daytime construction noise in this Study.

7.3 BASELINE AND FUTURE CONDITIONS

7.3.1 *Existing Conditions*

The proposed CMP IV is located to the north of Chek Lap Kok Airport, to the south of Tuen Mun, and to the west of The Brothers. The existing ambient noise in this region is derived from marine traffic and construction activities on Chek Lap Kok. The existing CMP IV site is currently used by vessels en route to and from Hong Kong (see *Section 2.8*).

7.3.2 *Future Conditions*

It is expected that the future ambient conditions will be dominated by airport noise associated with ground operations, aircraft take-off and landing.

7.4 NOISE SENSITIVE RECEIVERS

The nearby NSRs have been identified with reference to the most updated survey sheets and development plans, as well as a previous environmental study for the North of Lantau Marine Borrow Areas. The identified NSRs and their respective distances to the approximate centre of the CMP IV as required by the TM, are given in *Table 7.4a* below. These NSR locations are also illustrated in *Figure 7.4a*. The worst-case operational location at the CMP IV (ie the nearest operational position) would be at the boundary of Pit C. Although TM assessment procedures do not strictly require to assess the noise from this worst case position, it has been considered in this study for predicting the highest noise levels during the operations.

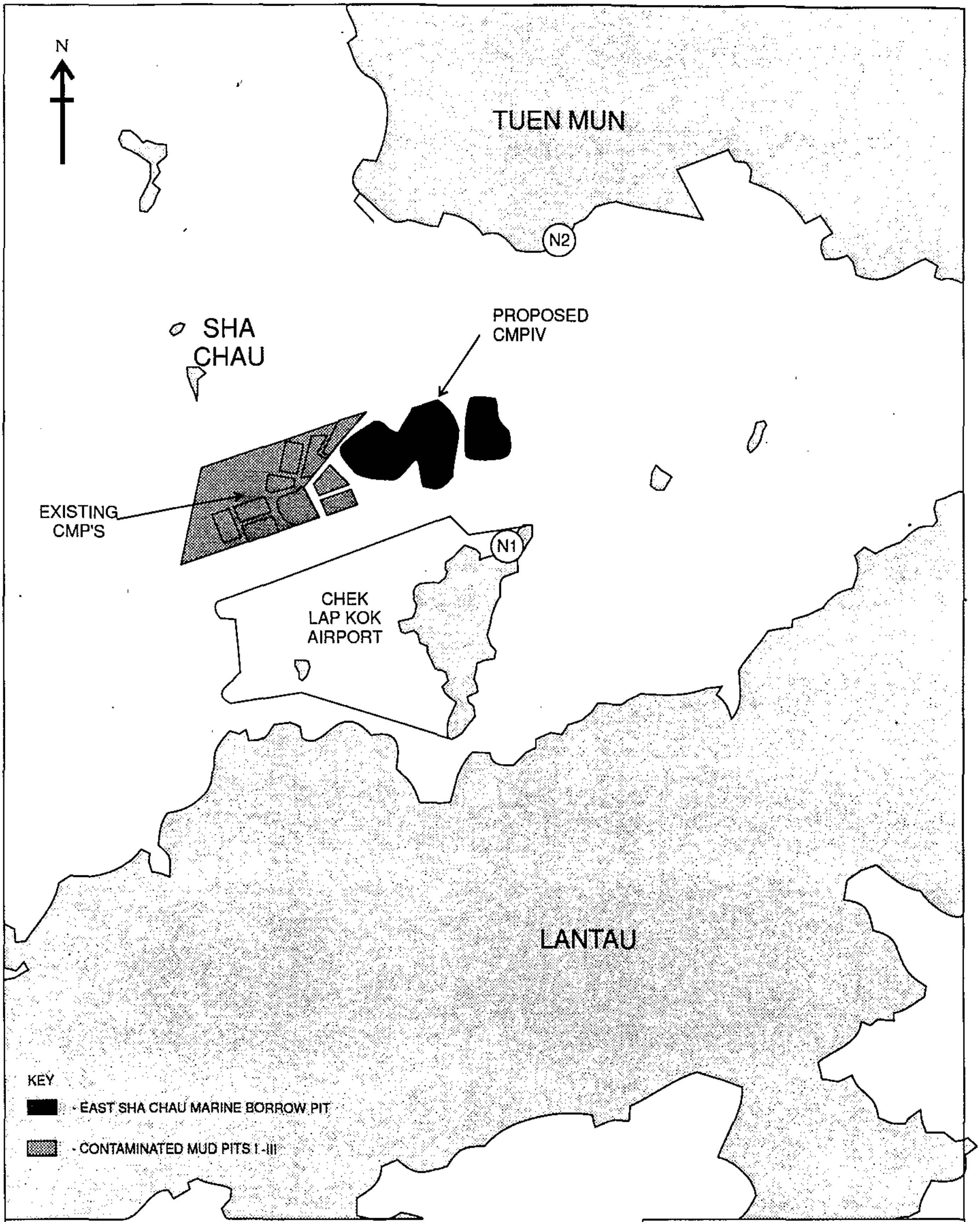


FIGURE 7.4a - LOCATIONS OF NOISE SENSITIVE RECEIVERS

ERM Hong Kong
6th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

Table 7.4a *Noise Sensitive Receivers near East Sha Chau CMP IV*

NSR Name	NSR Type	Area Sensitivity Rating	Approximate Distance from the NSR to the Centre of the Pit (m)		
			A	B	C
N1	Commercial use to the northeast of CLK Airport	C	2400	1500	1700 (1000)
N2	Pillar Point Refugee Camp	B	4700	4200	3600 (2700)

*Note: the worst case notional source points would be located at the boundary of Pit C, and its separation distances from the NSR are given in the parentheses.

As N1 will be located on the Chek Lap Kok Airport platform and directly affected by noise from the airport operations, its Area Sensitivity Rating is considered as 'C'. At the Pillar Point Refugee Camp (N2), the surrounding environment is basically rural in nature but contains Lung Mun Road which is a traffic noise source. Its Area Sensitivity Rating is therefore also considered as 'B'. For planning against aircraft flight noise, the Hong Kong Planning Standards and Guidelines (HKPSG) suggest any planned domestic premises be beyond the Noise Exposure Forecast (NEF) 25 contours. It has been checked that the aircraft noise exposure of N2 will meet this HKPSG requirement.

Although the Pillar Point Refugee Camp will be phased out after 1997, and therefore non-existing during the dumping operations, it has been assumed that the current landuse would remain for a worst case consideration of the potential noise impact arising from the proposed dumping operations.

In addition to human noise disturbance, there is a potential impact for noise disturbance to marine mammals, particularly *Sousa chinensis* which are social mammals using sound for echolocation. Noise disturbance could affect their ability to communicate, find food and socialise. Details are discussed in *Section 5*.

7.5 POTENTIAL SOURCES OF IMPACT

The contaminated mud is likely to be either grab-dredged or trailer-dredged material. Based on the operational design scheme, the grab-dredged material will be delivered to the site by barge/tug combination and placed by bottom-dumping methods. The trailer-dredged material will be delivered by dredger and also placed by bottom-dumping methods. The current design scheme estimates that there will be a maximum of 2 disposal events per day by trailer dredgers and approximately 20 disposal events by barge/tug combination per day.

For the purpose of this noise assessment, it has been assumed that operations within each pit of the CMP IV would use either one trailer dredger or one barge/tug combination. These operations are assumed to take place at a speed of 2-3 knots or slower. The sound power levels of the barge, tug boat and the trailer dredger are given below.

Table 7.5a *Assumed Plant Inventory and Sound Power Levels*

Plant	Number	TM Reference Number	Sound Power Level dB(A)
Derrick Barge	1	CNP 061	104
Tug Boat	1	CNP 221	110
Derrick Barge/Tug Boat combination			111
Trailer Dredger	1	-	111

The total sound power level of the barge/tug combination is 111 dB(A), and is identical to that of the trailer dredger. Therefore the potential noise impacts associated with these two plant are considered to be the same.

The following operational scenarios are assumed for analysing the potential noise impacts.

Table 7.5b *Assumed Operational Scenarios*

Scenario Code	Description
AN1	Trailer dredger disposal or Bottom dumping by barge/tug combination at the worst-case location (ie at the boundary of Pit C)
AN2-i	Trailer dredger disposal at Pit A with dredging at Pit C
AN2-ii	Trailer dredger disposal at Pit B with dredging at Pit C
AN3	Trailer dredger placement of cap at Pit A with trailer dredger disposal at Pit B

7.6 EVALUATION OF IMPACTS

The predicted noise levels at the nearby NSRs from the worst case operational positions at Pit C by either barge/tug combination or trailer dredger (AN1), and concurrent operations (AN2 and AN3) at more than one pit, are shown in *Table 7.6a* below.

Table 7.6a *Predicted Impacts at Noise Sensitive Receivers ($L_{Aeq,\,5min}$ dB)*

NSR	Acceptable Noise Level	Predicted Noise Levels			
	Day/Evening/Night	AN1*	AN2-i	AN2-ii	AN3
N1 at Chek Lap Kok Airport	75/70/55	46	43	45	44
N2 at Pillar Point	75/65/50	37	37	37	36

* Predicted level based on worst case operational positions at Pit C.

As shown above, no exceedances of the daytime, evening or night-time noise criteria at the nearby NSRs are predicted for the proposed disposal operations. As the separation distances between the NSRs and the boundary of Pits A and B are greater than the worst case position at Pit C, the noise levels from the 'worst case' concurrent activities for scenarios AN2 and AN3 would therefore not exceed 49 dB(A) and 40 dB(A) at N1 and N2, respectively. These levels are well within the acceptable noise levels. The predicted noise levels suggest that noise impacts would not arise even if the frequency and number of operations increased. In the night-time period (2300-0700 hours) when the NCO noise criteria are the most stringent (ie $L_{Aeq,5min}$ 50 and 55 dB for Pillar Point and Chek Lap Kok, respectively), the number of plant teams that could be used at the same time would be 25 at each pit for AN1 and 10 at each pit for AN2 and AN3. Each plant team could be either a combination of a derrick barge and a tug boat, or a trailer dredger.

7.7 *MITIGATION MEASURES*

7.7.1 *Human Habitation*

The noise assessment has indicated that no accedences of the ProPECC daytime noise guideline and the NCO noise criteria have been predicted for the proposed dumping activities. Therefore noise mitigation measures are not considered necessary. Nevertheless, good site practice, such as the use of well-maintained equipment should be adopted to prevent uncontrolled noise emissions.

7.8 *OUTLINE OF EM&A REQUIREMENTS*

As the proposed dumping operations at the East Sha Chau CMP IV would not cause unacceptable noise impacts at the nearby NSRs, environmental noise monitoring and audit is not recommended.

7.9 *CONCLUSIONS*

The proposed disposal operations at East Sha Chau Contaminated Mud Pit IV will not lead to unacceptable noise impacts at the nearby noise sensitive receivers. Noise monitoring will not be necessary, and therefore is not recommended as part of the project's environmental monitoring and audit programme.

8 CONCLUSIONS

This section summarizes the findings of the previous sections and presents an overall conclusion and impact hypothesis.

8.1 ENGINEERING AND MARINE TRAFFIC ISSUES

The proposed backfilling project involves placement of contaminated mud in three exhausted marine borrow pits at East Sha Chau to a level of -14 mPD. Preparatory work, such as backfilling the northern and southern access channels and building a bund between Pits A and B, is also proposed. The total estimated capacity for the three pits to receive contaminated mud is between 23.56 and 31.80 Mm^3. The cap design for the pits calls for a 1 m layer of sand (or clean mud) topped by a 2 m layer of clean mud and a 3 m layer of mud or granular/mixed material. Backfilling is expected to terminate in 2003 with the completion of the Pit C cap. Backfilling operations will be well clear of the major shipping route through Urmston Road and are not expected to significantly impact traffic along this route. In addition, the present usage of Urmston Road as a waiting and typhoon anchorage area for large vessels will not be affected.

8.2 WATER QUALITY

Water quality impacts associated with the proposed disposal of contaminated material at the East Sha Chau CMP IV were evaluated through use of a three-dimensional hydrodynamic model, TELEMAC, which predicts concentrations of suspended sediment, dissolved oxygen, nutrients and contaminants resulting from various operational scenarios. Disposal of material from both barges (16,800 m^3 day^{-1}) and trailers (16,000 and 40,000 m^3 day^{-1}) was modelled for Pits A, B and C at both empty and full phases. Validation of TELEMAC for wet and dry season spring and neap tides was achieved through comparison of modelled current velocities against those observed in the field.

All modelled scenarios complied with both the water quality objectives (for wet and dry seasons) and an assessment criterion of 10 mg l^{-1}. The maximum elevation in suspended sediment concentration was 4.2 mg l^{-1} at Sha Chau Beach in Scenario 4. This scenario was selected as a representative case on which to base contaminant modelling for seven metals, four PAHs, PCBs and TBT. All contaminants for which data on ambient concentrations were available, showed that predicted concentrations would not result in any measurable increase in ambient levels. As predicted levels are small fractions of ambient, predicted impacts will not cause a breach of applicable water quality standards. Modelling of pore water advective and diffusive flux rates indicated that contaminant fluxes due to pore water expulsion are very low with rates decaying rapidly and having a negligible effect on water quality.

The potential for erosion of the uncapped contaminated mud and the cap itself has been investigated. Analyses have shown that adequate protection from mobilization of contaminated mud during storm events is provided by adopting a maximum backfilling level of -14 mPD. Analyses have also shown that even the erosional forces associated with the most severe storm events would be incapable of breaching the cap and that any erosion of the cap would be compensated by natural deposition processes.

Since predicted elevations/depletions in suspended sediment, dissolved oxygen, nutrients and contaminants will be negligible in comparison to both ambient levels and applicable water quality objectives and standards, it is unlikely that backfilling activities at CMP IV will contribute significantly to cumulative water quality impacts within the study area. Mitigation measures, in the form of operational design and management measures, have been defined. An environmental monitoring and audit programme, which represents a continuation of approved monitoring and audit practices at the CMPs, will be implemented to verify the findings of the EIA.

8.3 *COMMERCIAL FISHERIES*

A review of existing information on commercial fisheries resources located within and around the ESC CMP IV has identified the area as supporting low abundances of demersal fisheries resources and high abundances of pelagic fisheries resources. While earlier studies have indicated that the East Sha Chau area is an important nursery and spawning ground, initial results from ongoing studies show that the area supports a low abundance of juvenile fisheries resources in comparison to other areas in Hong Kong. Disturbances to benthic habitats are predicted to be confined within the CMP IV, and as recolonisation of sediments is expected to occur following completion of works, the project will be of long term benefit in restoring benthic fauna, epifauna and demersal fisheries resources to the area.

Impacts arising from the proposed backfilling operations are predicted to be largely confined to the CMP IV, and will not cause adverse effects to any habitats or species of commercial or conservation importance. While no special mitigation measures are required for fisheries resources, mitigation measures recommended to reduce impacts to water quality to acceptable levels are also expected to mitigate impacts to fisheries resources.

8.4 *MARINE ECOLOGY*

A review of existing information on ecological resources located within and around the ESC CMP IV has identified the area as supporting soft bottom benthic fauna, fisheries resources and the Chinese white dolphin *Sousa chinensis*. Information on baseline ecological conditions suggests that no species of conservation importance have been recorded from the area, with the exception of *Sousa chinensis* and *Tachypleus gigas*. Sighting records of *Sousa chinensis* indicate that it is often located near the CMP IV, though it prefers habitat surrounding Sha Chau and Lung Kwu Chau, and ranges throughout the Pearl River Estuary. *Tachypleus gigas* has been recorded from trawl catches taken recently in the ESC region, though none have been taken directly from within CMP IV.

Disturbances to benthic habitats were predicted to be confined to within the CMP IV, and as colonization of sediments is expected to occur following the completion of works, the project will be of benefit in restoring benthic fauna and epifauna to the area. Although little information on the effects of disturbance to *Sousa chinensis* is available, impacts arising from noise and habitat disturbances were not predicted.

Potential impacts associated with contaminant release were examined through a review of several detailed risk assessment studies which indicated that minimal risk to human health and *Sousa chinensis* arises from metals release from contaminated sediments, via the food chain. Although elevated levels of organics in marine mammal tissue are of concern, the application of risk assessment techniques for organics is constrained by a lack of empirically-derived input data. Based on the available information, no unacceptable impacts to human health and *Sousa chinensis* are predicted to result from the disposal of contaminated mud at CMP IV.

Impacts arising from the proposed backfilling operations are predicted to be largely confined to the CMP IV, and will not cause adverse effects to any habitats or species of conservation importance. There are no predicted impacts to water quality or ecological resources within the marine park at Sha Chau and Lung Kwu Chau. Mitigation measures recommended to reduce impacts to water quality to acceptable levels are expected to also mitigate for effects on ecology. Therefore, no special mitigation measures are recommended for ecological sensitive receivers.

8.5 *AIR AND NOISE*

No exceedances of the AQOs have been predicted and thus no major impacts to air quality are expected during the disposal, capping and dredging operations, singly and in combination, at CMP IV. Therefore, no insurmountable air quality impacts associated with CMP IV operations are expected and mitigation measures and an air quality monitoring programme are not required for the disposal operations.

Similarly, the proposed disposal operations at East Sha Chau CMP IV will not lead to exceedances of the ProPECC daytime noise guideline and the NCO noise criteria at the nearby noise sensitive receivers in day or nighttime periods. Since no unacceptable impacts are predicted, no mitigation or monitoring measures are necessary.

8.6 *OVERALL CONCLUSIONS*

The detailed assessment of environmental consequences arising from backfilling of the CMP IV at East Sha Chau with contaminated mud indicates there are unlikely to be any insurmountable or unacceptable residual environmental impacts associated with the proposed operations. The operational design has been developed to incorporate mitigation measures as design features and is specified as follows:

- Backfilling level: the proposed backfilling level of -14mPD will provide adequate protection against erosion of uncapped contaminated material and is thus acceptable;
- Cap thickness: the cap design of 6m will be resistant to erosion under even extreme storm events (ie similar to Typhoon Signal No. 8) and is thus acceptable;
- Backfilling rates: average rates of 16,800 m^3 for barges and 16,000 m^3 for trailers resulted in no exceedances of applicable water quality objectives and

standards. Until higher rates are investigated through further modelling and agreed within Government, disposal rates should be limited to those stated above;

- Plant specifications: modelling of bottom-dumping of both barges and trailers showed no exceedances of applicable water quality objectives and standards and are thus acceptable;
- Temporal Restrictions on Disposal: all assessments indicated the operation of one vessel within each pit at any one time is acceptable;
- Spatial Restrictions on Disposal: disposal from vessels at points within the pit boundaries is acceptable.

Details of the operational procedures and controls are provided in the Operations Plan, which is released as a separate document to this EIA.

According to the detailed findings of the previous sections, the proposed project is considered environmentally acceptable. The impact hypothesis is defined for this project as follows:

Impacts associated with disposal of contaminated mud in the East Sha Chau CMP IV are not expected to result in exceedances of water quality objectives at sensitive receivers nor cause exceedances of applicable water quality standards. The operational design has been specified such that disposal of sediments shall not cause a detectable deterioration in sediment quality outside the CMP IV. Physical impacts to fisheries and marine ecological sensitive receivers (eg Sousa chinensis) are not expected and no change in contaminant levels in marine organism tissue are predicted to arise from this project. Air and noise impacts are expected to be undetectable.

This impact hypothesis has been tested under this EIA, and will be verified under the environmental monitoring and audit (EM&A) programme. This programme is defined in the EM&A Manual which is released as a separate document to this EIA.

Annex A

Glossary of Terms

Glossary

The four main items of plant which might be used at East Sha Chau during the backfilling of the pits are briefly described below.

Barge

The barges used for the transport of dredged materials are, almost without exception, 'dumb' barges (i.e. they are have no propulsion system of their own and must be towed by a tug). The barges used for open-sea transport to locations such as East Sha Chau typically have hopper capacities in the range of 400 to 1,200 m^3. The most common sizes are 800 and 1,000 m^3.

The barges are usually used to transport materials which have been dredged using grab dredgers. They can be used to transport material dredged using a cutter suction dredger but there are difficulties associated with loading barges in this manner and the practice is almost unknown in Hong Kong except when the material being dredged is sand rather than mud. The barges discharge in one of two ways, either splitting along the full length of the hull ('split-barge') allowing the hopper contents to fall out, or by opening with chain-operated bottom doors.

Cutter suction dredger ('Cutter')

A cutter suction dredger is a long pontoon equipped with a hinged 'ladder' at one end. The outer end of the ladder is lowered to the seabed and soil is loosened by a rotating cutterhead. The loosened sediment is swept into a hydraulic transport pipeline which carries the soil-water mixture up the ladder into the hull of the pontoon. The mixture can be discharged into barges moored alongside the dredger or can be pumped through floating or submerged pipelines to a remote disposal or reclamation site.

Cutter suction dredgers are rarely used to dredge mud in Hong Kong because the distances to suitable disposal sites are either too far for hydraulic transport or because the pipelines represent a hindrance to other marine traffic or would be damaged by wave action in exposed areas. They are generally not used to load mud into barges because the dilution of the material during dredging leads to a considerable increase in volume which would require an excessive number of barges. In addition, there are considerable difficulties associated with loading relatively small barges with a dredger which is typified by a high rate of production that needs to be maintained if the operation is to remain economic. In the case of the pits at East Sha Chau, however, they may be used to move mud by pipeline from one pit to another because distances are relatively short.

Cutter dredgers vary considerably in size and depth capability. However, very few are able to dredge to depths of more than approximately 20 metres.

Grab Dredger ('Grab')

Grab dredgers are very common in Hong Kong and are used most frequently to dredge mud particularly in confined areas where trailers dredgers are constrained. They comprise a pontoon-mounted crane which simply grabs the material from the seabed using a specially-designed grab bucket, raises it to the surface and then swings round to place the material in a barge moored alongside. The pontoon is held in place by means of a four-point anchor system which is used to move the dredger across the area to be dredged as required.

The advantage of grab dredgers with respect to the dredging of mud, especially contaminated mud, is that there is very little dilution of the soil during the dredging process. Bulking factors during dredging are generally of the order of 1.1 to 1.2. The disadvantage of using a grab dredger is that they tend to release large amounts of sediment unless sophisticated, purpose-designed, enclosed grabs are used and limitations are placed on the speed of operation.

In theory, there is no limitation on the dredging depth of grabs. However, as water depths increase, they become progressively slower and the accuracy of dredging diminishes. They are only rarely used to dredge in water depths in excess of 25 to 30 metres. The exceptions to this are special grab dredgers designed for mineral extraction but, such dredgers are not used for capital or maintenance dredging.

Trailing Suction Hopper Dredger ('Trailer')

Trailing suction hopper dredgers are self-propelled, seagoing vessels. They dredge by lowering a suction pipe from each side of the hull (sometimes they are equipped with only one suction pipe) and sucking a sediment-water mixture up the pipe into a large hopper. When loaded, they sail to the disposal or reclamation area. They usually discharge their load in a similar manner to barges, i.e. through bottom doors or valves. Some vessels discharge by splitting along the full length of the hull. Most modern trailers are also equipped with a pump-ashore facility which enables them to pump the sediment-water slurry through a floating pipeline or to 'jet' the material through a bow-mounted spray nozzle.

Trailers are usually rated according to hopper capacity which may range from 1 to 200 m^3 to 18,000 m^3. Most of the trailers which have been used in Hong Kong recently have hopper capacities in the range of 4 to 12,000 m^3.

Annex B

Telemac 3D Flow Model Technical Description

Introduction

There are many situations in estuarine, coastal and marine hydraulics where a standard depth-integrated model is inadequate to represent the complex flows which occur. These arise most commonly through variations in the water density, which is a function of temperature and salinity, or in response to wind stresses on the water surface. For example, estuaries with appreciable fresh water inflow are frequently stratified with fresher, less dense water near the surface and more saline water near the bed. The structure of the salinity field is usually dominated by the combined action of the suppression of turbulence by the vertical stratification and the gravitational circulation caused by a horizontal density gradient. These are 3-dimensional, unsteady processes with dynamic links between the flow and buoyancy; therefore demanding a 3D, unsteady and dynamically coupled model of flow and salt.

Similar processes occur in the presence of large temperature variations, which are most often caused by power station cooling water or by solar heating: seas and lakes often have a seasonal thermocline. Wind driven flows can also produce complex 3D structure which cannot be represented by 2D models, even in the absence of density variations. This is particularly true in relatively deep and slow moving coastal waters where the effect of bathymetry is important and in offshore waters where Coriolis forces lead to complex vertical structure.

Equations solved

The equations governing these processes describe the conservation of water volume, the conservation of momentum in the x and y directions and the transport of heat and salinity. The heat and salinity equations are coupled to the flow equations through the water density which is given by an equation of state, defining the density as function of temperature and salinity. TELEMAC-3D assumes that the pressure is hydrostatic, which is valid for most civil engineering and oceanographic applications. The flow equations are solved on a grid which in the horizontal is similar to a 2D flow model, but has several layers in the vertical. The horizontal mesh consists of an unstructured grid of triangles, allowing arbitrary variation of the grid resolution and accurate representation of complex coastlines. The equations given below are very similar to those for a 2D flow model in each layer but wind stress and bed friction apply to the top and bottom layers respectively and turbulent transport between the layers is modelled to extend these effects through the body of water. The equations can be expressed in terms of a Cartesian or a spherical coordinate system, which introduces a number of extra terms. It is important to use spherical coordinates when the model covers a large geographical area. The vertical layers form "sigma" planes which are defined in terms of a proportion of the water depth and which will move as the water surface varies.

Conservation of water volume

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (1)$$

Conservation of momentum in the x and y directions

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} + \frac{1}{\rho}\frac{\partial p}{\partial x} = \Omega v + v_H \nabla^2 u = \frac{1}{\rho}\frac{\partial \tau_x}{\partial z} \tag{2}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} + \frac{1}{\rho}\frac{\partial p}{\partial y} = -\Omega u + v_H \nabla^2 v + \frac{1}{\rho}\frac{\partial \tau_y}{\partial z} \tag{3}$$

Where the hydrostatic pressure is

$$p = -g \int_z^n \rho dz \tag{4}$$

Conservation of salt

$$\frac{\partial S}{\partial t} + \frac{\partial}{\partial x}(uS) + \frac{\partial}{\partial y}(vS) + \frac{\partial}{\partial z}(wS) = k_H \nabla^2 S + \frac{\partial f_{sz}}{\partial z} \tag{5}$$

Conservation of heat

$$\frac{\partial T}{\partial t} + \frac{\partial}{\partial x}(uT) + \frac{\partial}{\partial y}(vT) + \frac{\partial}{\partial z}(wT) = k_H \nabla^2 T + \frac{\partial f_{tz}}{\partial z} \tag{6}$$

where

x,y,z	are Cartesian co-ordinates, z vertically upwards (m)
u,v,w	are the corresponding velocity components (m/s)
t	is time (s)
ρ	is density (kg/m^3)
p	is pressure (N/m^2)
Ω	is the Coriolis parameter (s^{-1})
∇^2	is $\partial^2/\partial x^2 + \partial^2/\partial y^2$ (m^{-2})
η	is the value of z at the free surface (m)
v_H	is the horizontal eddy viscosity (m^2/s)
τ_x,τ_y	are horizontal components of vertical turbulent momentum transport (N/m^2)
S	is salinity (kg/m^3)
k_H	is horizontal eddy diffusivity (m^2/s)
f_{sz}	is vertical turbulent flux of salt (kg/m^2/s)
f_{tz}	is vertical turbulent flux of heat (°C/m^2/s)

The vertical fluxes of salt and heat depend on the turbulent diffusivity. This is calculated in the model either using a mixing-length approach or the k-ϵ approach. The mixing length description of the turbulence takes account of different size eddies dominating the turbulent diffusion at different levels in the water column, and includes the effect of turbulent damping by vertical density variations via a function of the Richardson number. The k-ϵ approach requires the solution of two additional transport equations, for the turbulent energy and the turbulent dissipation rate. From these two parameters, an eddy viscosity is calculated at each node at each time step.

The effect of a wind stress on the surface can be included in the model. The wind induced flow may be complex due to the Coriolis force and any stratification which may be present.

Numerical method

The numerical method solves the equations by means of a decomposition in fractional steps: an advection step, a diffusion step and a free surface-continuity-pressure step. There are a number of options available in the software for the solution of the advection step, including characteristics, SUPG (streamline upwind Petrov-Galerkin) and a hybrid characteristics-centred scheme. The other two steps are solved using a Galerkin finite element method.

The space discretisation used consists of a finite element discretisation in prisms, with vertical sides, so that each layer of the mesh is identical in the horizontal and is made up of triangles. Thus the mesh generation procedure is the same for TELEMAC-3D as for TELEMAC-2D. The layers of the mesh are defined by a set of values θ between 0 and 1. The sea bed corresponds to $\theta=0$ and the free surface corresponds to $\theta=1$. The intermediate values need not be evenly spaced through the depth and can be chosen by the user. Due to the movement of the free surface, the 3D mesh moves with time. By means of the classical σ-transformation, the equations can be transformed to a mesh which is independent of time. This approach is used for the advection step of the calculation. However, this approach is not ideal for the solution of the diffusion step, because of the side-effect of creeping diffusion which arises from neglecting some of the complicated σ-transformed diffusion terms. An alternative approach has been chosen in TELEMAC-3D, which is to solve the diffusion step on the real mesh at time $t=t_n$. Ideally, this step should be carried out on the mesh at time $t=t_{n+1}$, but this is not known at this stage of the calculation. The continuity step is solved in the transformed mesh.

Finite element methods appear in the diffusion and pressure-continuity steps. In the latter step, 3D equations must be integrated along the vertical, leading to shallow water like equations. The matrices are stored element-by-element, with only the matrix diagonals being assembled. This leads to efficient use of memory and allows vectorisation of the code for use on vector computers. Coefficients of matrices are computed exactly (as opposed to the commonly used Gaussian quadrature methods). The value of every coefficient is explicitly written in the program in the form of a polynomial, generated by a symbolic manipulation program, REDUCE. By hand the task would be tedious and a likely source of errors.

The finite element formulations lead to the resolution of a linear system of equations. This system is solved in TELEMAC-3D using one of a choice of conjugate gradient style iterative solvers. The number of iterations is reduced by either diagonal or Crout preconditioning. The latter is the preferred method, and can reduce the computing cost of the diffusion step by about 30% compared to diagonal scaling.

Annex C

Telemac 3D Sediment Plume Model Technical Description

Flow in a coastal region consists of large-scale tidal motion, wind-driven currents and small-scale turbulent eddies. In order to model the dispersal of suspended mud in such a region, the effects of these flows on suspended mud plumes must be simulated. The random walk dispersal model, SEDPLUME-3D, represents turbulent diffusion as random displacements from the purely advective motion described by the turbulent mean velocities computed by the three dimensional free surface flow model, TELEMAC-3D.

Representation of mud disturbance

In SEDPLUME-3D, the release of suspended mud in coastal waters is represented as a regular or intermittent discharge of discrete particles. Particles are released throughout a model run to simulate continuous mud disturbance or for part of the run to simulate mud disturbance over an interval during the tidal cycle, for instance to represent the resuspension of fine sediment during dredging operations. At specified sites a number of particles are released in each model time-step and, in order to simulate the release of suspended mud, the total mud released at each site during a given time interval is divided equally between the released particles. Particles can be released either at the precise coordinates of the specified sites, or distributed randomly, centred on the specified release sites. The particles can be released at the surface or evenly distributed through the water column.

Large scale advection

TELEMAC-3D simulates tidal flows in coastal waters, including the effects of any thermal or saline stratification and any three dimensional structure induced by bed friction or wind stress. Three components of current speed are calculated at a number of points through the depth and these values are interpolated to establish the precise current at the position of each SEDPLUME particle. Each particle is then advected by the local flow conditions. Because the three dimensional structure of the flow is calculated by TELEMAC-3D, effects such as shear dispersion of plumes are automatically represented.

Turbulent diffusion

In order to simulate the effects of turbulent eddies on suspended mud plumes in coastal waters, particles in SEDPLUME-3D are subjected to random displacements in addition to the ordered movements which represent advection by mean currents. The motion of simulated plumes is, therefore, a random walk, being the resultant of ordered and random movements. Provided the lengths of the turbulent displacements are correctly chosen, the random step procedure is analogous to the use of turbulent diffusivity in depth-averaged mud transport models. This is discussed in more detail below.

(a) Lateral diffusion

The horizontal random movement of each particle during a time-step of SEDPLUME-RW consists of a displacement derived from the parameters of the simulation. The displacement of the particle in each of the orthogonal horizontal directions is calculated from a Gaussian distribution, with zero mean and a variance determined from the specified lateral diffusivity. The relationship between the standard deviation of the displacement, the time-step and the diffusivity is defined in Reference 1 as:

$$\frac{\Delta^2}{\Delta t} = 2D \qquad (1)$$

where

Δ = standard deviation of the turbulent lateral displacement (m)
Δt = time-step (s)
D = lateral diffusivity (m^2s^{-1}).

In a SEDPLUME-3D simulation, a lateral diffusivity is specified, which the model reduces to a turbulent displacement using Equation (1). No directional bias is required for the turbulent movements, as the effects of shear diffusion are effectively included through the calculated depth structure in the mean current profile.

(b) Vertical diffusion

Whilst lateral movements associated with turbulent eddies are satisfactorily represented by the specification of a constant diffusivity, vertical turbulent motions can vary significantly horizontally and over the water depth, so that vertical diffusivities must be computed from the characteristics of the mean flow field, rather than specified as constants. In neutral conditions, the vertical diffusivity, K_z, is given by:

$$K_z = 0.16h^2\left(1-\frac{h}{d}\right)\frac{\partial u}{\partial z} \qquad (2)$$

where

h = height of particle above the bed
d = water depth
0.16 = (von Karman constant)^2
u = current speed
z = vertical coordinate

The value of the vertical diffusivity is calculated at each particle position, then a vertical turbulent displacement is derived for each particle from its K_z value using an equation analogous to (1) for the lateral turbulent displacement.

If the water density varies in the vertical, then stable stratification can occur, whereby the turbulence is damped by buoyancy effects. In this case the mixing length as adapted by a function of the Richardson number, based on field measurements (Reference 2).

(c) Drift velocities

A particle undergoes a random walk as follows:

$$x^n = x^{n-1} + A(x^{n-1},t^{n-1})\Delta t + B(x^{n-1},t^{n-1})\sqrt{\Delta t}\,\xi^n \qquad (3)$$

where x^n is the position of the particle at time t^n, A is the advection velocity at timestep n-1 and B is a matrix giving the diffusivity. ξ is a vector of three random numbers, each drawn from a normal distribution with unit variance and zero mean. In the case of SEDPLUME-3D, B is diagonal, with the first two entries equal to $\sqrt{(2D)}$ (as introduced in the previous section) and the third diagonal entry being equal to the local value of $\sqrt{(2K_z)}$.

The movement of a particle undergoing a random walk as described in equation (3) can be described by the Fokker-Planck equation in the limit of a very large number of particles and a very short timestep, where we introduce subscripts i,j and k running over the three coordinate directions:

$$\frac{\partial f}{\partial t} + \frac{\partial}{\partial x_i}(A_i f) = \frac{\partial^2}{\partial x \partial x_j}(\frac{1}{2}B_{ik}B_{jk}f) \qquad \textbf{(4)}$$

The probability density function $f(x,t \mid x_0,t_0)$ is the probability of a particle which starts at position x_0 at time t_0 being at position x at time t.

Equation (4) can be compared with the advection-diffusion equation for the concentration of a pollutant, c:

$$\frac{\partial c}{\partial t} + \frac{\partial}{\partial x_i}(u_i c) = \frac{\partial}{\partial x_i}(K_{ik}\frac{\partial}{\partial x_k}c) \qquad \textbf{(5)}$$

where K_{ik} is the eddy diffusion matrix, diagonal in our case but not necessarily so. Thus identifying f with c, we can see that the two equations are equivalent provided that we take the advection velocity as:

$$A_i = u_i + \frac{\partial}{\partial x_k}K_{ik} \qquad \textbf{(6)}$$

In the case of SEDPLUME-3D, the diffusivity varies only in the vertical and is constant in the horizontal, so the horizontal advection velocity is simply the flow velocity (assuming that the relatively small effects of changing water depth can be neglected). However, when considering the movement of particles in the vertical it is important to include the gradient of the diffusivity (often referred to as a drift velocity) in the advection step. If this term is omitted then particles tend to accumulate in regions of low diffusivity, which in our case means at the surface and at the bed.

This subject is discussed in considerably more detail in References 3,4,5 and 6.

Sedimentation Processes

(a) Settling

In SEDPLUME-RW, the settling velocity (w_s) of suspended mud is assumed to be related to the mud concentration (c) through an equation of the form:

$$w_s = \max(w_{\min}, Pc^{Q}) \qquad \textbf{(7)}$$

where $w_{\min}$, P and Q are empirical constants. Having computed a suspended mud concentration field, as described subsequently in this section, a settling velocity can be computed in each output grid cell from Equation (7) and used to derive a downward displacement for each particle during each time-step of a model simulation. This displacement is added vectorially to the other computed ordered and random particle displacements. Note that there is a specified minimum value of w_s. This results in settling velocities being constant at low suspended mud concentrations, as indicated by recent research at HR. (Reference 7).

(b) Deposition

SEDPLUME-3D computes bed shear stresses from the input tidal flow fields using the rough turbulent law, based on a bed roughness length input by the user. If the effects of storm waves on mud deposition and erosion at the sea bed are to be included in a model simulation, a bed shear stress associated with wave orbital motions, computed from the results of mathematical wave model simulations, is added to that resulting from the simulated tidal currents (Reference 8). Where the computed bed stress, τ_b, falls below a specified critical value, τ_d, and the water is sufficiently deep, then deposition is assumed to occur. Mud deposition is represented in SEDPLUME-3D by particles approaching the sea bed becoming inactive when τ_b is below τ_d. Whilst active particles in the water column contribute to the computed suspended mud concentration field, as described subsequently in this appendix, inactive particles contribute to the mud deposit field.

In shallow areas, where tidal currents are sufficiently weak to allow mud accretion, normal wave action can prevent mud deposition. This effect is included empirically in SEDPLUME-3D, by specifying a minimum water depth below which deposition does not occur.

(c) Erosion

The erosion of mud deposits from the sea bed is represented in SEDPLUME-3D by inactive particles returning to the water column (becoming active) when τ_b exceeds a specified erosional shear strength, τ_e. The number of particles which become re-suspended in each cell of the output grid in each time-step of a simulation is determined by the equation:

$$\text{Erosion Rate} = M(\tau_b - \tau_e) \qquad (8)$$

where M is an empirical erosion constant.

Computation of suspended mud concentrations

In SEDPLUME-3D, suspended mud concentrations are computed on a multi-layer square grid designed to resolve the essential features of relatively small-scale plumes. The layers of the output grid are separated by the element planes of the TELEMAC-3D grid, so that if there are N planes in the TELEMAC-3D mesh, there are N-1 layers in the SEDPLUME-3D output grid. In each SEDPLUME-3D grid cell a concentration is derived by dividing the total suspended mud represented by all the active particles in that cell by the volume of the cell.

Computation of mud deposit distributions

SEDPLUME-3D computes mud deposit distributions by summing the mass of mud represented by the inactive particles in each cell of the output grid, and assuming that the resulting mass is evenly distributed over the cell area.

References

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8 HR Wallingford. Port and Airport Development Strategy - Enhancement of the WAHMO Mathematical Models. Testing of the North West New Territories Coastal Waters Mud Transport Model for Storm Wave Conditions in the Wet Season. Report EX 2267, January 1991.

Annex D

Water Quality Modelling Results for Scenario 1

Scenario 1 (Annex D)

Scenario 1 modelled the disposal of 16,800 m^3 day^{-1} from barges at the centre of Pit A (empty) on the dry season spring tide. On the ebb tide the plume extends past the northeastern corner of Chek Lap Kok and south of the Brothers at concentrations of 1-10 mg l^{-1}. Some of the tidal stream, at the northern edge of the pit, splits off and flows to the North of the Brothers which results in a slight elevation in suspended sediment concentration (1-10 mg l^{-1}) in the area from the northern edge of the CMP IV to the north of the Brothers. On the flood tide a plume of elevated suspended sediment (up to 20 mg l^{-1}, but mostly in the range of 1-10 mg l^{-1}) is predicted to extend northwards to mid-way between the Sha Chau group of islands and the Castle Peak power station.

Predicted sediment deposition indicate that the majority of the sediment is predicted to settle onto the seabed within the confines of Pit A at rates of up to 4 kg m^{-2} day^{-1}. Other areas of deposition (0.5-1 kg m^{-2} day^{-1}) are predicted immediately outside the western boundary of Pit A and on the fringes of Pit B. DO depletions and nutrient elevations are predicted only in the area immediately surrounding the disposal point at concentrations of up to 0.1 mg l^{-1} and 0.004 mg l^{-1}, respectively.

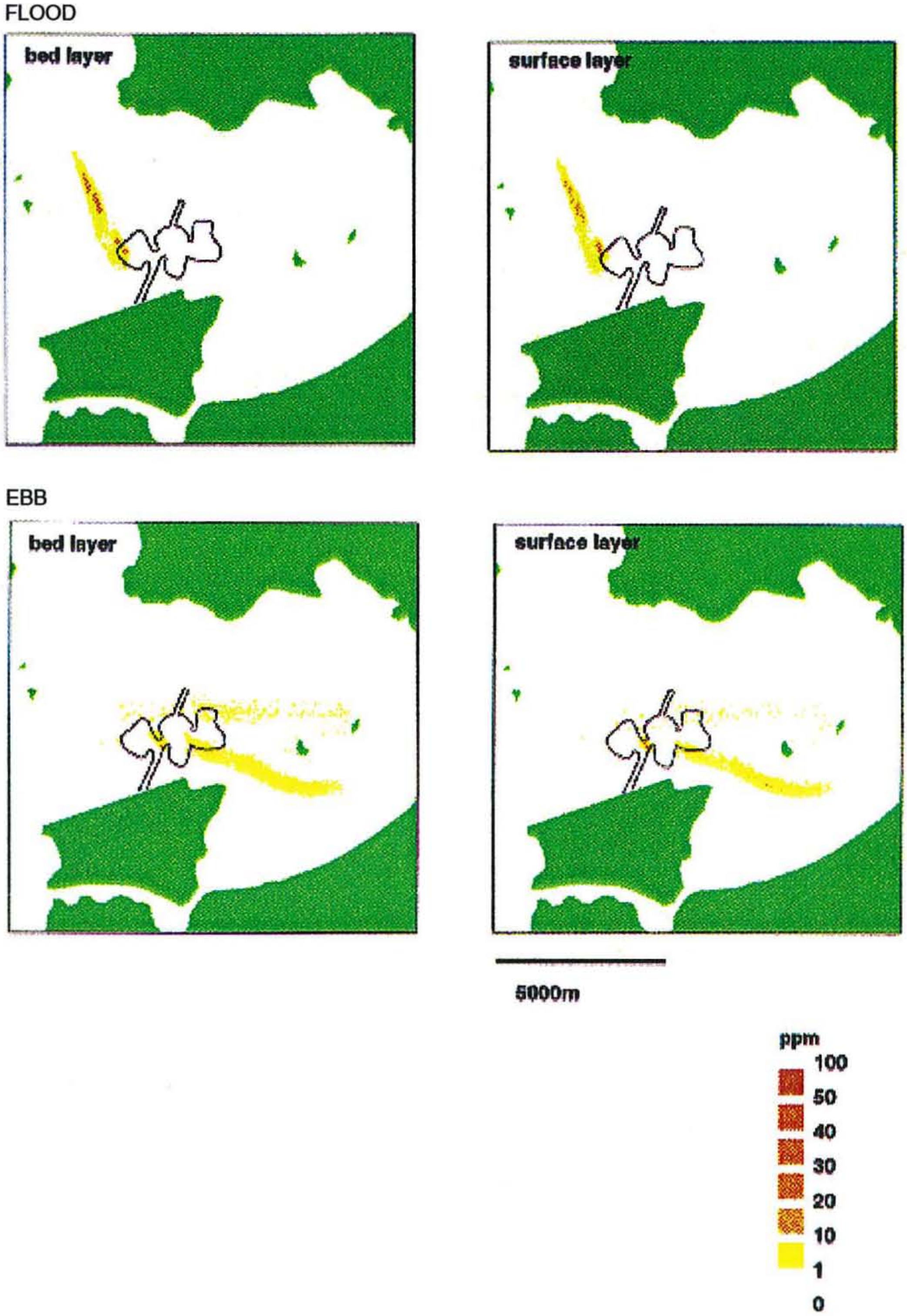

FIGURE D1 - SCENARIO 1: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS AT PEAK FLOOD AND PEAK EBB TIDES

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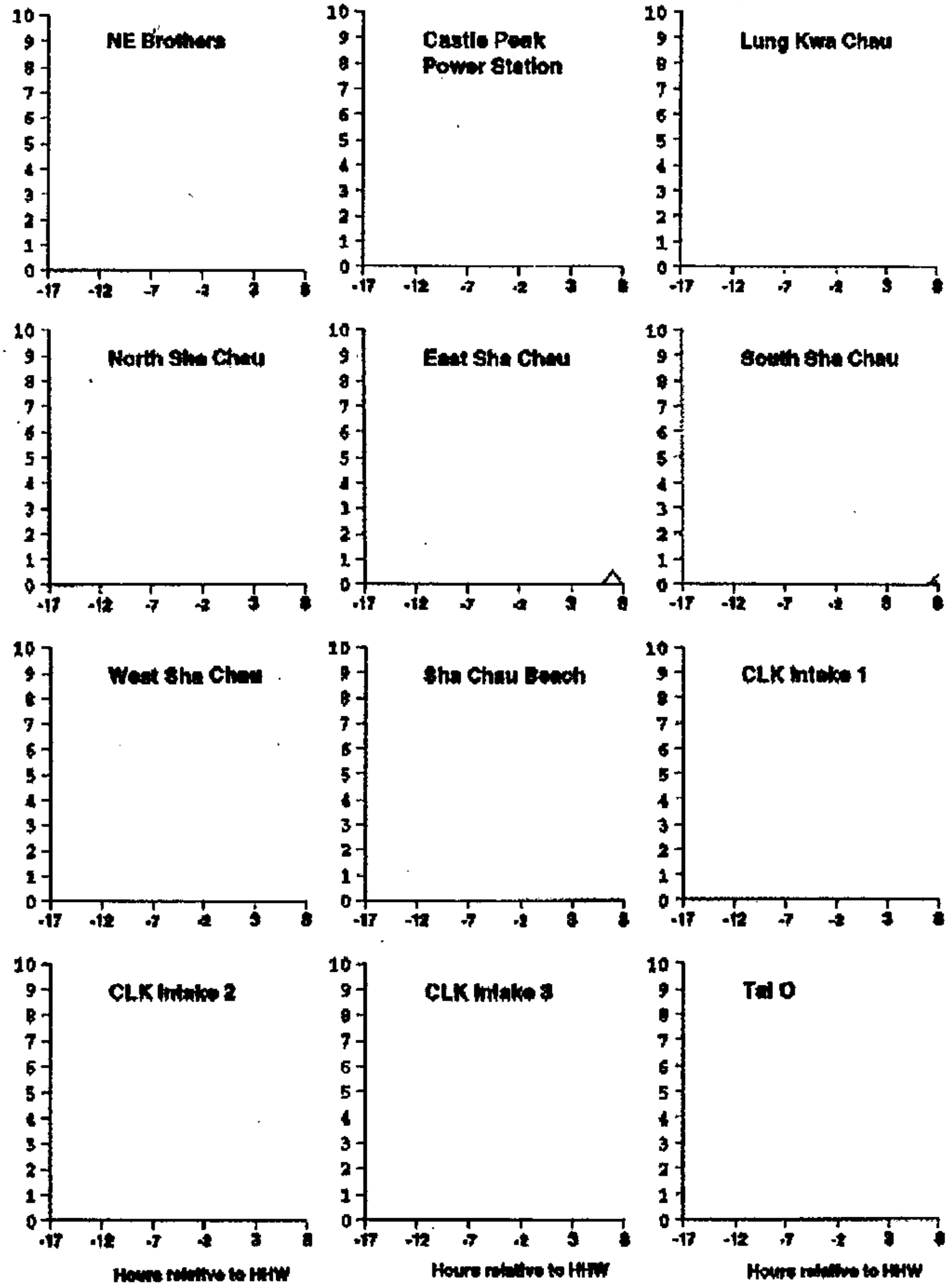

FIGURE D2 - SCENARIO 1: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS OVER THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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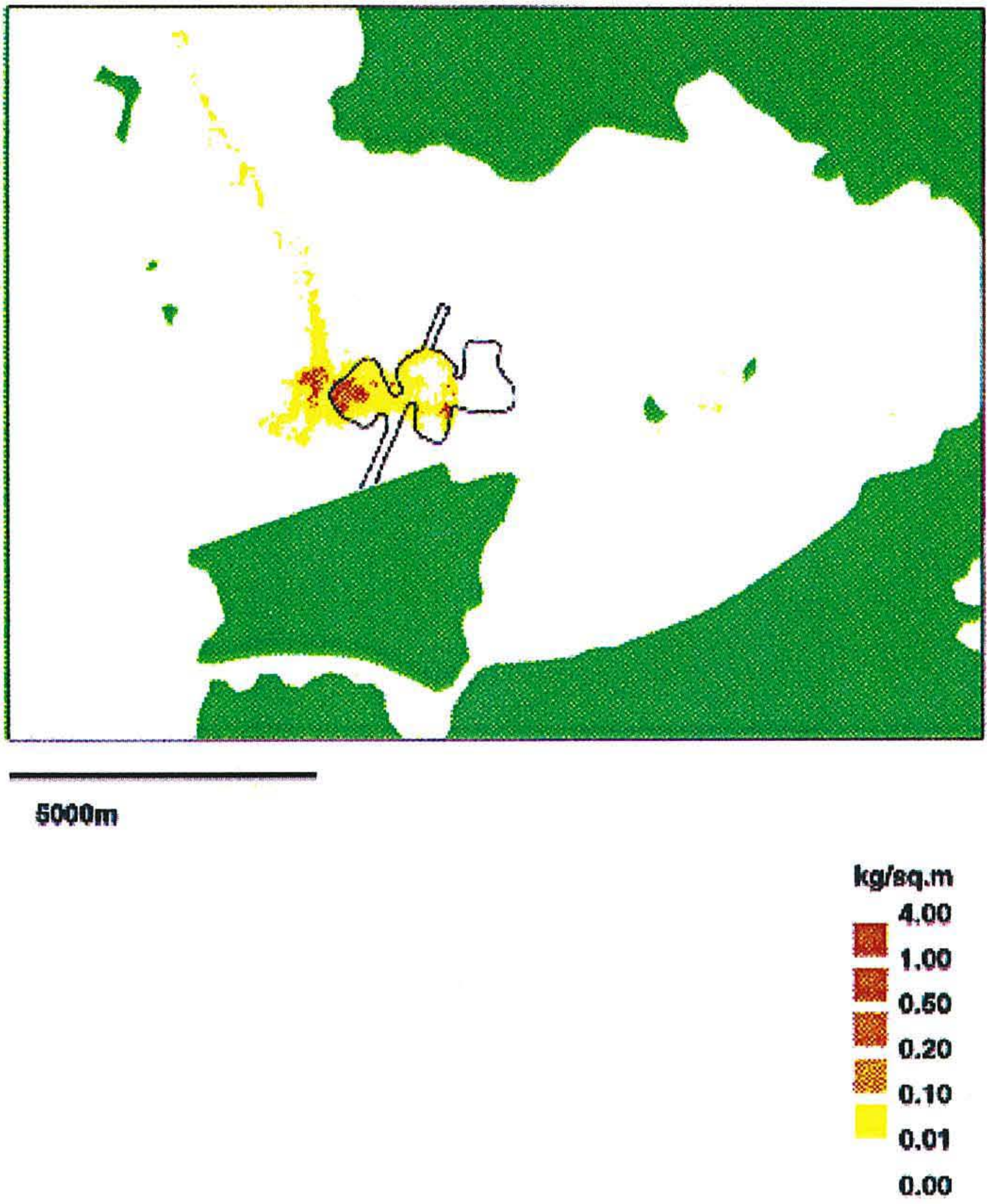

FIGURE D3 - SCENARIO 1: PREDICTED SEDIMENT DEPOSITION PER DAY

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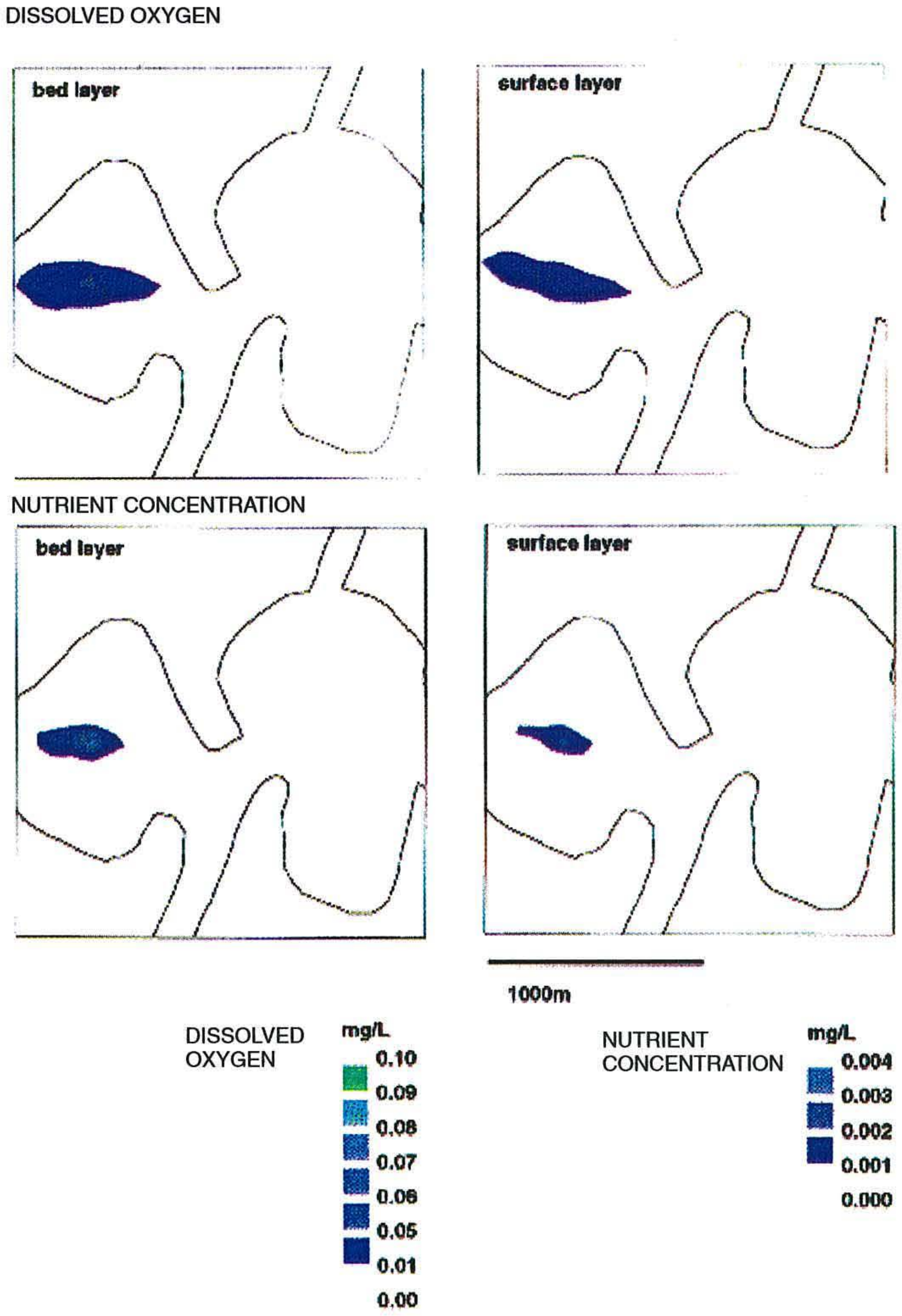

FIGURE D4 - SCENARIO 1: PREDICTED DISSOLVED OXYGEN AND NUTRIENT ELEVATION

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Annex E

Water Quality Modelling Results for Scenario 2

Scenario 2 Results (Annex E)

Scenario 2 modelled the disposal of 16,800 m^3 day^{-1} from barges at the centre of empty Pit B on the dry season spring tide. On the ebb tide the plumes are similar in pattern to those from Scenario 1, but show longer plumes extending past the south of the Brothers (at localized concentrations of up to 20 mg l^{-1}), due to the fact that Pit B is within the main ebb tidal stream. On the flood tide, due to lower flood currents in Pit B relative to Pit A, a continuous plume (1-10 mg l^{-1}) is predicted with areas of higher concentration (10-20 mg l^{-1}) extending from the disposal point for a short distance in a northerly direction.

Predicted sediment deposition occurs within Pit B (up to 4 kg m^{-2}), and to a lesser extent, Pit A (1 kg m^{-2}). Similar to Scenario 1, low deposition rates (0.01-0.1 kg m^{-2}) are predicted to the north of the pits, along the line of the flood plume. As in Scenario 1, only areas in the immediate vicinity of the disposal point are predicted to be impacted by DO depletions (maximum of 0.05 mg l^{-1}) and nutrient elevations (up to 0.004 mg l^{-1}).

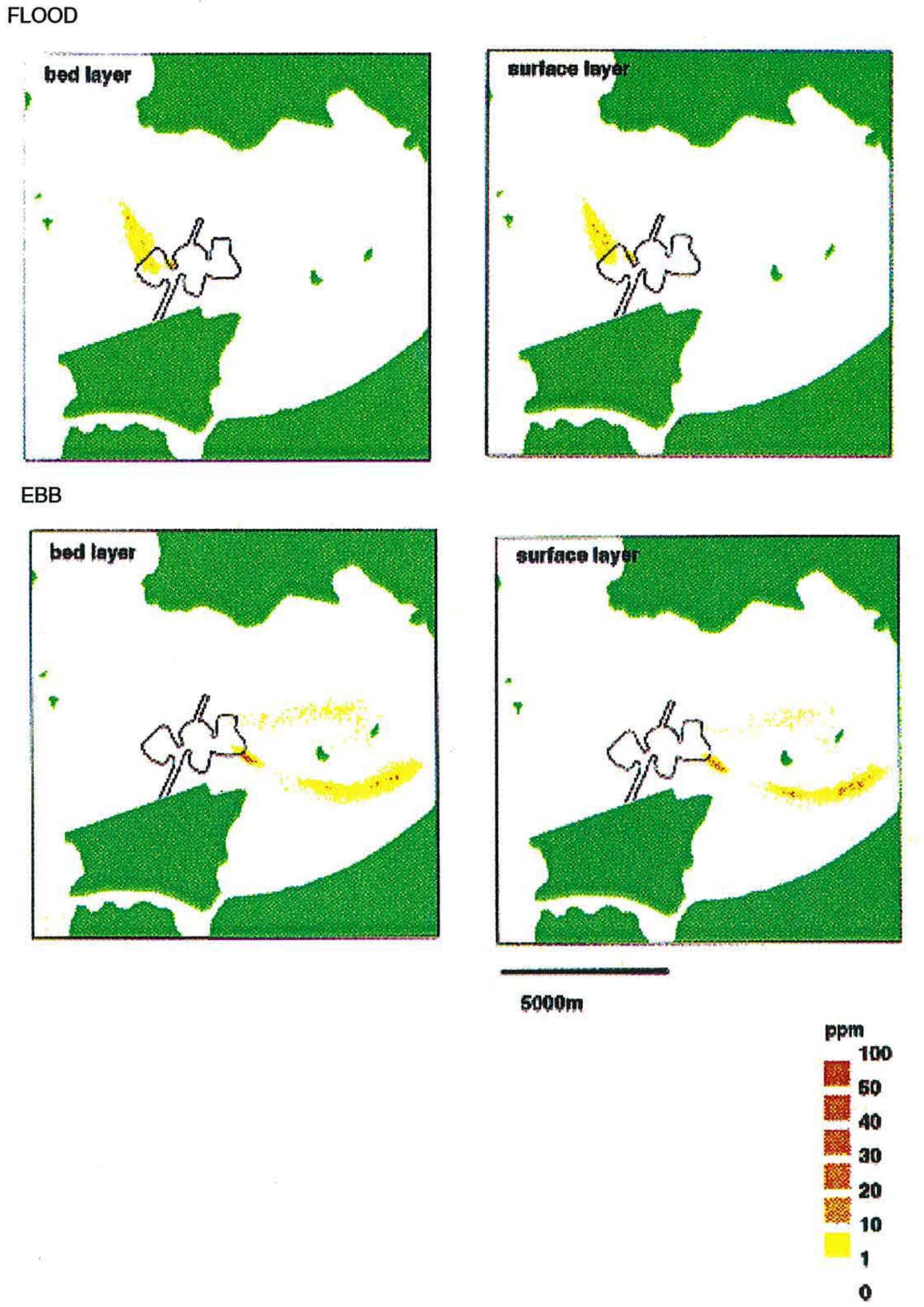

FIGURE E1 - SCENARIO 2: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS AT PEAK FLOOD AND PEAK EBB TIDES

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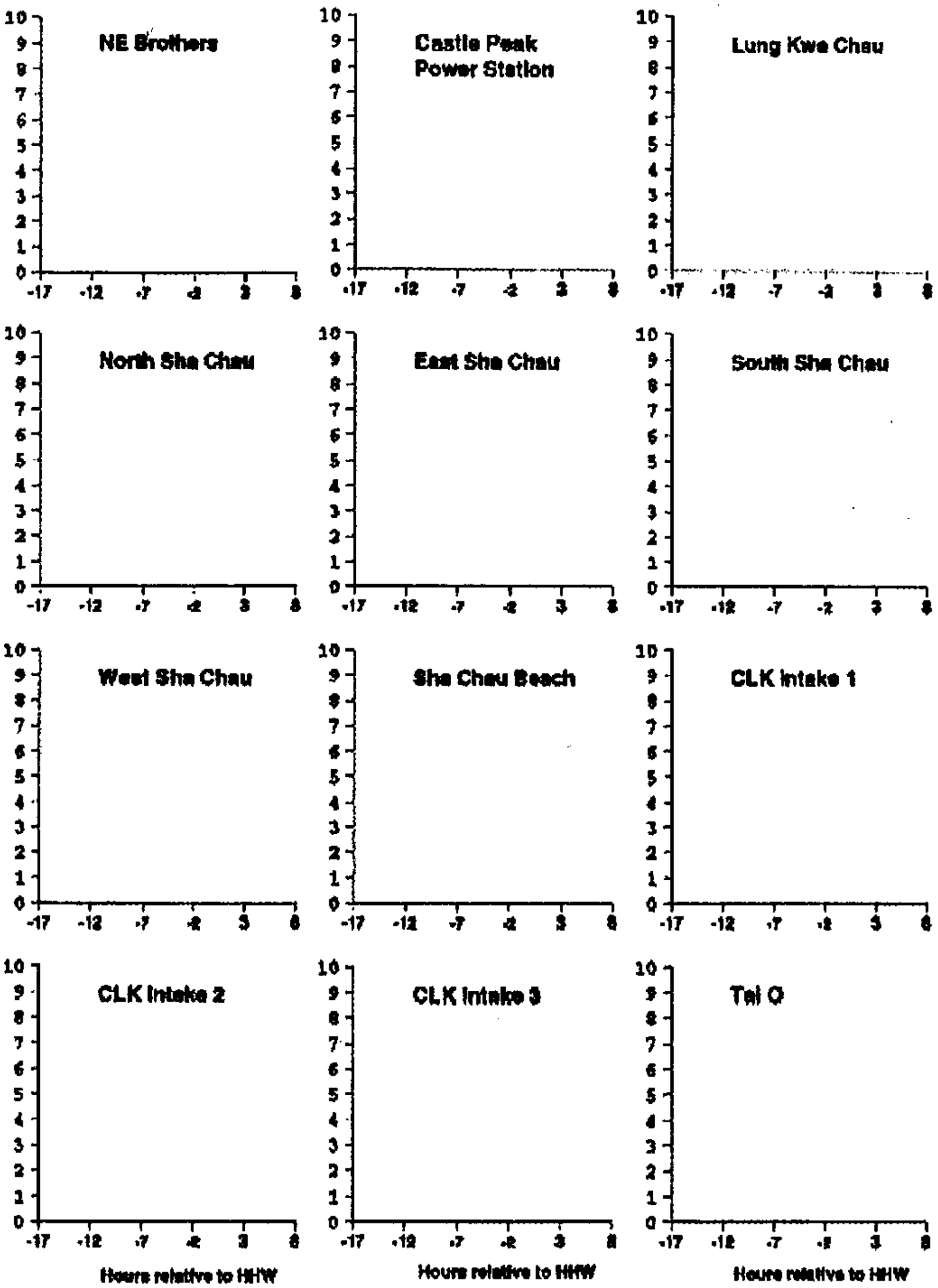

FIGURE E2 - SCENARIO 2: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS OVER THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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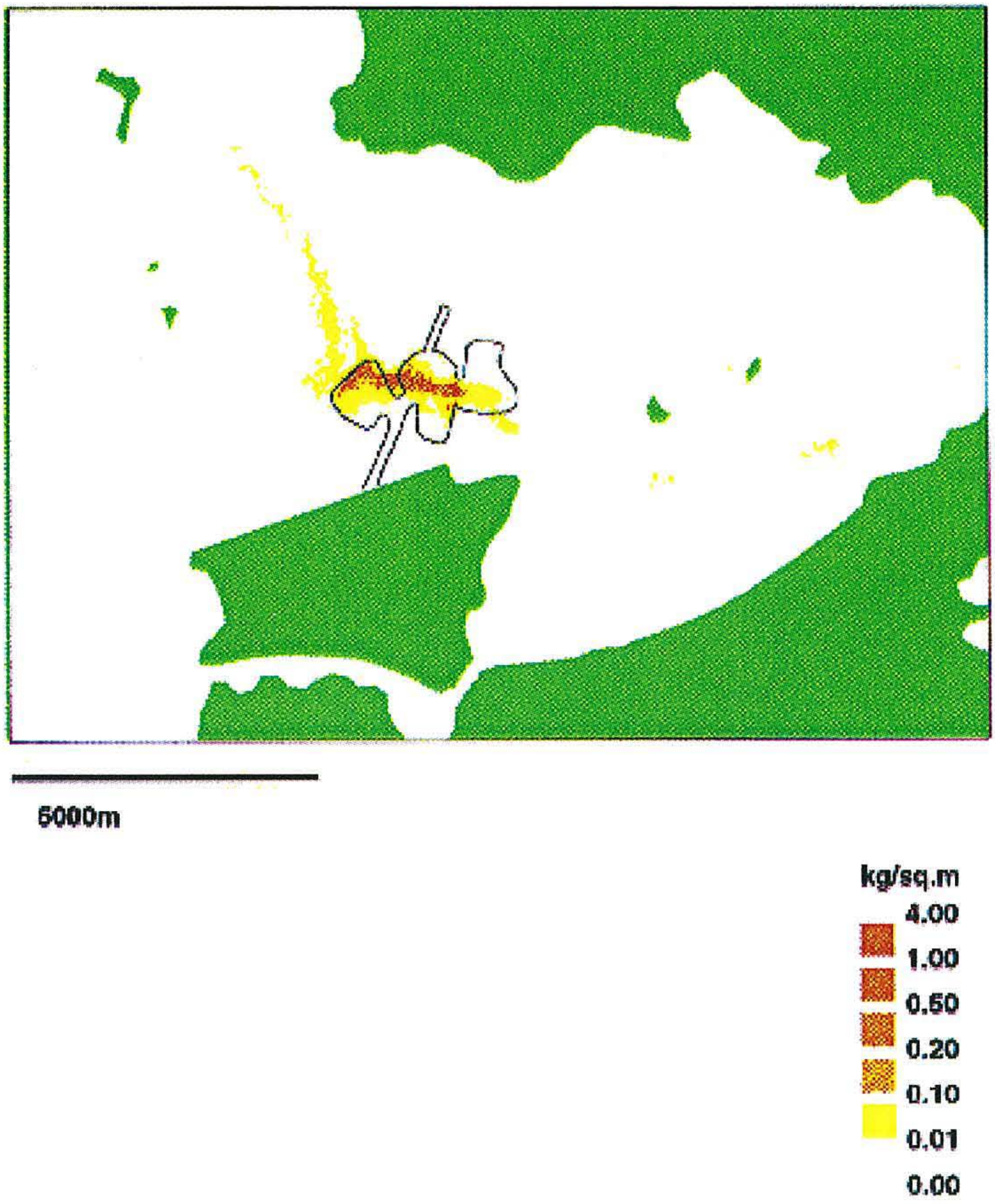

FIGURE E3 - SCENARIO 2: PREDICTED SEDIMENT DEPOSITION PER DAY

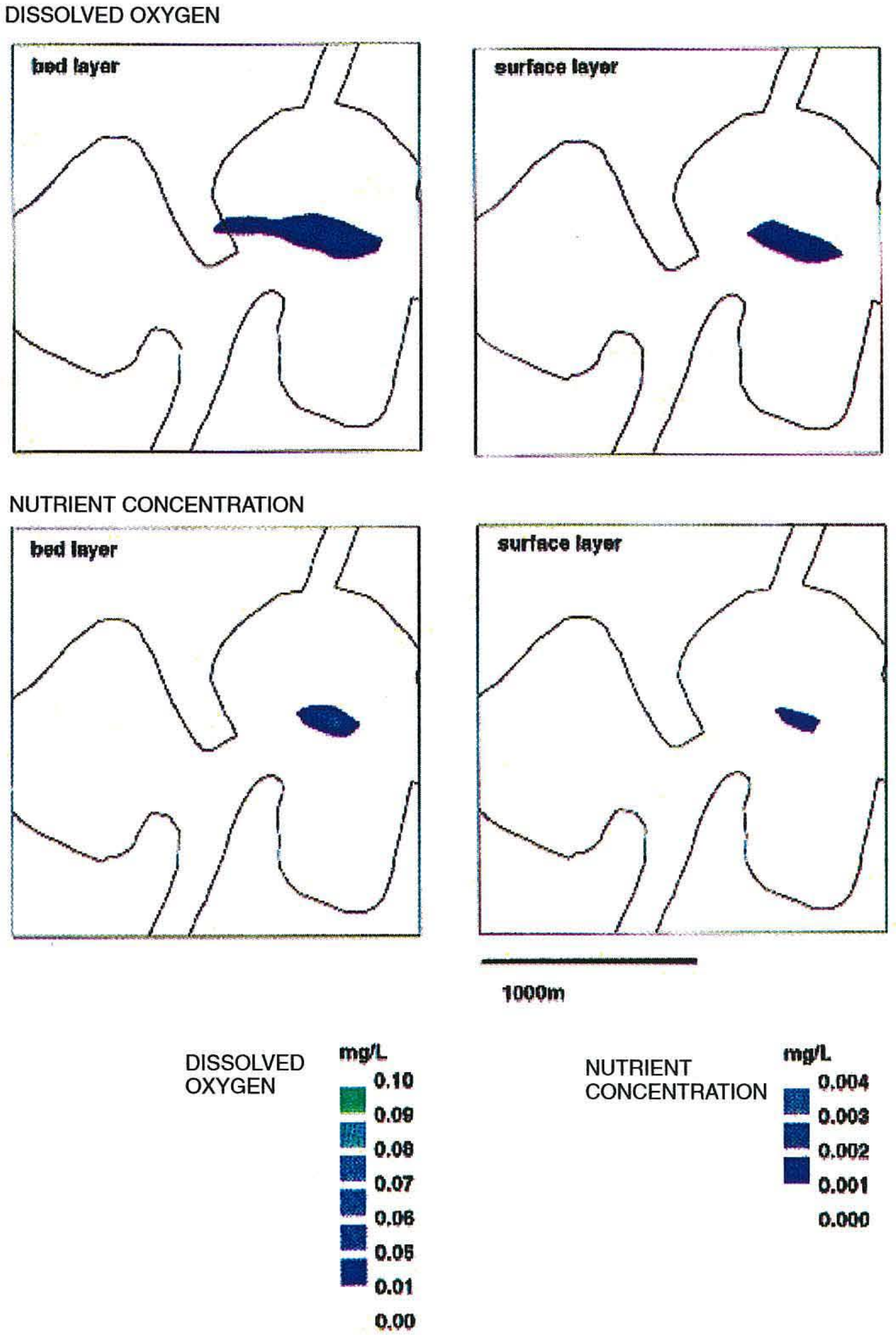

FIGURE E4 - SCENARIO 2: PREDICTED DISSOLVED OXYGEN AND NUTRIENT ELEVATION

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Annex F

Water Quality Modelling Results for Scenario 3

Scenario 3 Results (Annex F)

This scenario is identical to Scenario 1 except for the inclusion of re-erosion during the modelling simulations to provide a conservative prediction of suspended sediments and assess the sensitivity of the modelling results to re-erosion. On the ebb tide, both the pattern of suspended sediment concentration and concentrations to the east of the disposal point are similar in Scenarios 1 and 3. However, in Scenario 3, there are also areas of low suspended sediment (1-10 mg l^{-1}) concentration around the western edges of the pits which are caused by erosion of the material deposited after previous disposal events. On the flood tide, Scenario 3's plume extends slightly further beyond Sha Chau than the plume predicted under Scenario 1. This is due to sediment being re-eroded from the seabed and combining with the sediment already in suspension to form concentrations of 1-10 mg l^{-1}.

Predicted sediment deposition contours indicate the same deposition rates within the Pits as for Scenario 1. However, less sediment is predicted to be deposited outside of the Pits due to re-erosion by tidal currents. This re-eroded sediment appears as additional suspended sediment concentrations in the Scenario 3 plumes. Predicted tidal averaged DO depletion concentration plots and nutrient elevations are very similar to Scenario 1 plots although the areal extent of the DO deficits and nutrient elevations are slightly smaller in Scenario 3.

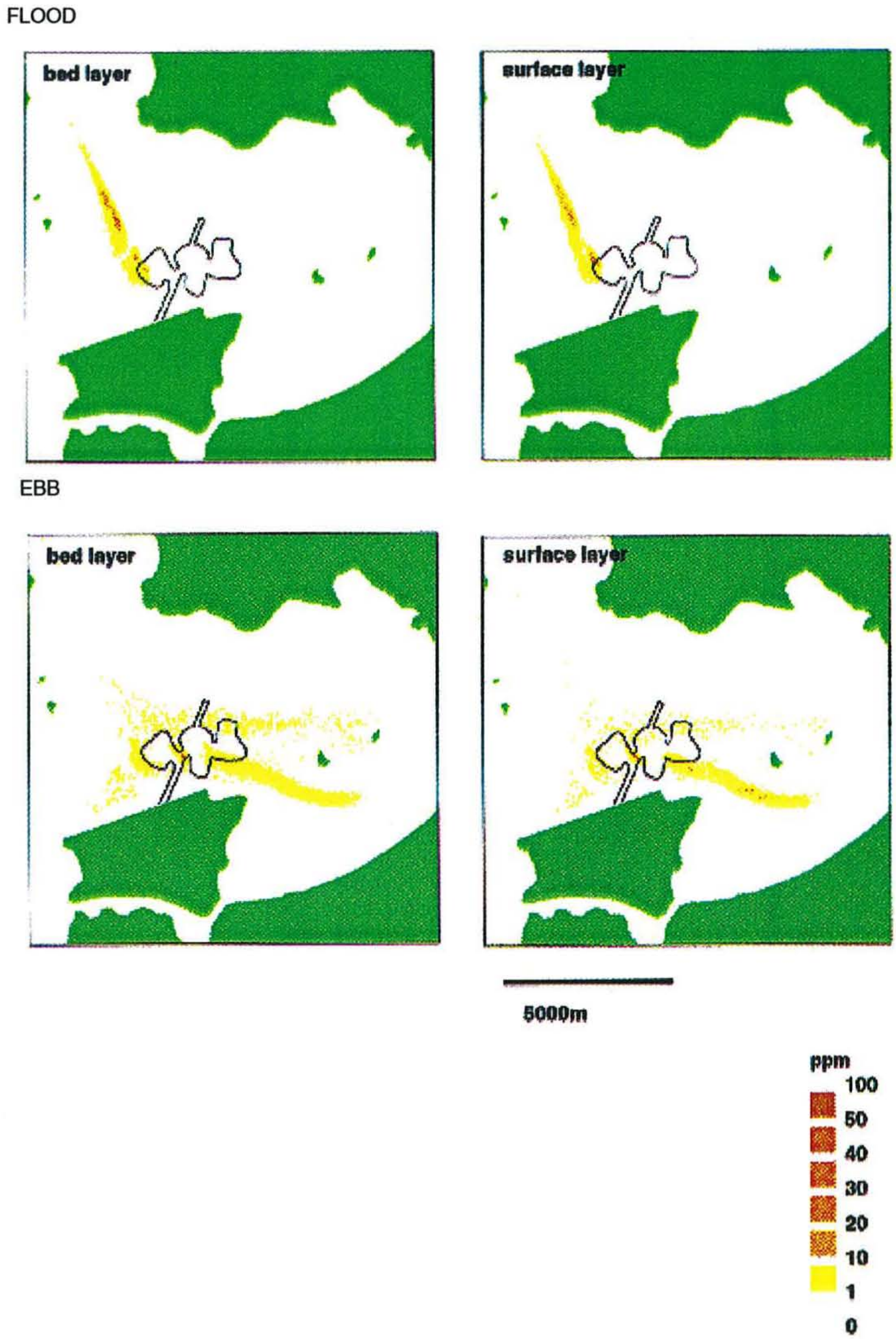

FIGURE F1 - SCENARIO 3: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS AT PEAK FLOOD AND PEAK EBB TIDES

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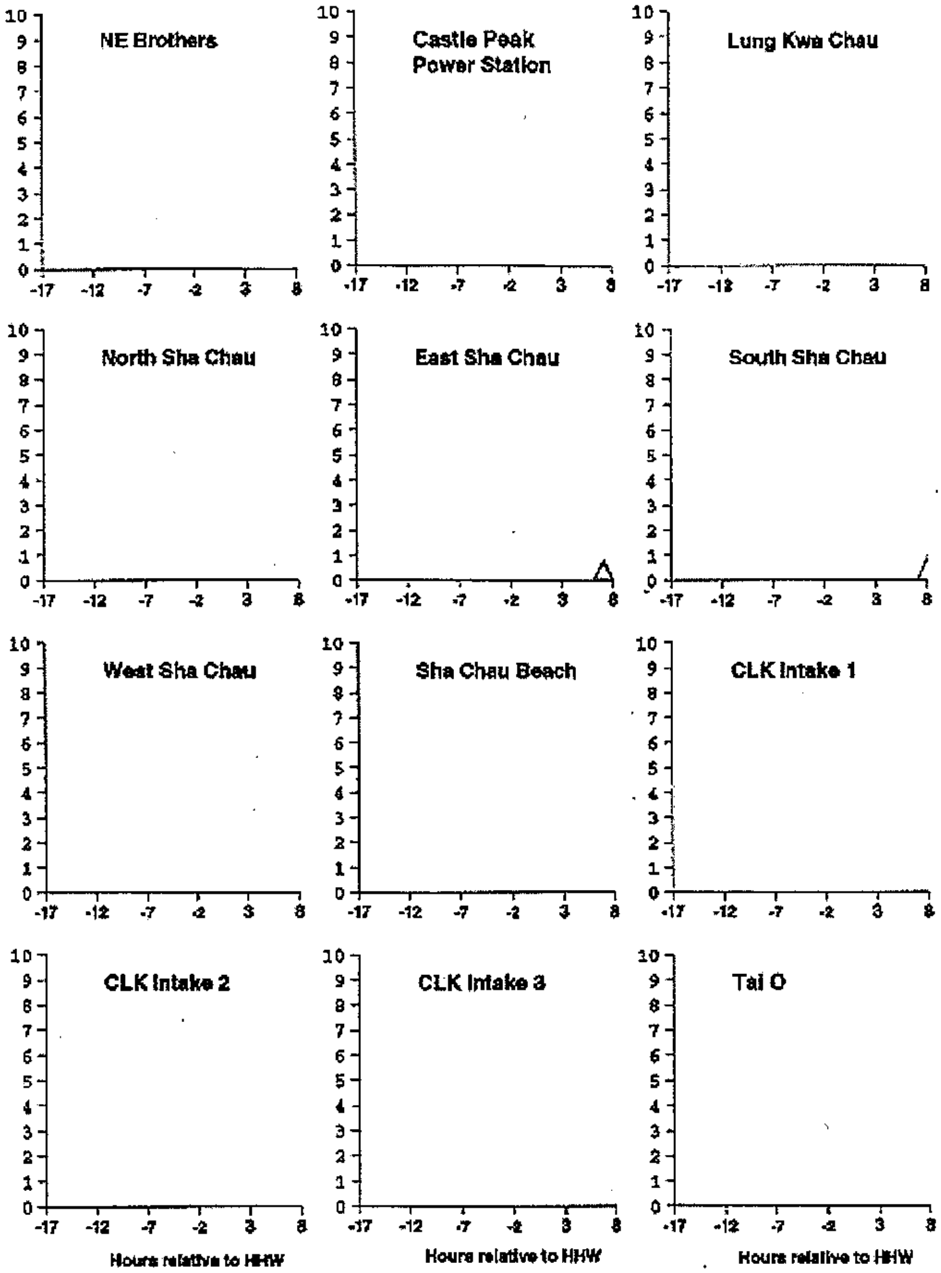

FIGURE F2 - SCENARIO 3: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS OVER THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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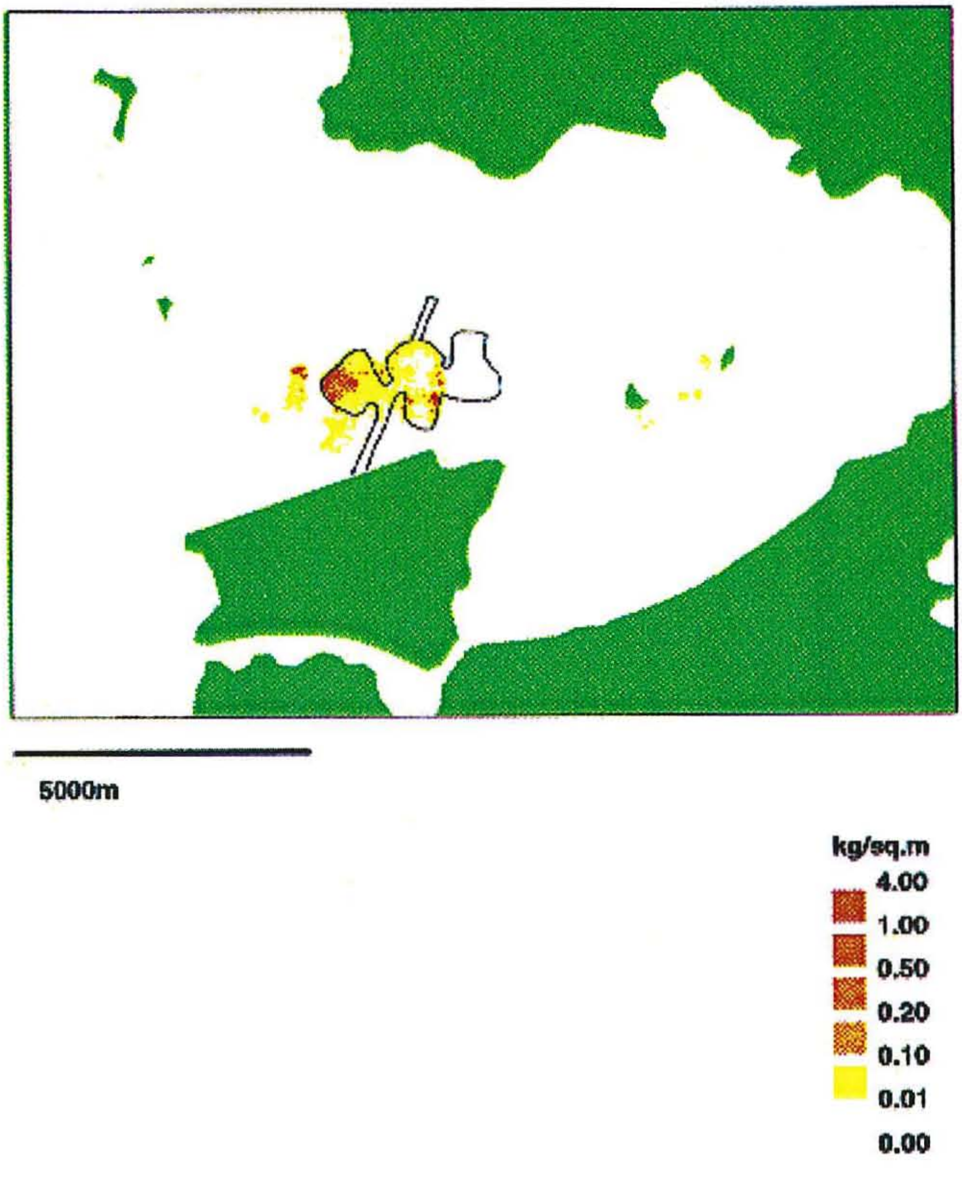

FIGURE F3 - SCENARIO 3: PREDICTED SEDIMENT DEPOSITION PER DAY

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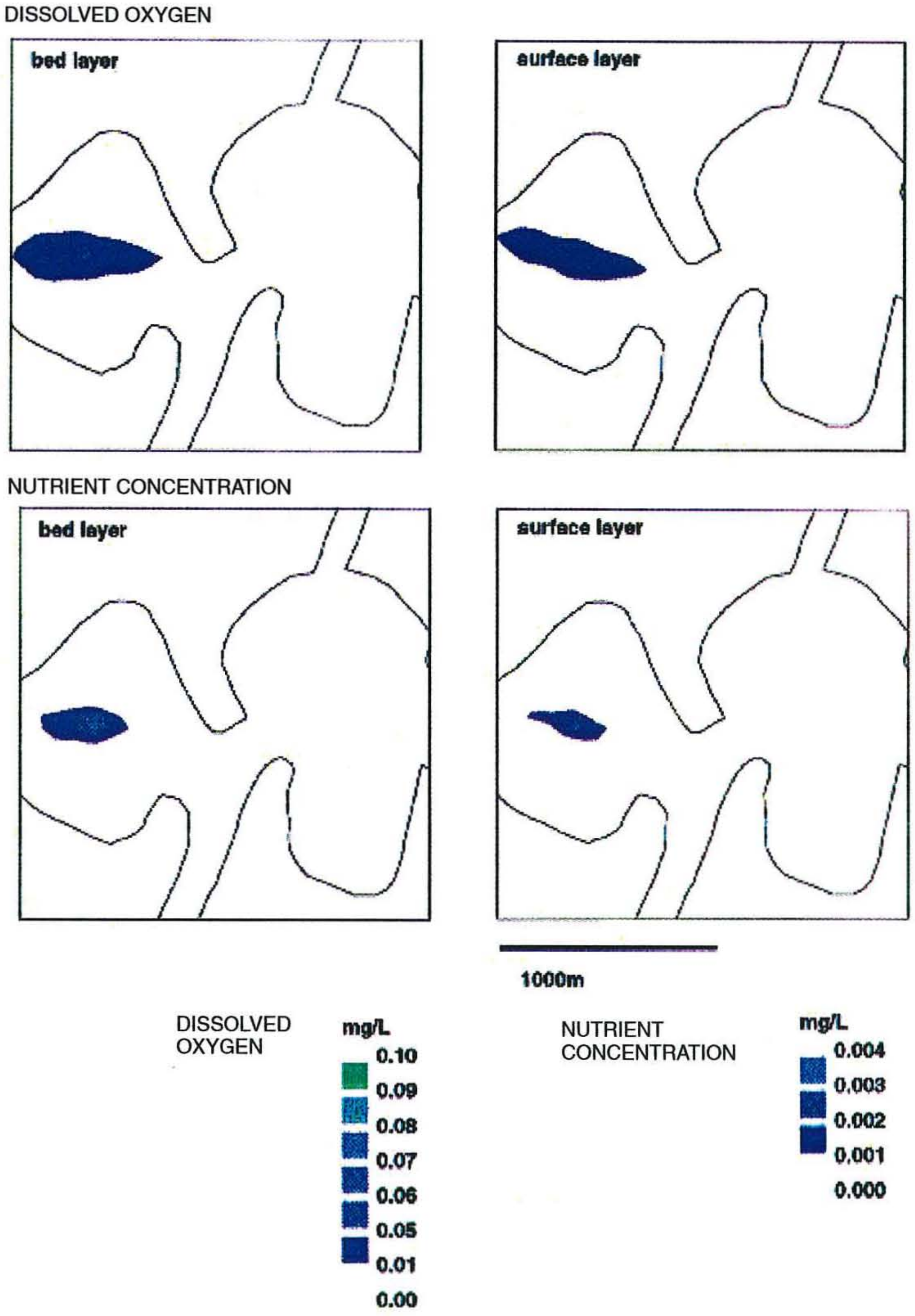

FIGURE F4 - SCENARIO 3: PREDICTED DISSOLVED OXYGEN AND NUTRIENT ELEVATION

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Annex G

Water Quality Modelling Results for Scenario 4

Scenario 4 Results (Annex G)

Scenario 4 modelled the disposal of 16,000 m^3 day^{-1} from trailers at the centre of full pit A on the dry season spring tide. On the flood tide, the plume extends several kilometres to the north of Lung Kwu Chau, with concentrations of up to 5-10 mg l^{-1} in the bed layer and concentrations below 5 mg l^{-1} in the surface layer. On the ebb tide, the plume extends both to the east and the southwest. Both arms of the plume represent a previously modelled disposal event on the ebb phase of the tide which have remained in suspension and are now carried by ebb tidal currents. Because this part of the plume has been carried in suspension for some time, it is more dispersed, covering a relatively large area but at a low concentration (< 5 mg l^{-1}). In the bed layer, suspended sediment concentrations exceed 50 mg l^{-1} in a small area around the eastern edge of CMP IV.

The majority of the deposition occurs close to the release point within the area of Pit A at a maximum value of just under 4 kg m^{-2} day^{-1}. Deposition occurring in the areas outside of the pit will be eroded by wave action and transported away from the area of the pits by the tidal currents. Only the areas closest to the release point (Pit A) are affected by DO depletion, and only the bed layer is impacted outside the Pit at values lower than 0.05 mg l^{-1}. Nutrient concentrations show a similar pattern, with all values smaller than 0.002 mg l^{-1}.

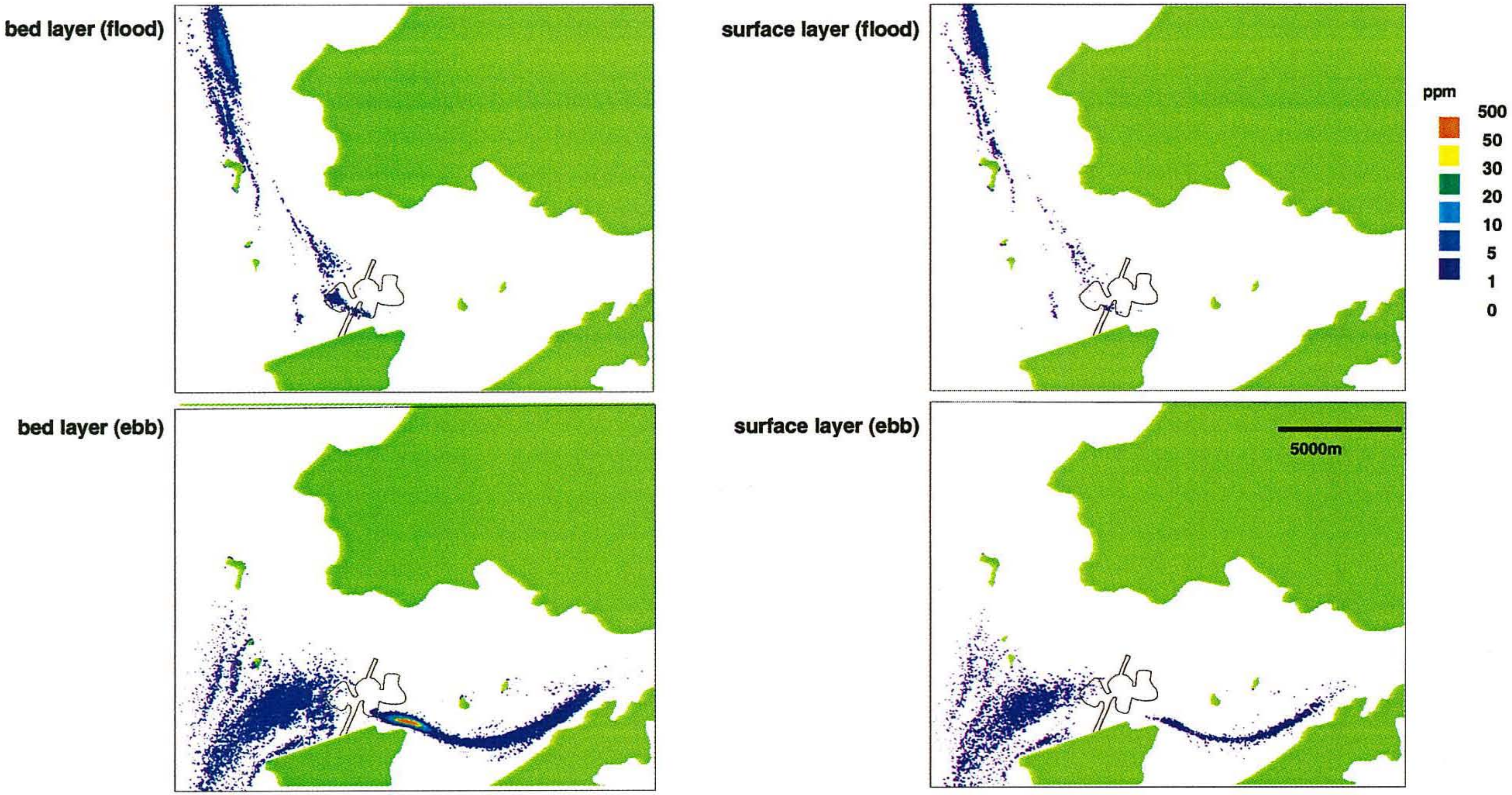

FIGURE G1 - SCENARIO 4: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS AT PEAK EBB AND PEAK FLOOD TIDES

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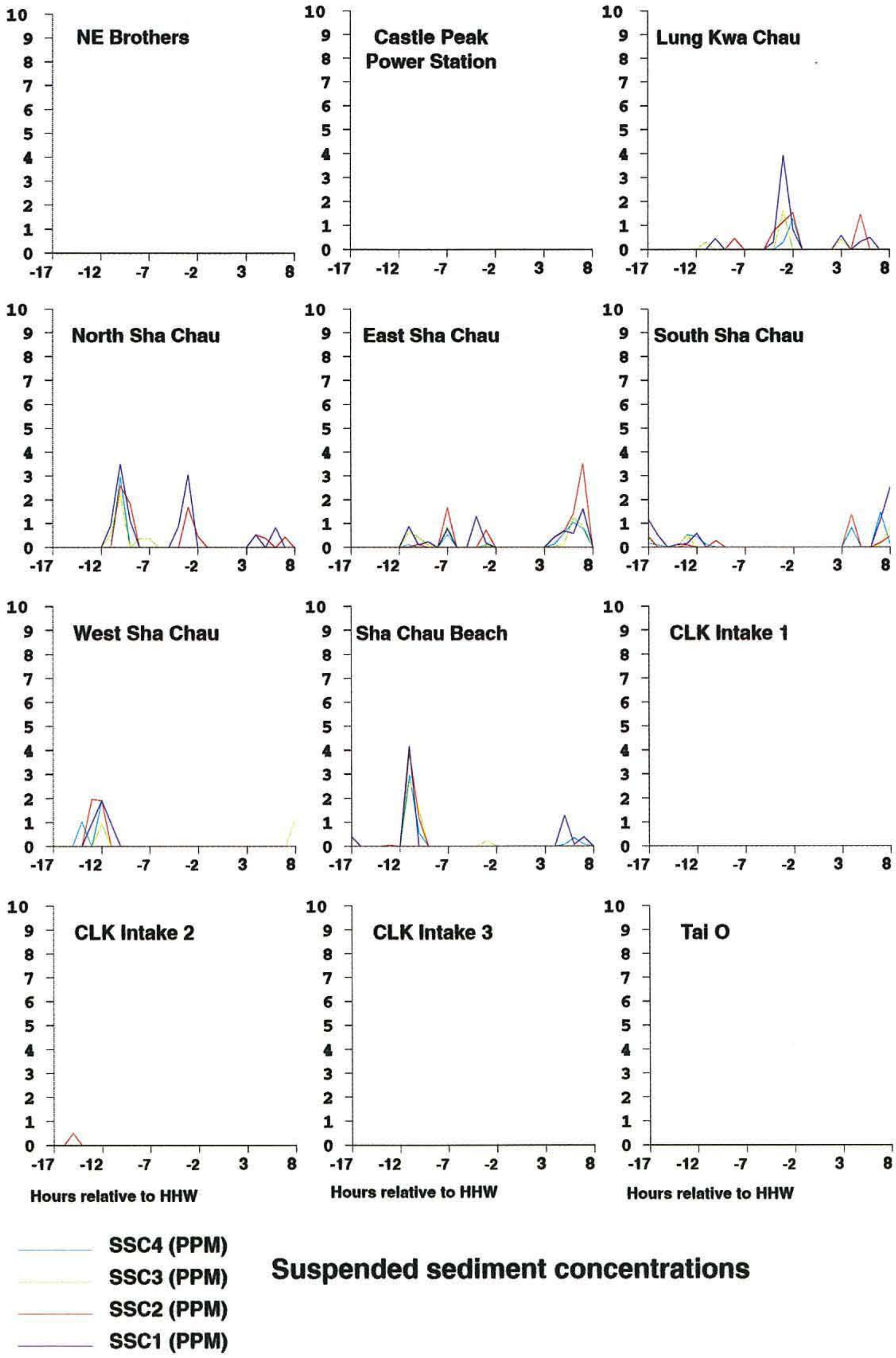

FIGURE G2 - SCENARIO 4: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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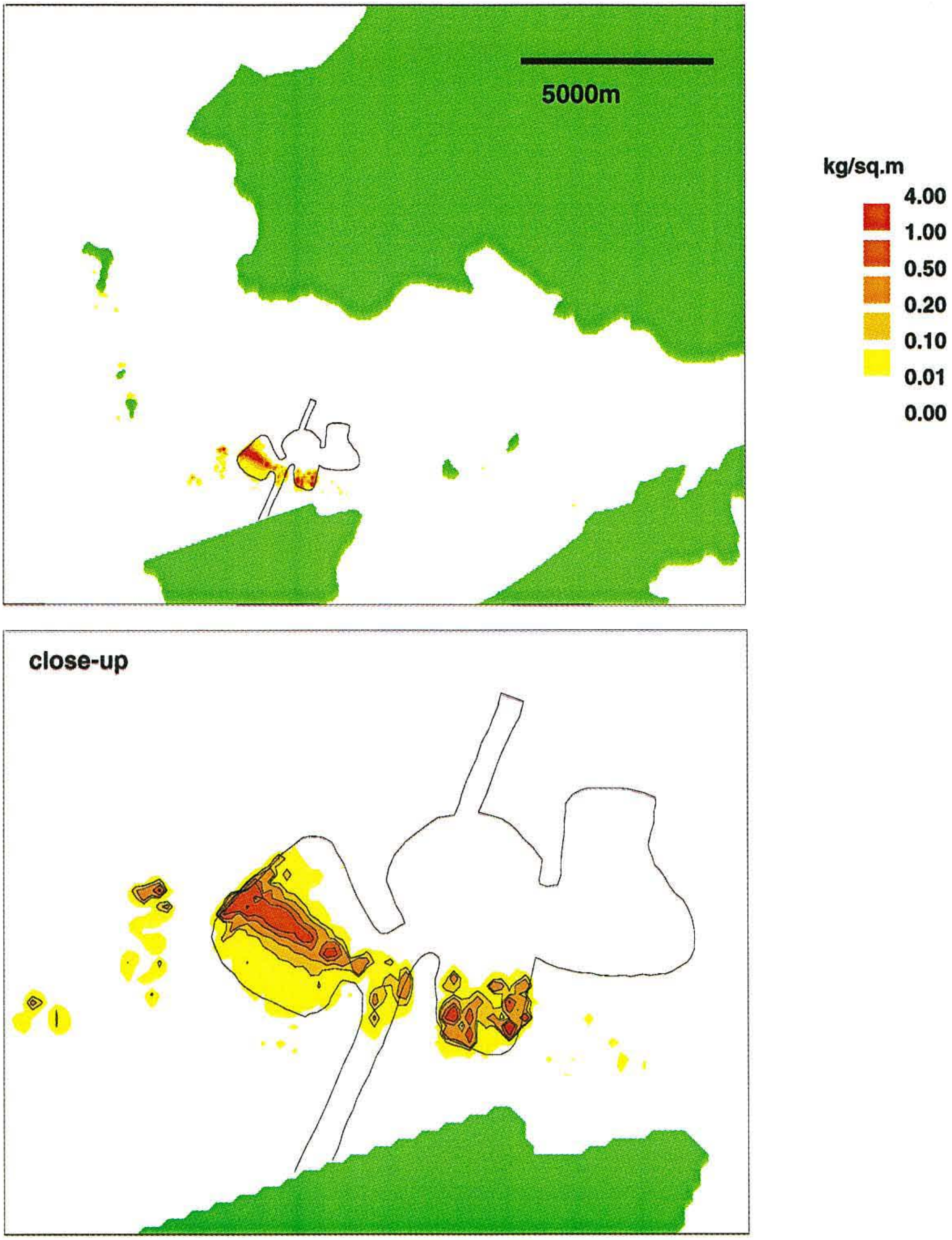

FIGURE G3 - SCENARIO 4: PREDICTED SEDIMENT DEPOSTION PER DAY

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Sensitivity Test for Scenario 4

This sensitivity test modelled Scenario 4 using current speeds in the flow model which had been increased by a factor of 1.25. The contours of suspended sediment concentrations at peak flood show a narrower plume with lower concentrations than was the case in the original Scenario 4. This is because the faster current speeds are causing greater dispersion of the plume and the same quantities of sediment are being spread over a greater distance. The greatest differences between the sensitivity test and the original Scenario 4 are shown on the peak ebb contours of suspended sediment concentrations. The plume, having been transported further to the north, is then carried back on a different path than previously and suspended sediment is shown to the south of Lung Kwu Chau and around Sha Chau. The suspended sediment concentrations shown in the area of Lung Kwu Chau and Sha Chau are a combination of sediment carried in suspension to this area and re-erosion of sediment deposited in this area from previous dumps. The majority of the suspended sediment concentrations in this area are less than 5 mg l^{-1} with small areas of greater than 5 mg l^{-1} but less than 10 mg l^{-1} shown in the bed layer. The main ebb plume, to the south east of Pit A, is shown extending a longer distance than previously and the area of higher concentration close to the north eastern corner of Chek Lap Kok is shown to have increased in size. The apparent increase in size in this area is because the higher current speeds are giving rise to more rapid re-erosion of the deposited sediments.

The contours of net deposition over 1 tidal cycle show reduced deposition within the pit boundaries to the south east of the dump site. This is caused by the higher current speeds on the ebb tide transporting more of the sediment out of the pit before deposition can occur. Outside of the pits the area of deposition shown to the west of Pit A has been reduced in size and magnitude because the higher current speeds have resulted in increased re-erosion in these shallow areas. Also there is reduced deposition shown around Lung Kwu Chau and Sha Chau which is again caused by higher current speeds re-eroding the deposited material. Tidal average dissolved oxygen depletion and nutrient concentrations are similar to Scenario 4 in the surface layer, and over a broader area, but at similar concentrations in the bed layer.

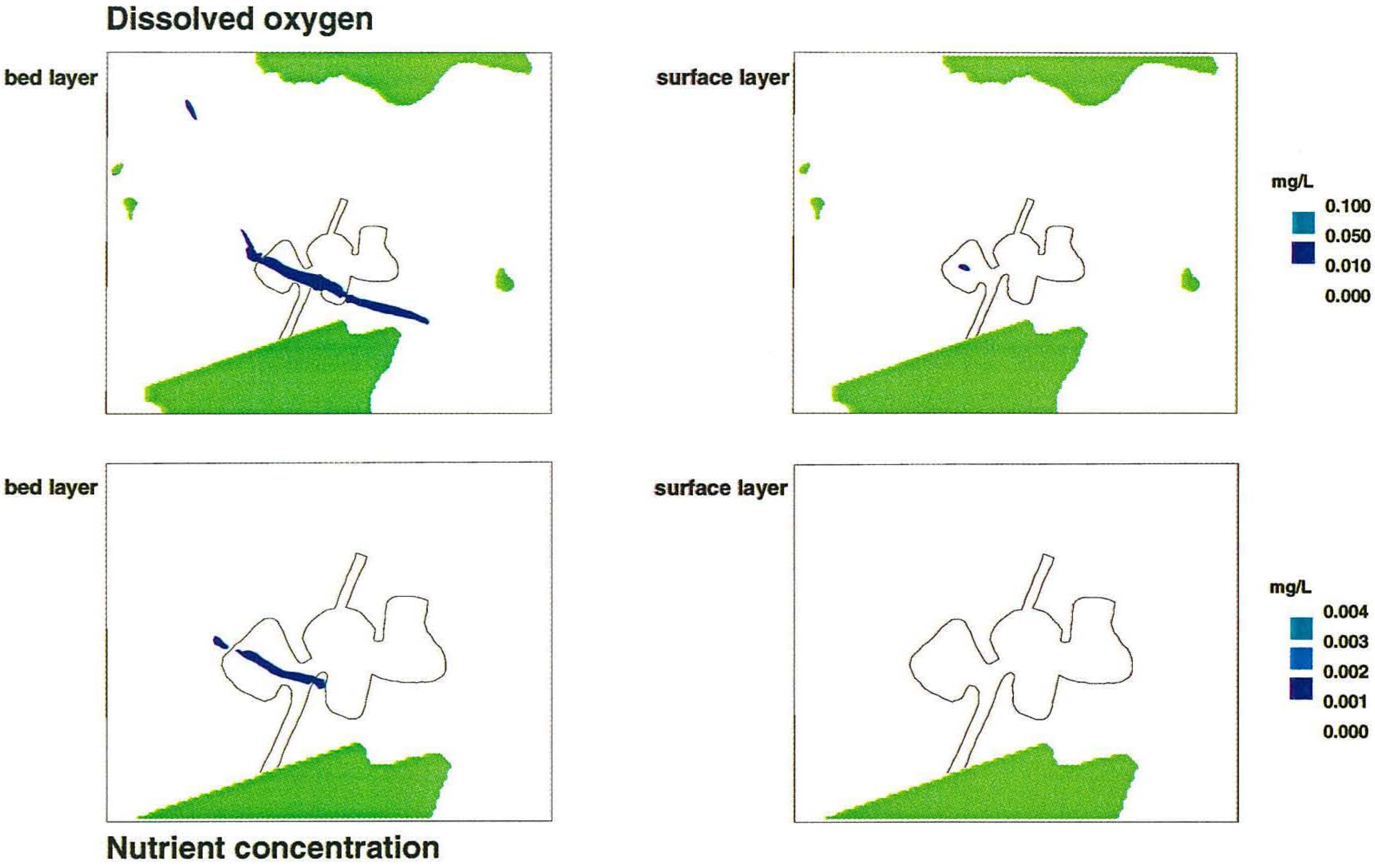

FIGURE G4 - SCENARIO 4: PREDICTED DISSOLVED OXYGEN DEPLETION AND NUTRIENT ELEVATION

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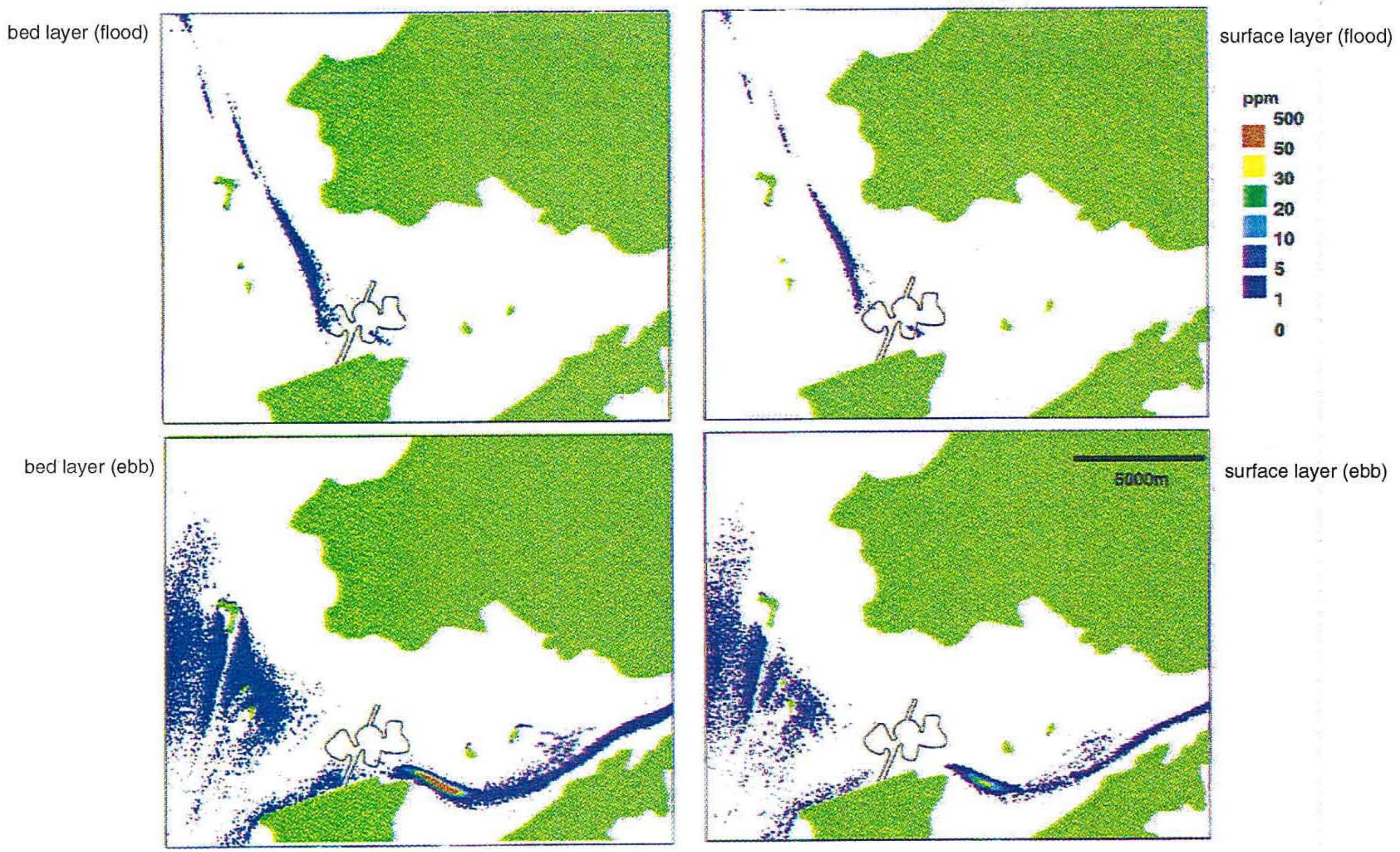

FIGURE G5 - SENSITIVITY TEST FOR SCENARIO 4 : PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS AT PEAK E88 AND PEAK FLOOD TIDES

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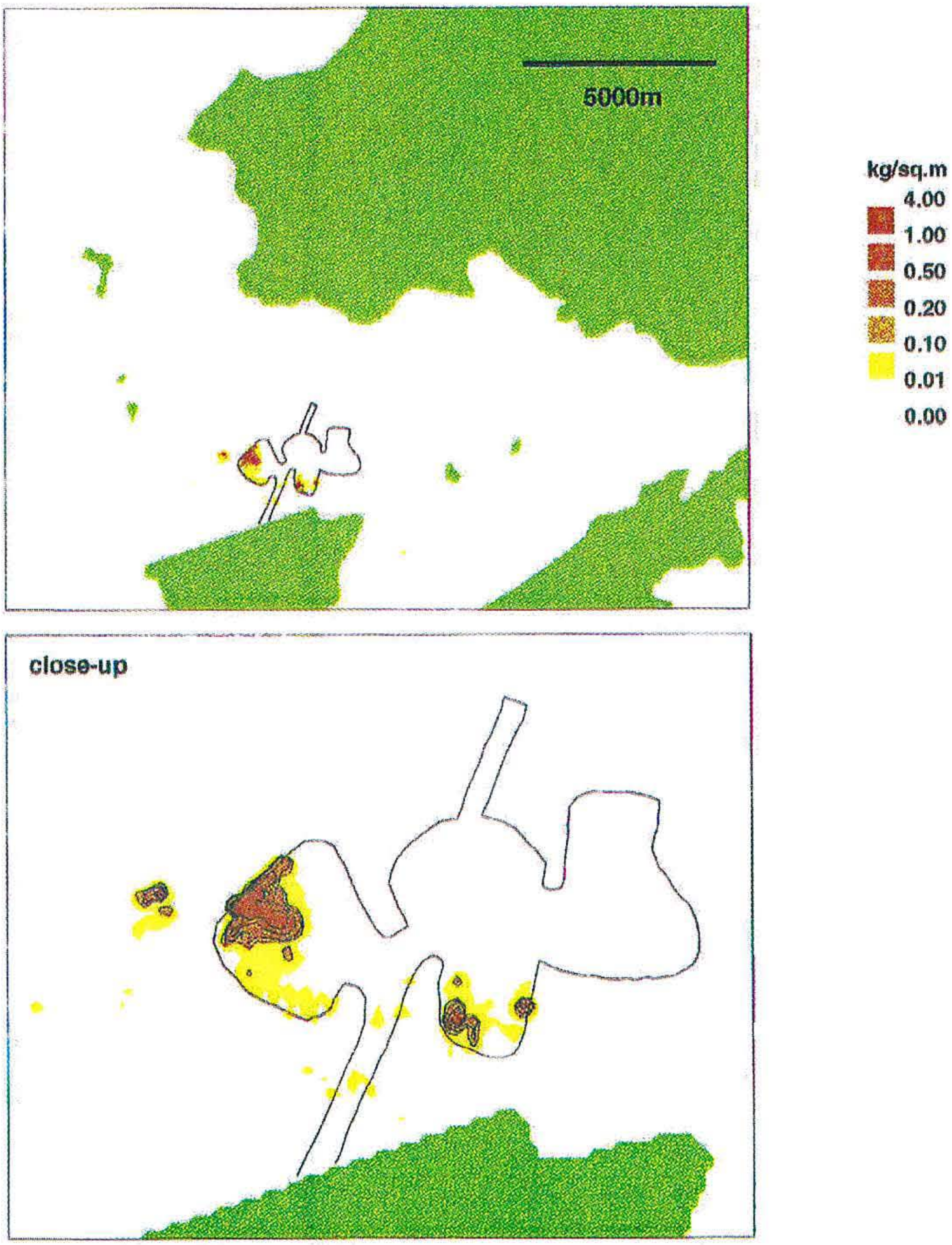

FIGUREG6 - SENSITIVITY TEST FOR SCENARIO 4 - PREDICTED SEDIMENT DEPOSITION PER DAY

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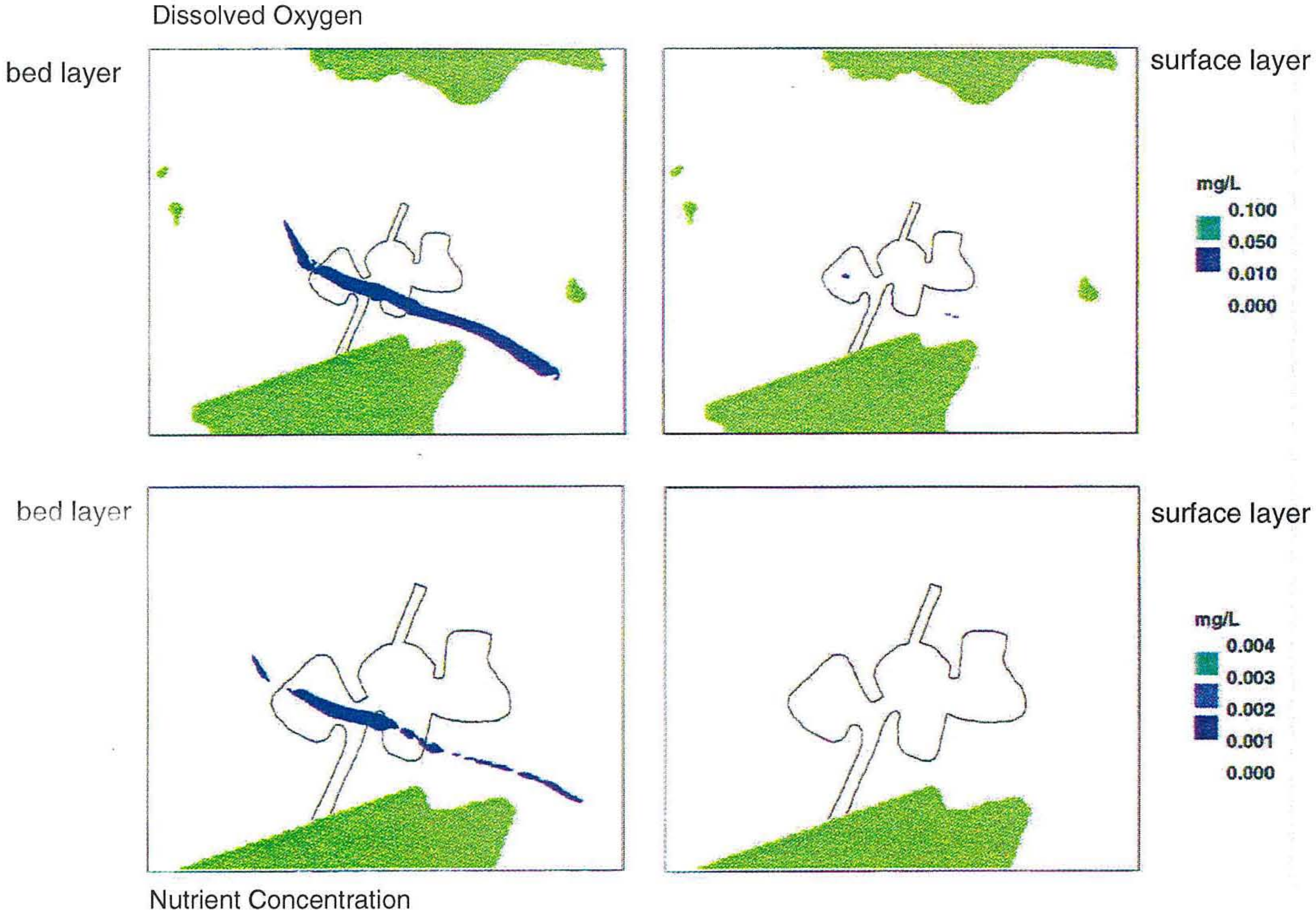

FIGURE G7 - SENSITIVITY TEST FOR SCENARIO 4 : PREDICTED DISSOLVED OXYGEN DEPLETION AND NUTRIENT ELEVATION

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Annex H

Water Quality Modelling Results for Scenario 5

Scenario 5 Results (Annex H)

Scenario 5 consisted of the disposal of 16,000 m^3 day^{-1} of trailer dredged material at the centre of full Pit A on a dry season neap tide. The sediment plume shows a similar general pattern to Scenario 4, but has lower concentrations and covers a smaller area. This is due to slower current speeds on the neap tide which allow a larger proportion of the sediment to settle onto the bed close to the release point and reduce dispersion of sediment which remains in suspension. The effect of turbulent mixing, which acts to spread the sediment through the vertical, is weaker on the neap tide than the spring tide. Therefore, the ratio of near surface concentration to near bed concentration will be lower for the neap tide. Peak concentrations of 30-50 mg l^{-1} occur on the ebb tide in the bed layer close to the south eastern edge of CMP IV.

Sediment deposits in three generalized areas: Pit A (the release point), Pit B and to the west of Pit A. Due to the lower tidal current speeds on the neap tide relative to the spring tide, more deposition occurs in Scenario 5 within the pits than in Scenario 4. The dissolved oxygen deficit exceeds 0.01 mg l^{-1} only in the vicinity of CMP IV and primarily in the bed layer. The predicted increases in nutrient concentrations due to the sediment disposal exceed 0.001 mg l^{-1} only very close to the release point and are always smaller than 0.002 mg l^{-1}.

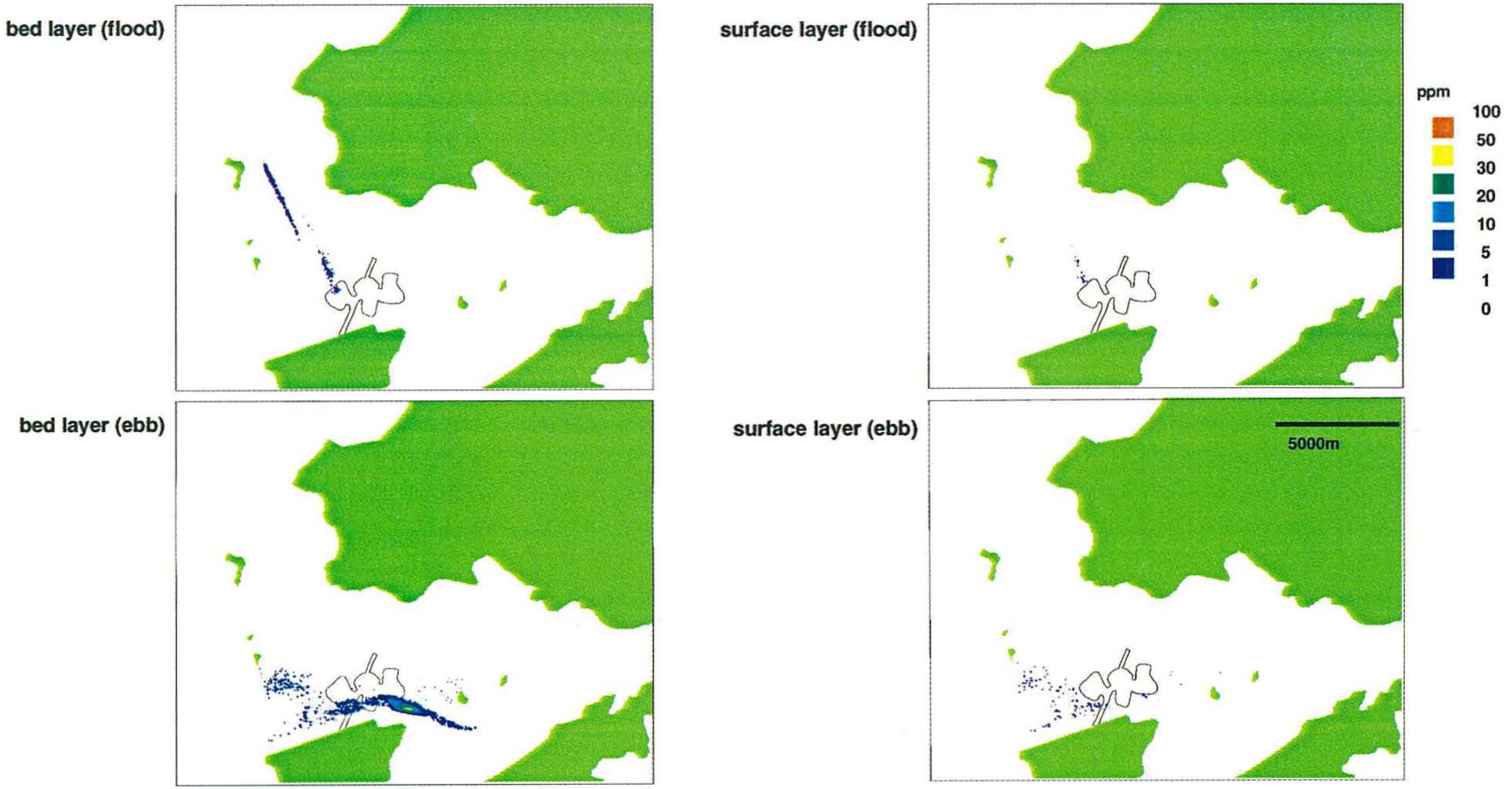

FIGURE H1 - SCENARIO 5: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS AT PEAK EBB AND PEAK FLOOD TIDES

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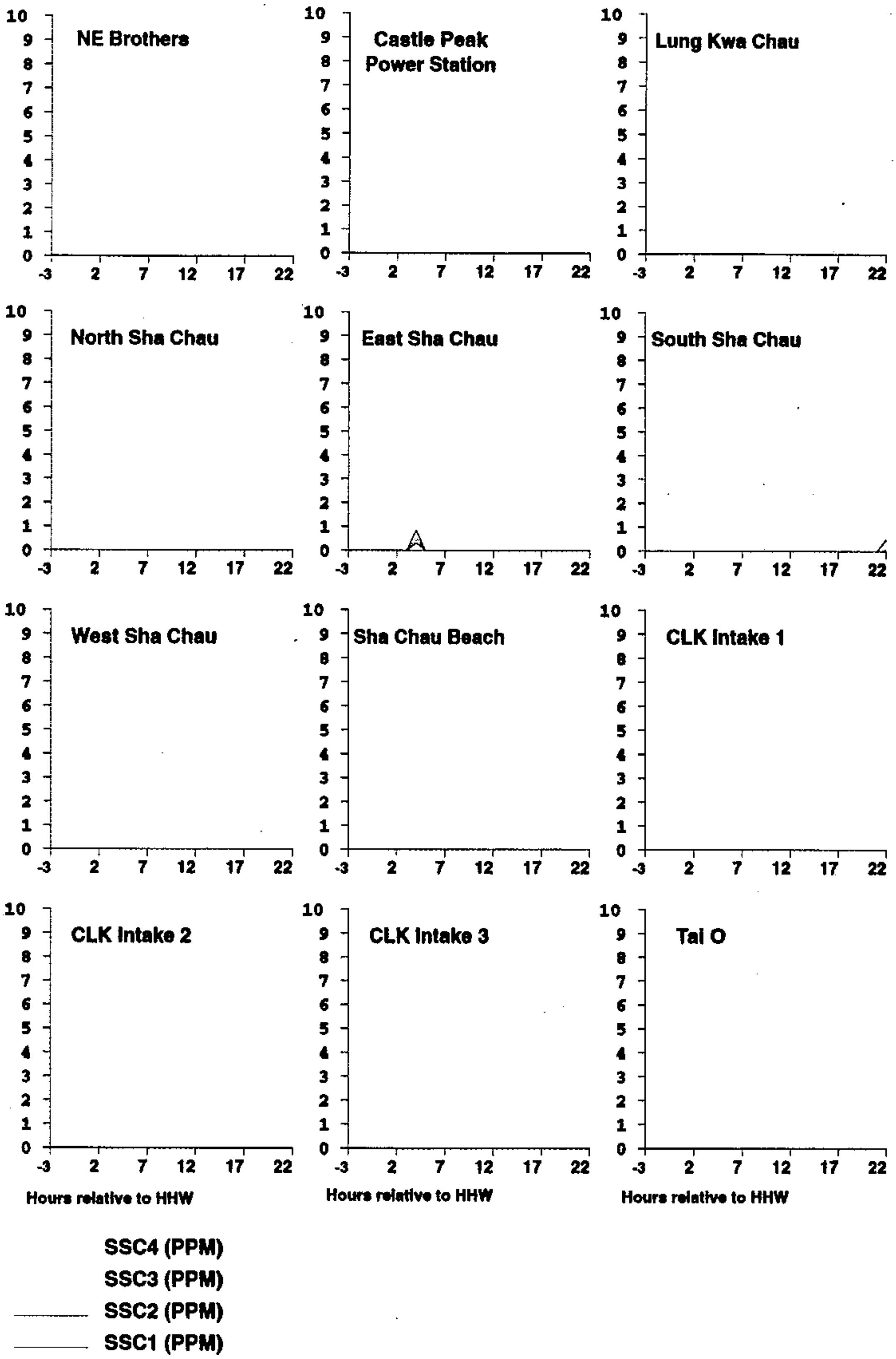

FIGURE H2 - SCENARIO 5: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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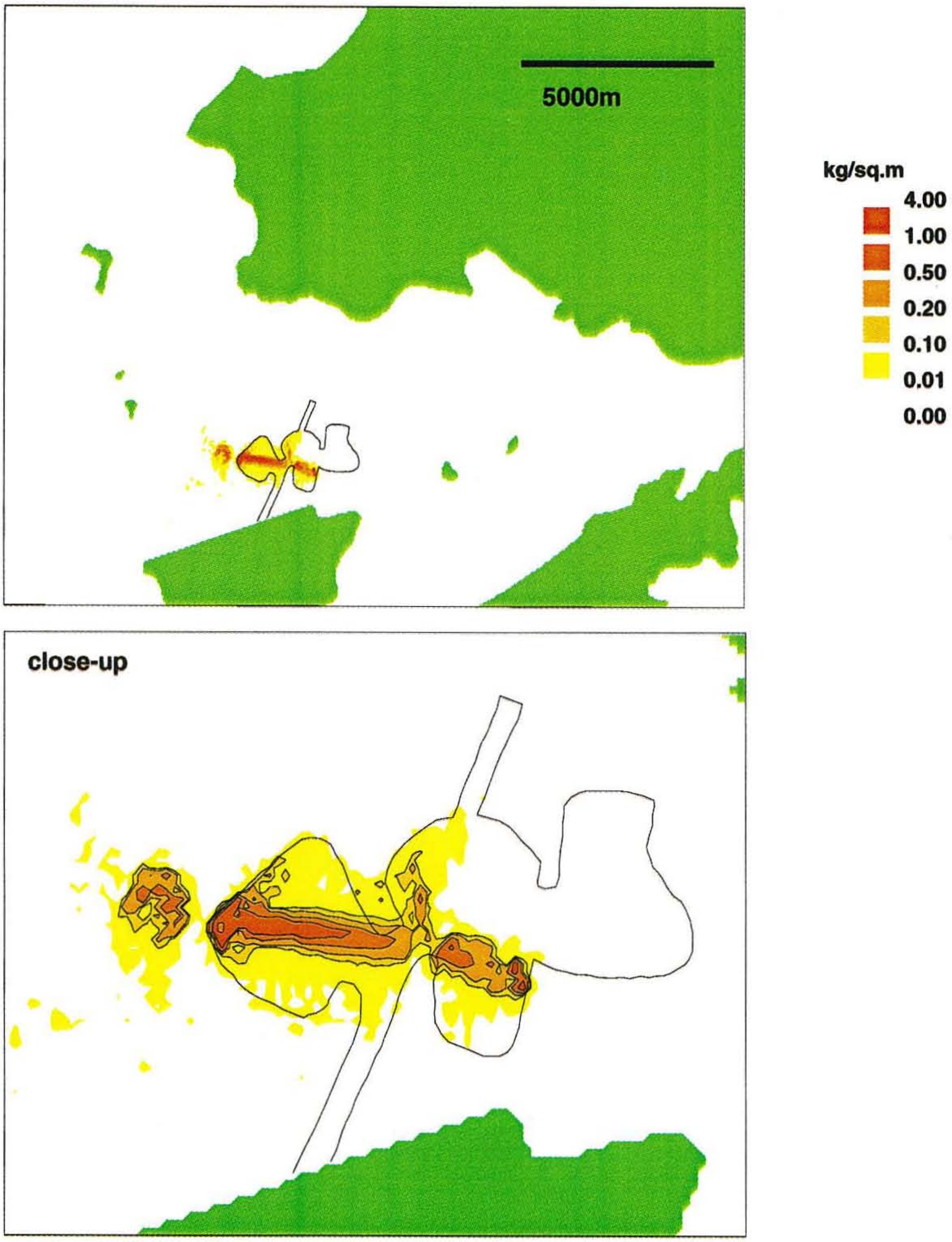

FIGURE H3 - SCENARIO 5: PREDICTED SEDIMENT DEPOSITION PER DAY

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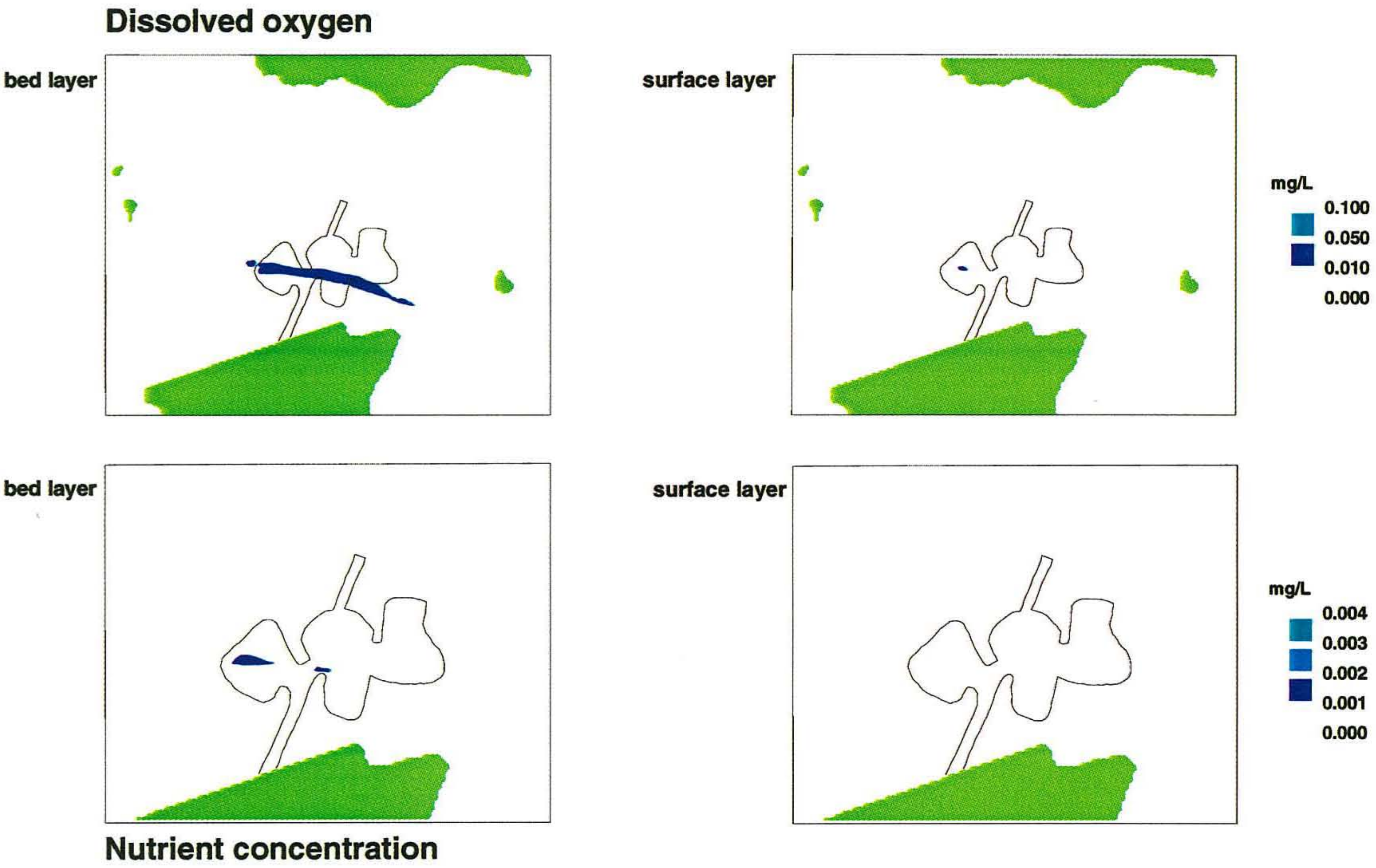

FIGURE H4 - SCENARIO 5: PREDICTED DISSOLVED OXYGEN DEPLETION AND NUTRIENT ELEVATION

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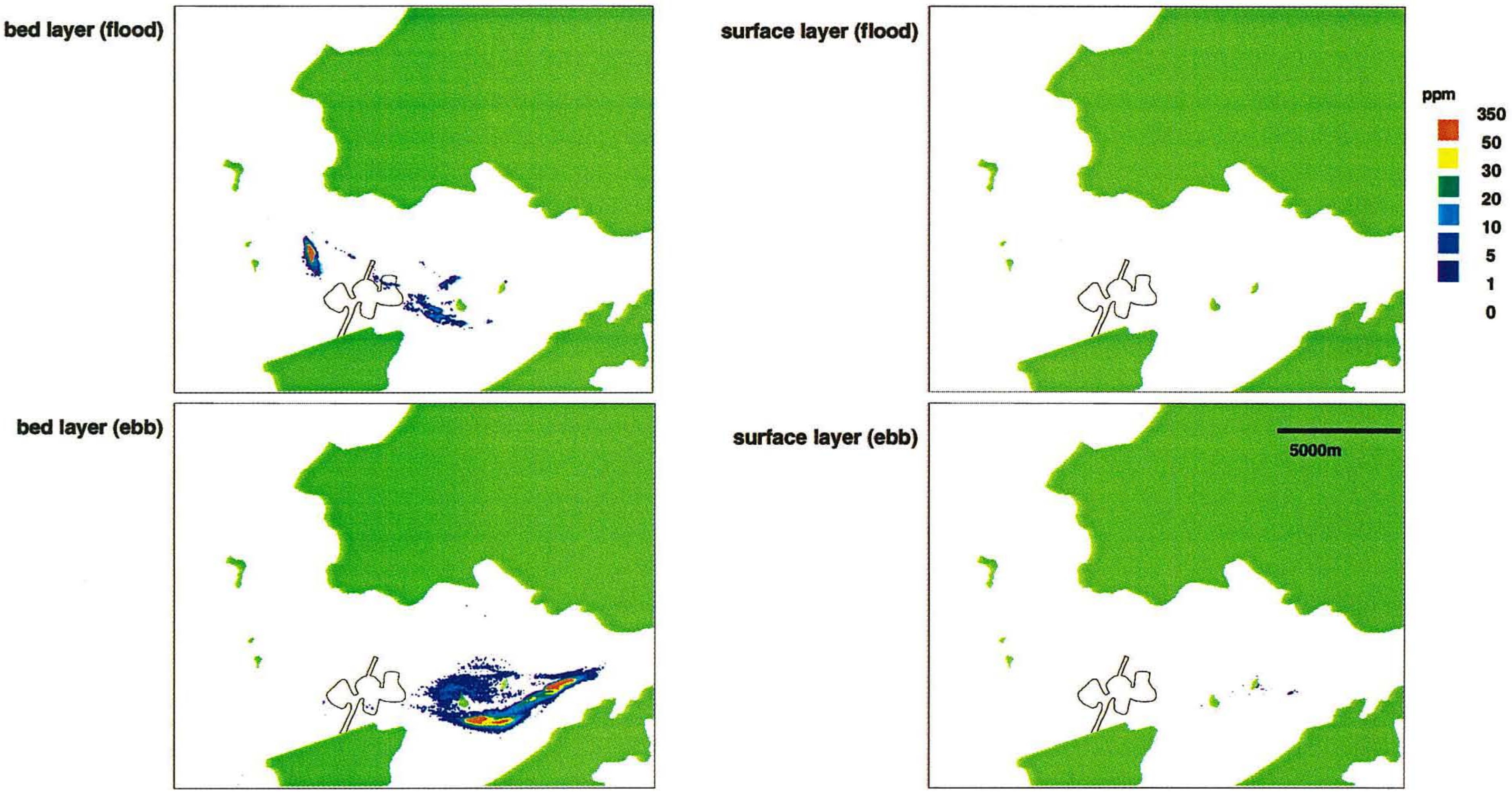
Annex I

Water Quality Modelling Results for Scenario 6

Scenario 6 Results (Annex I)

Scenario 6 consisted of the disposal of 16,000 m^3 day^{-1} of trailer dredged material at the centre of full Pit A on a wet season spring tide. The majority of the suspended sediment is found in the near bed layer due to the interaction of the gravitational settling and turbulent mixing due to tidal currents. In the wet season, stratification of the water column into a saline near bed layer and fresher near surface layer inhibits vertical turbulent mixing and exaggerates the tendency for suspended sediment concentrations to be higher near the bed. On the flood tide, the near bed concentrations show a plume extending north west towards Lung Kwu Chau, with a maximum concentration in the range 20-30 mg l^{-1}. On the ebb, the bed layer plume extends both north and south of the Brothers with a secondary high concentration area at its eastern tip (50-150 mg l^{-1}) arising from earlier modelled releases which have not been fully dispersed or settled to the bed by this time.

The majority of sediment deposits are formed in Pit A (<4 kgm^{-2} day^{-1}), with a secondary deposits in Pit B. Small areas of deposition, with a low mean deposition rates (< 0.20 kgm^{-2} day^{-1}) occur around the Brothers as sediment settles out of the dispersing plume during periods of slack water. DO depletion values exceed 0.01 mg l^{-1} only in the immediate area of the release point. Near bed values of DO depletion are higher than those near the surface, reflecting the pattern of suspended sediment concentration. The nutrient concentration elevations show a similar pattern with only a small area around Pit A exceeding 0.001 mg l^{-1} and all values are smaller than 0.002 mg l^{-1}.


bed layer (flood)

surface layer (flood)

bed layer (ebb)

surface layer (ebb)

FIGURE I1 - SCENARIO 6: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS AT PEAK EBB AND PEAK FLOOD TIDES

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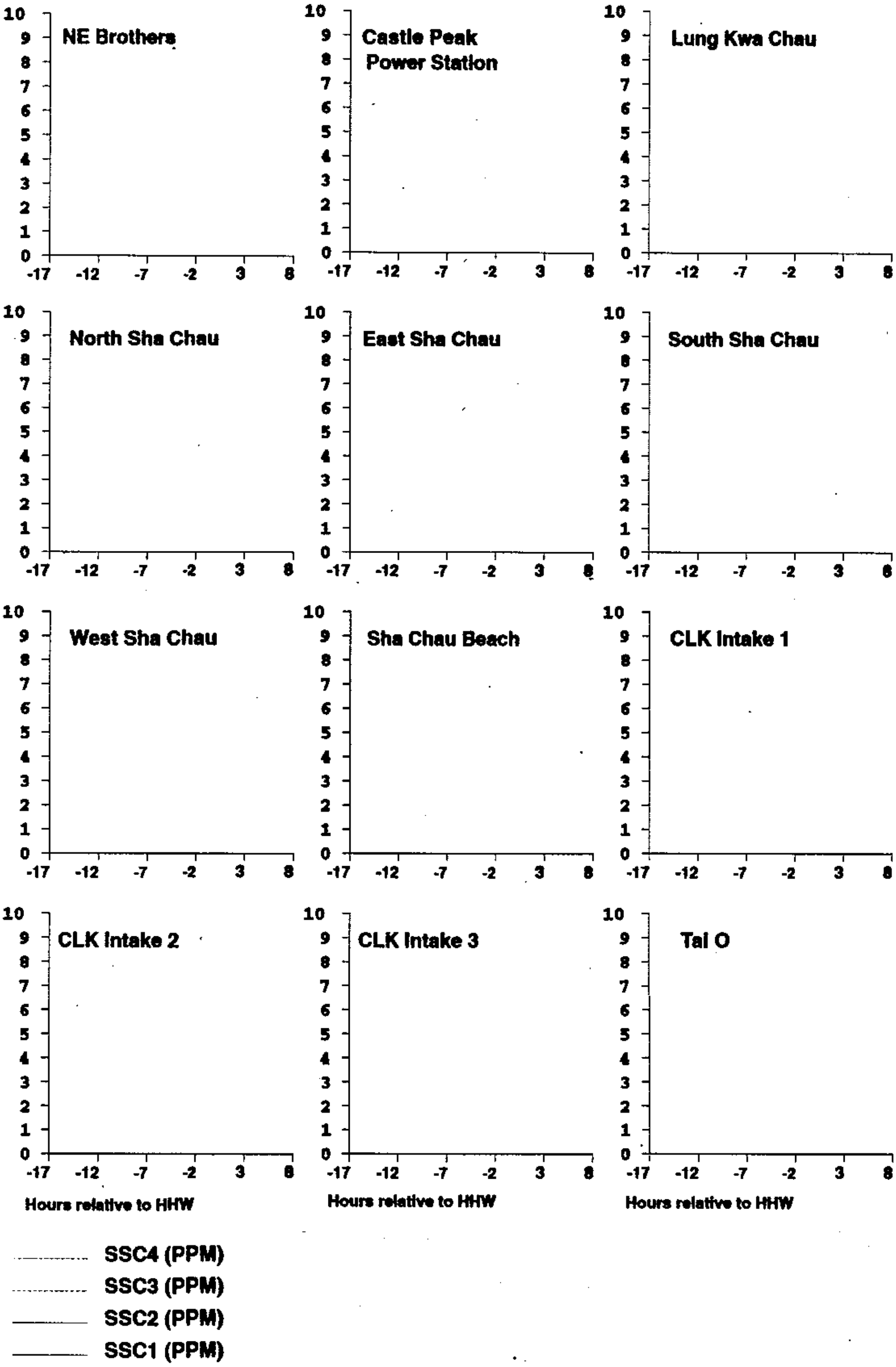

FIGURE I2 - SCENARIO 6: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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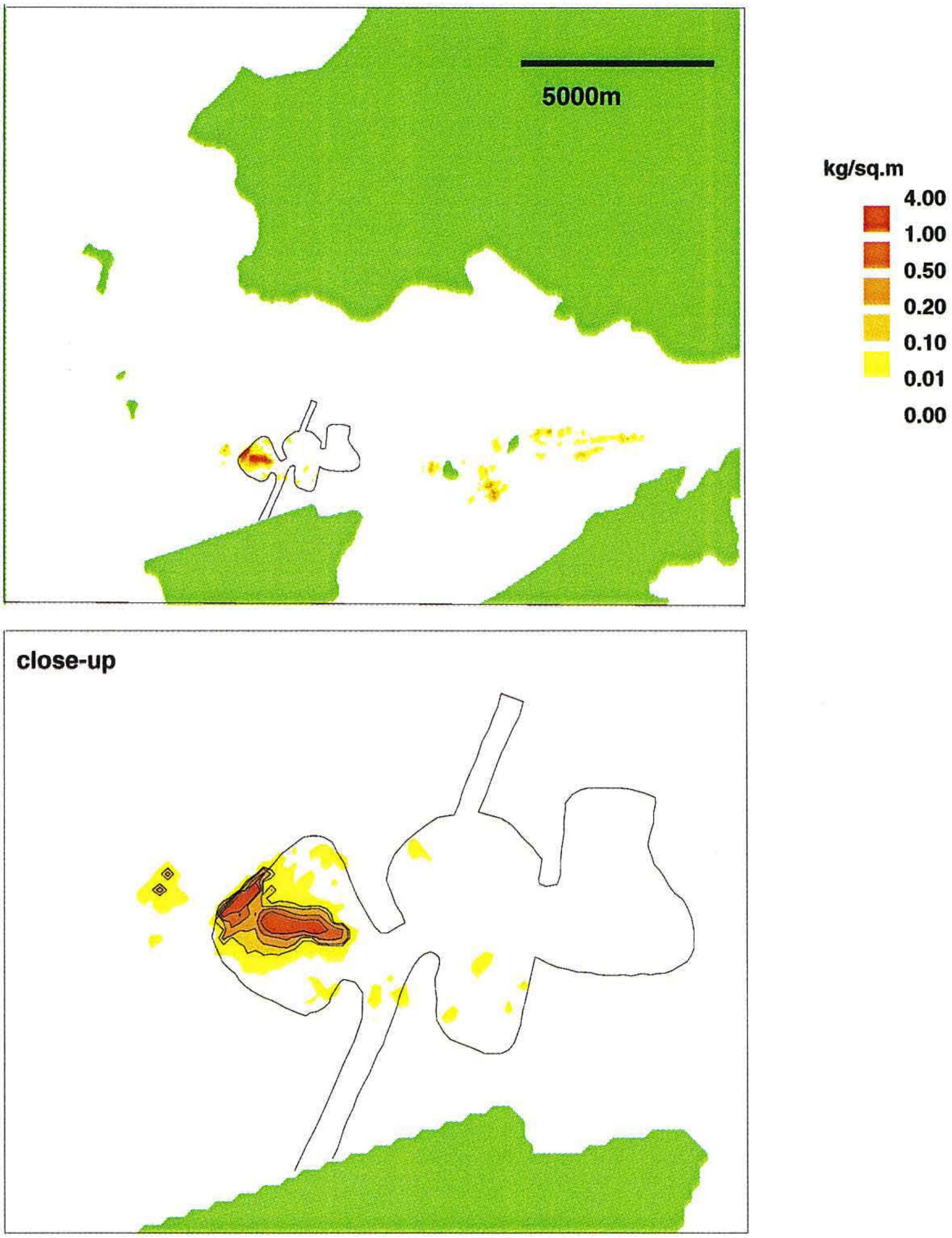

FIGURE I3 - SCENARIO 6: PREDICTED SEDIMENT DEPOSTION PER DAY

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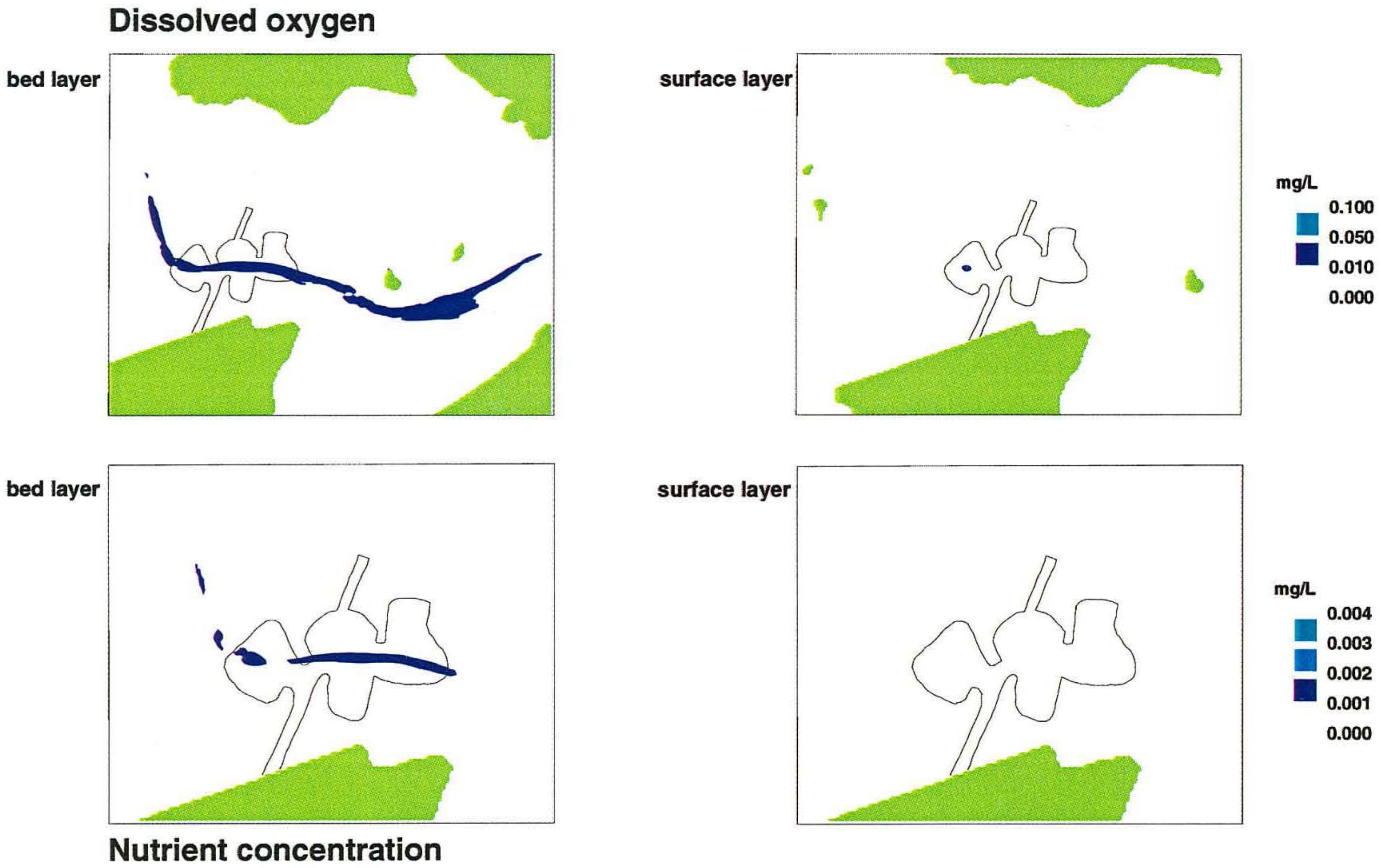
Dissolved oxygen

Nutrient concentration

FIGURE I4 - SCENARIO 6: PREDICTED DISSOLVED OXYGEN DEPLETION AND NUTRIENT ELEVATION

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Annex J

Water Quality Modelling Results for Scenario 7

Scenario 7 (Annex J)

Scenario 7 consisted of a backfilling rate of 16,000 m^3 day^{-1} trailer dredged material with disposal at full Pit A on the wet season neap tide. As with the wet season spring tide (Scenario 6) very little suspended sediment remains in the surface layer. This effect is more pronounced on the wet season neap tide than on the wet season spring tide because the current speeds are lower. On the flood tide, a small plume is transported north west from the disposal site at concentrations ranging from 50-150 mg l^{-1}. The other scattered parts of the plume correspond to earlier disposal events which have not yet been fully dispersed or settled onto the bed. On the ebb tide, the main part of the plume is found in the southeastern part of Pit B at peak concentrations of 50 mg l^{-1}. The secondary plume further to the northeast extends past the Brothers and originates from the modelled disposal event on the previous flood tide.

The majority of the sediment settles in the area of Pit A and Pit B, with a peak deposition rate of less than 5 $kgm^{-2}day^{-1}$. A low proportion of disposed material forms small patches of deposits to the west of Pit A and to the southeast of Pit C. The spatial extent of dissolved oxygen depletions (peak of 0.05 mg l^{-1}) and nutrient elevations (maximum of 0.003 mg l^{-1}) are almost entirely contained within the area of CMP IV.

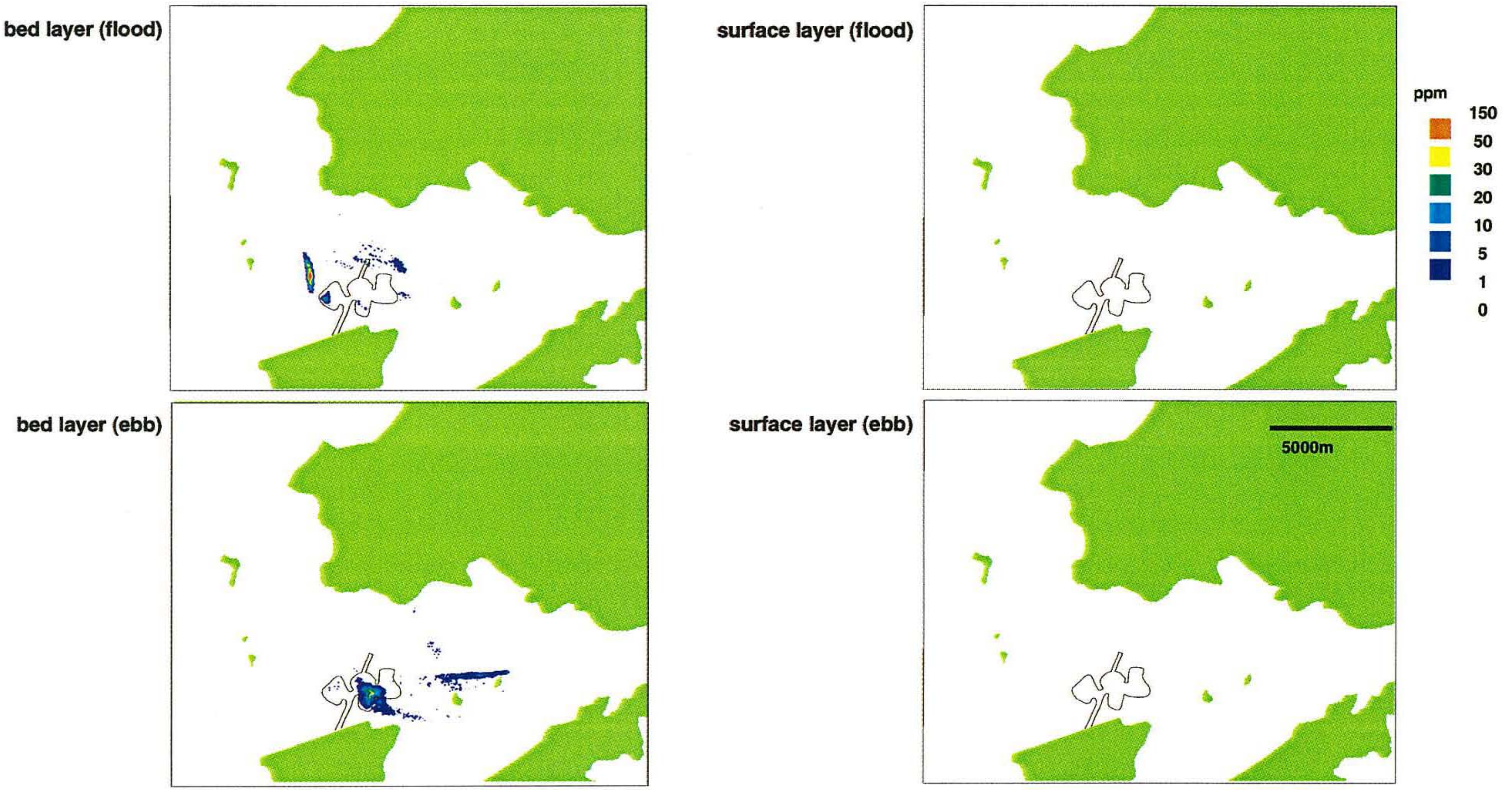

FIGURE J1 - SCENARIO 7: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS AT PEAK EBB AND PEAK FLOOD TIDES

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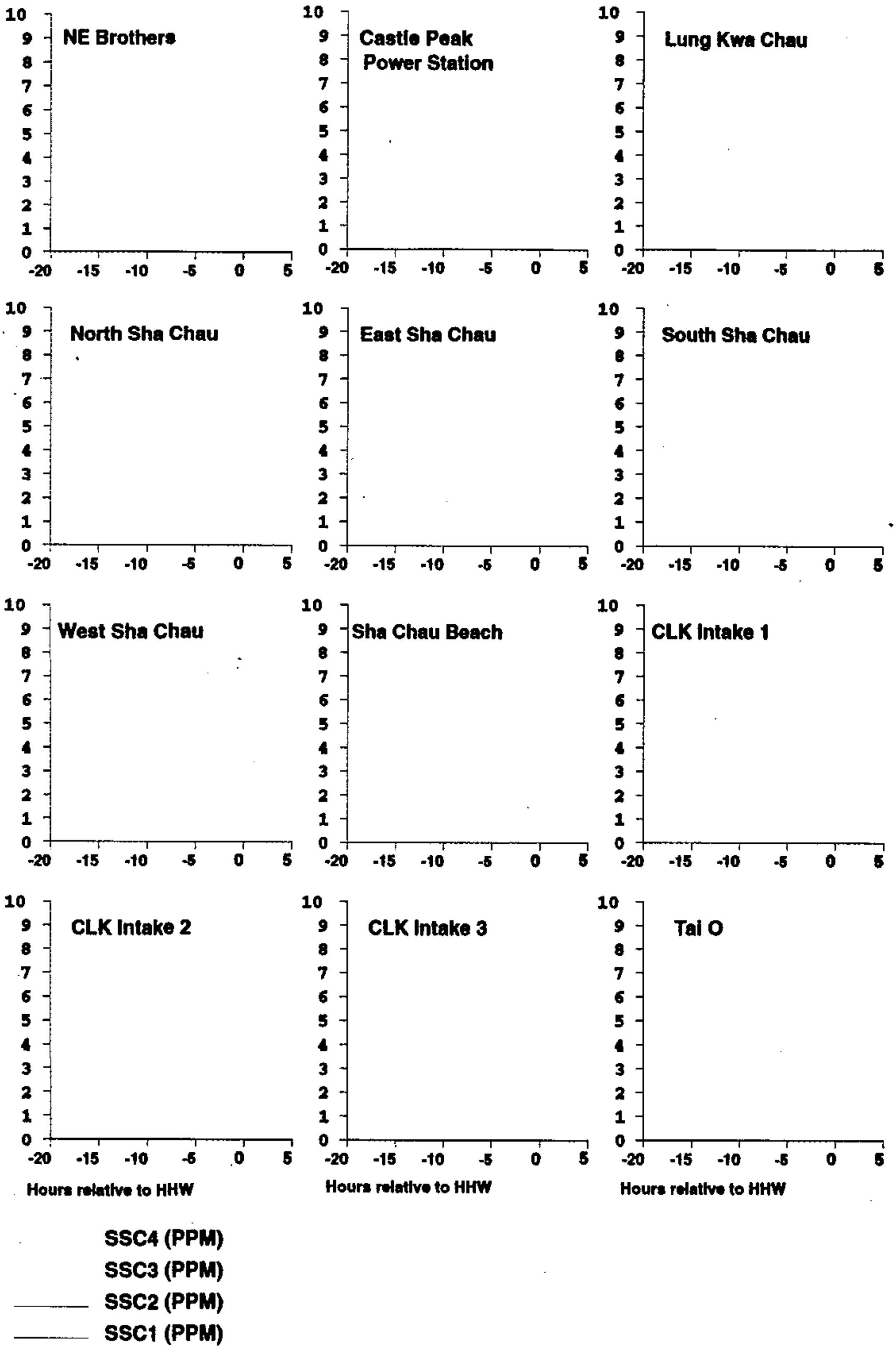

FIGURE J2 - SCENARIO 7: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

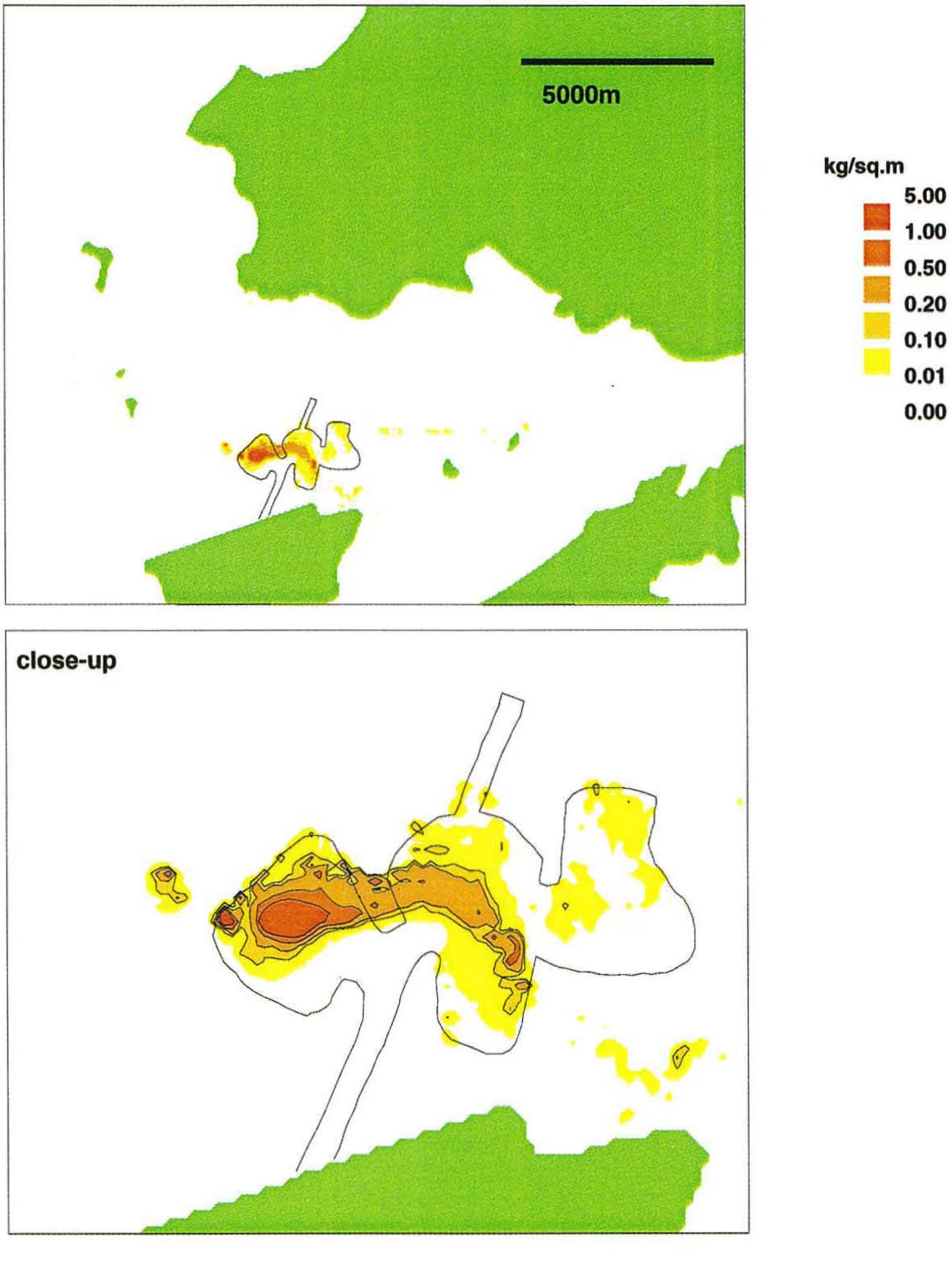

FIGURE J3 - SCENARIO 7: PREDICTED SEDIMENT DEPOSITION PER DAY

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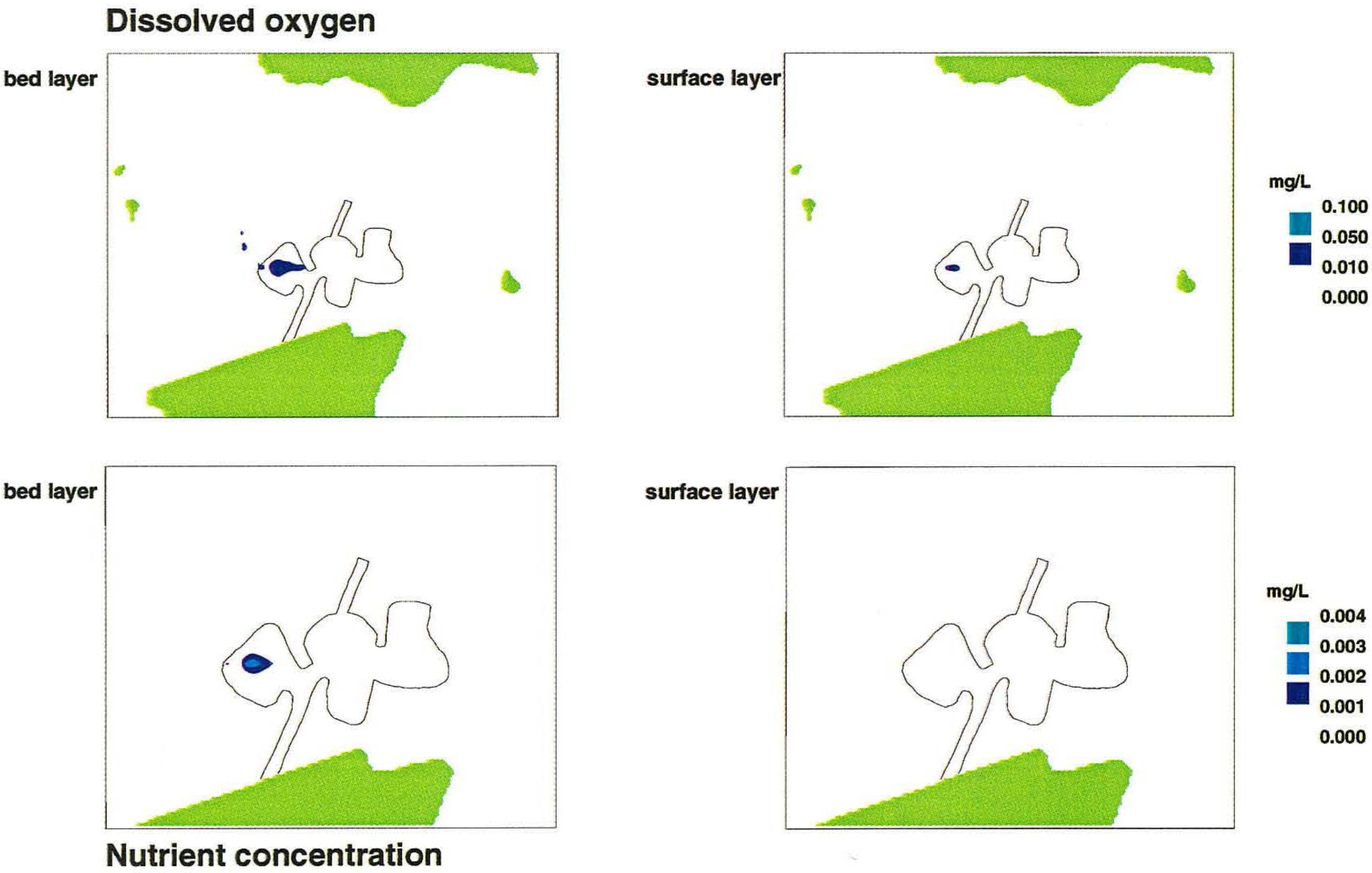

FIGURE J4 - SCENARIO 7: PREDICTED DISSOLVED OXYGEN DEPLETION AND NUTRIENT ELEVATION

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Annex K

Water Quality Modelling Results for Scenario 8

Scenario 8 Results (Annex K)

Scenario 8 tested the effect of an increased backfilling rate of 40,000m^3 day^{-1} of trailer dredged material using similar conditions to Scenario 4 (ie disposal at full Pit A on the dry season spring tide). The pattern of plumes on the flood tide is similar to that in Scenario 4 except that concentrations are slightly higher in Scenario 8 (10-20 mg l^{-1}) and there is a relatively low concentration plume (5-10 mg l^{-1}), arising from modelled disposal events on the previous ebb phase of the tide, now returning westward on the flooding currents. The pattern of suspended sediments is broadly similar to that of Scenario 4 for the ebb tide as well except that the plume extends further eastward towards Ma Wan (concentration of 1-5 mg l^{-1}).

The pattern of bed deposits in Scenario 8 is very similar to that for Scenario 4 with the bulk of deposits in Pit A. However, the deposition rate is higher (peak value of 15kgm^{2}day$^{-1)}$. The pattern of dissolved oxygen depletion and elevated nutrient concentrations are also similar but show higher peak values for dissolved oxygen (0.20 mg l^{-1}) and nutrients (0.008 mg l^{-1}).

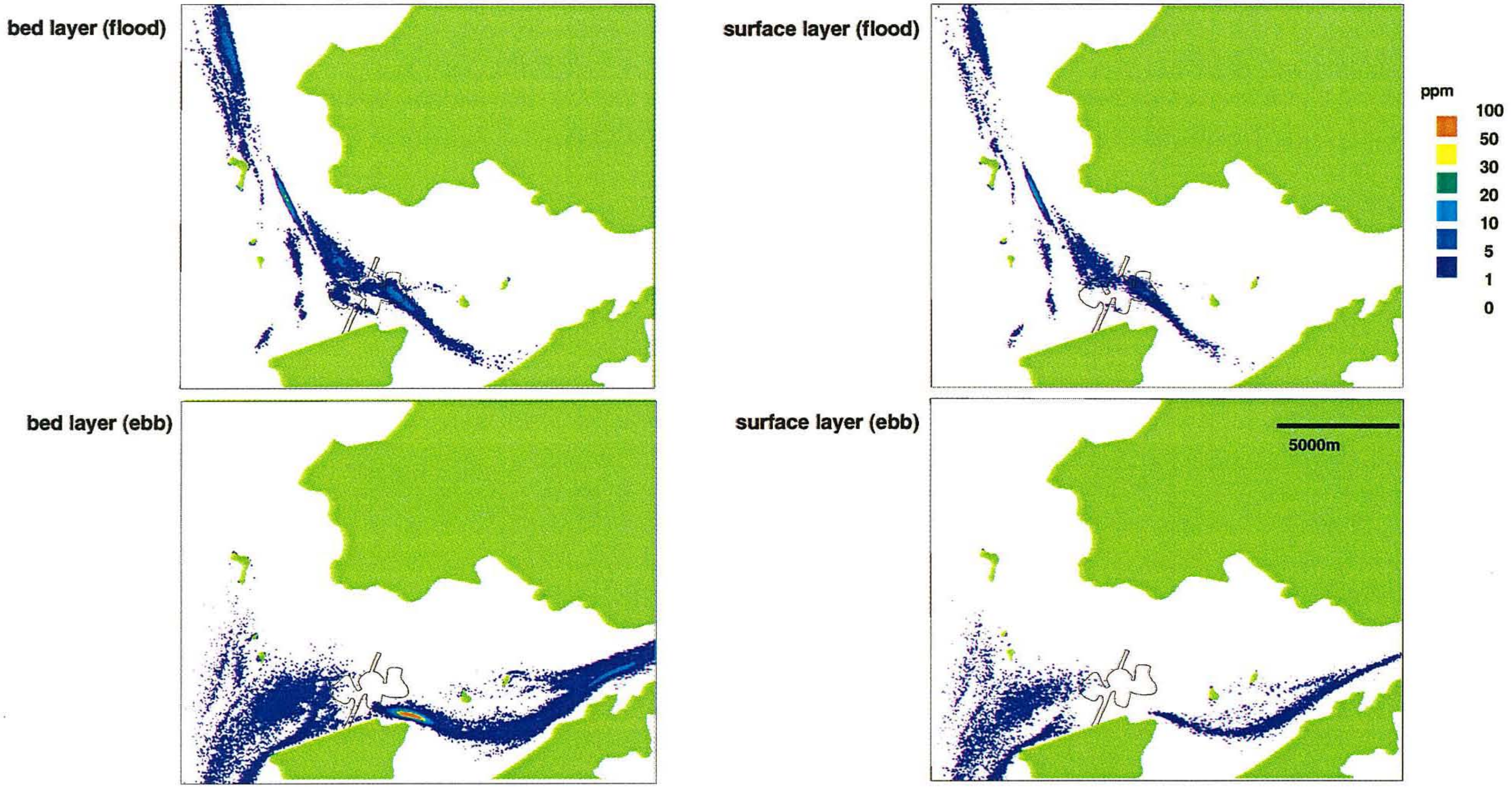

FIGURE K1 - SCENARIO 8: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS AT PEAK EBB AND PEAK FLOOD TIDES

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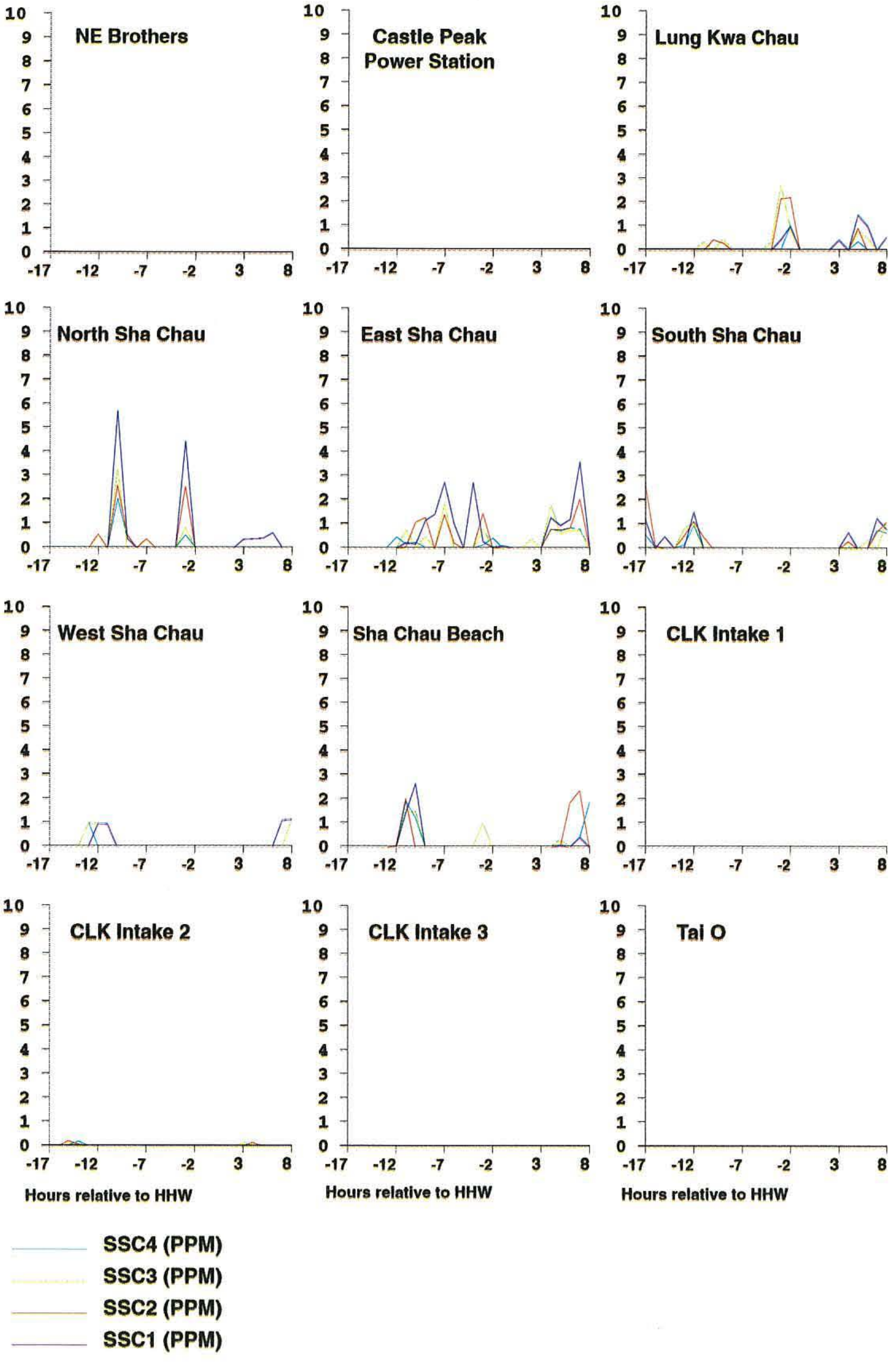

FIGURE K2 - SCENARIO 8: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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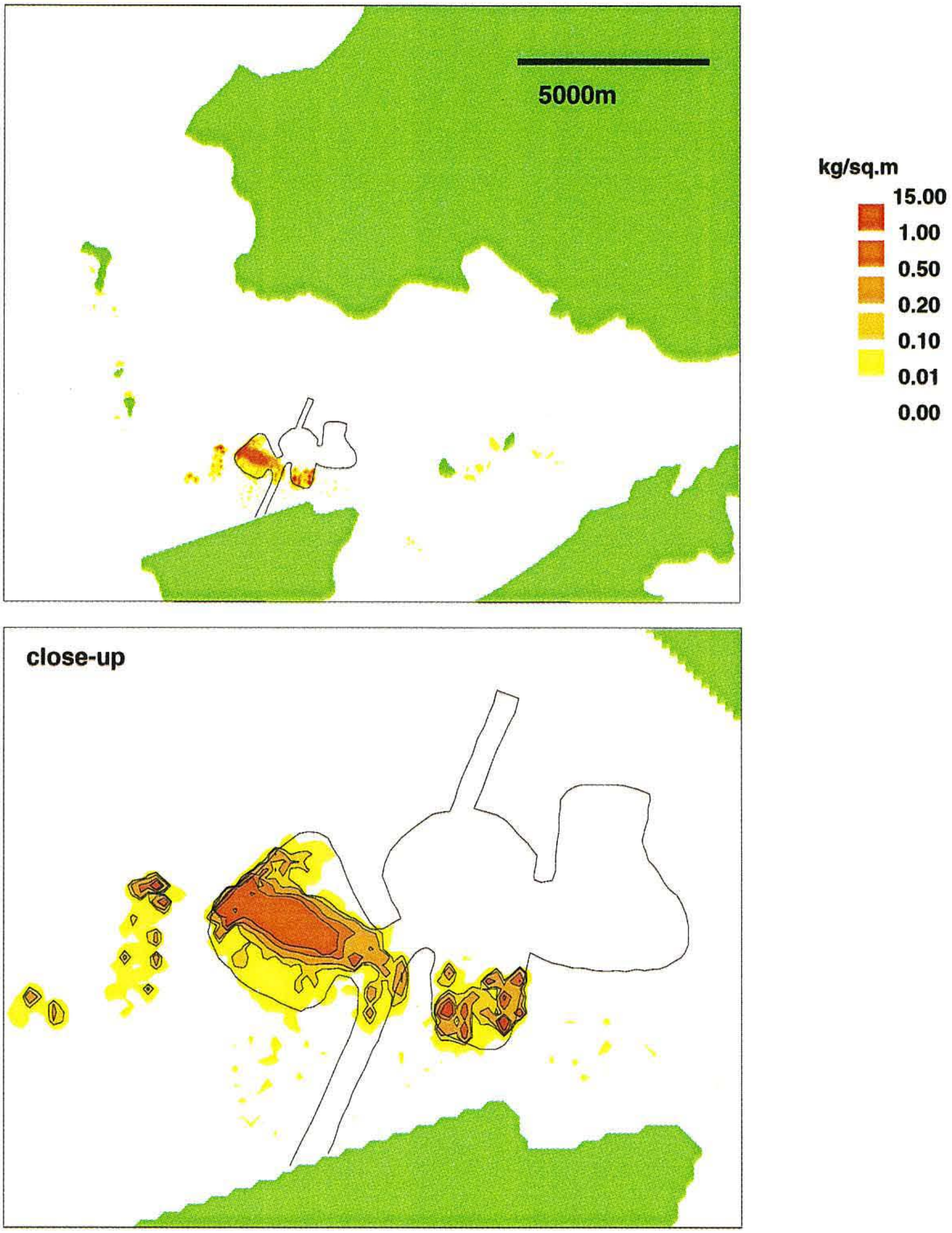

FIGURE K3 - SCENARIO 8: PREDICTED SEDIMENT DEPOSTION PER DAY

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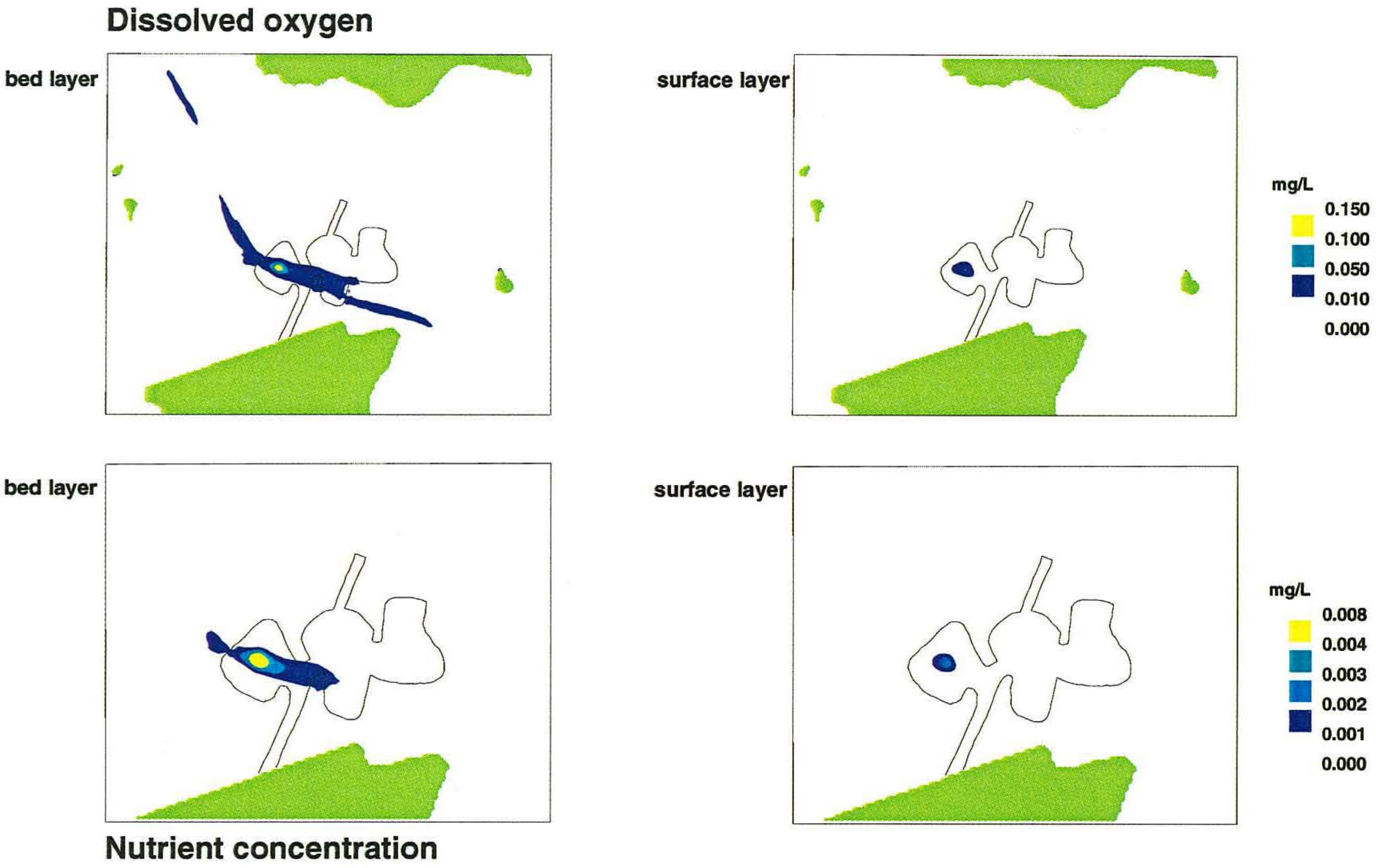

FIGURE K4 - SCENARIO 8: PREDICTED DISSOLVED OXYGEN DEPLETION AND NUTRIENT ELEVATION

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Annex L

Water Quality Modelling Results for Scenario 9

Scenario 9 (Annex L)

Scenario 9 consisted of a backfilling rate of 16,000 m^3 day^{-1} trailer dredged material at empty Pit A on the dry season spring tide. It is therefore similar to Scenario 4 in all respects except the pit backfill level. On the flood tide, the plume of resuspended sediment reaches as far as Black Point, with a peak near bed concentration of 10-20 mg l^{-1} and concentrations in the surface layer below 5 mg l^{-1}. On the ebb tide, the western part of the sediment plume is the now much diluted residue of the flood tide disposal event (1-5 mg l^{-1}) whereas the eastern part of the plume is a result of low current speeds in the deep borrow pits, which allow sediment to settle, producing concentrations of 10-20 mg l^{-1}.

The majority of the deposition forms with Pit A and Pit B, with small secondary patches to the west of Pit A and some deposition in the shallower area between the northern parts of Pit A and Pit B. There is more deposition in Pit B in Scenario 9 than in Scenario 4, due to the deeper pit, which has a stronger effect in reducing current speeds; thus allowing more settling of sediment and slower advection of the sediment away from the pit area. The area predicted to be affected by dissolved oxygen deficits (less than 0.05 mg l^{-1} in the bed layer only) is centred around the disposal location, with an additional arm of slight dissolved oxygen depletion extending towards the north west. The maximum increase in near bed nutrient concentrations is less than 0.002 mg l^{-1} and occurs only in the bed layer.

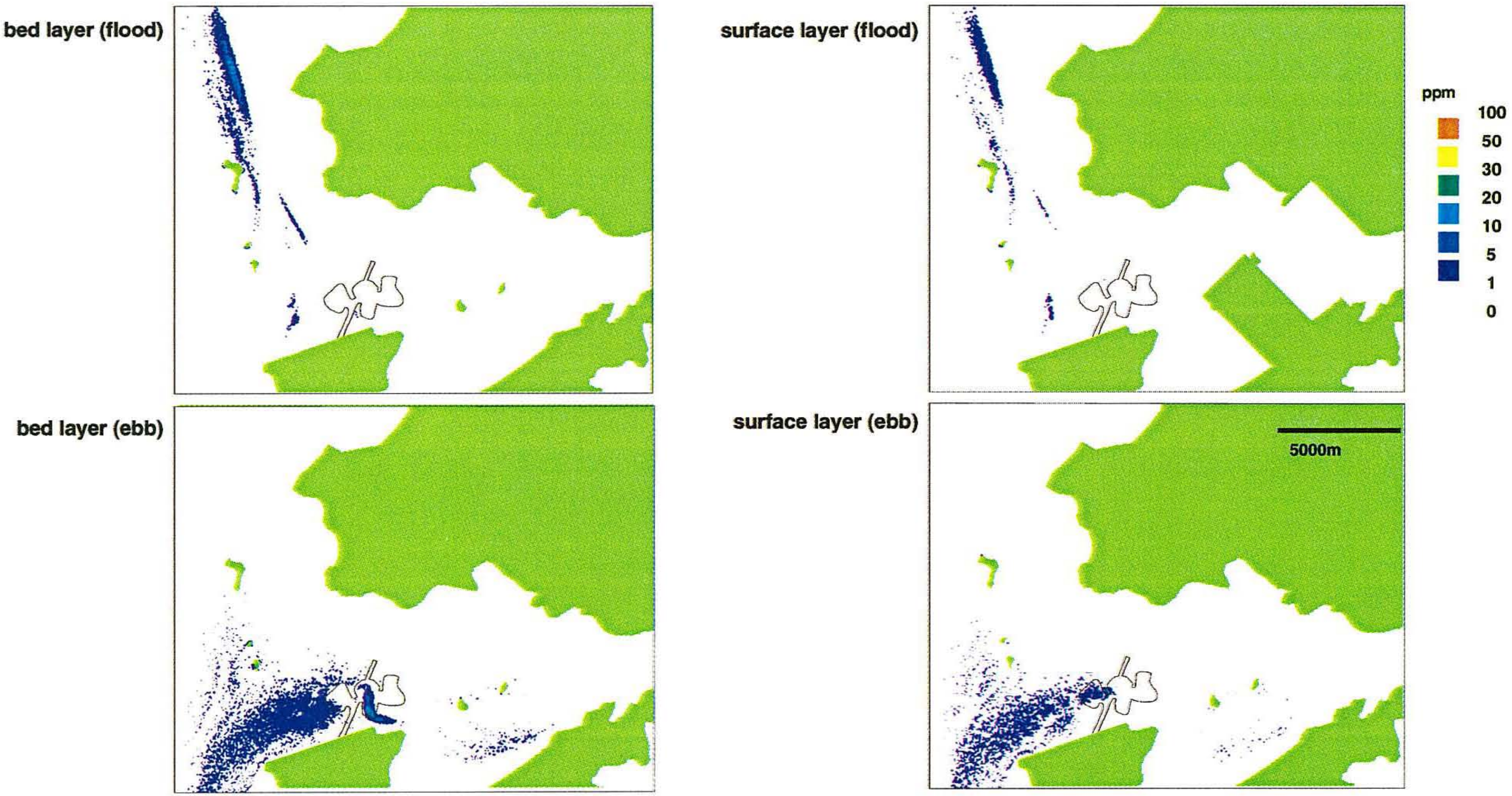

FIGURE L1 - SCENARIO 9: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS AT PEAK EBB AND PEAK FLOOD TIDES

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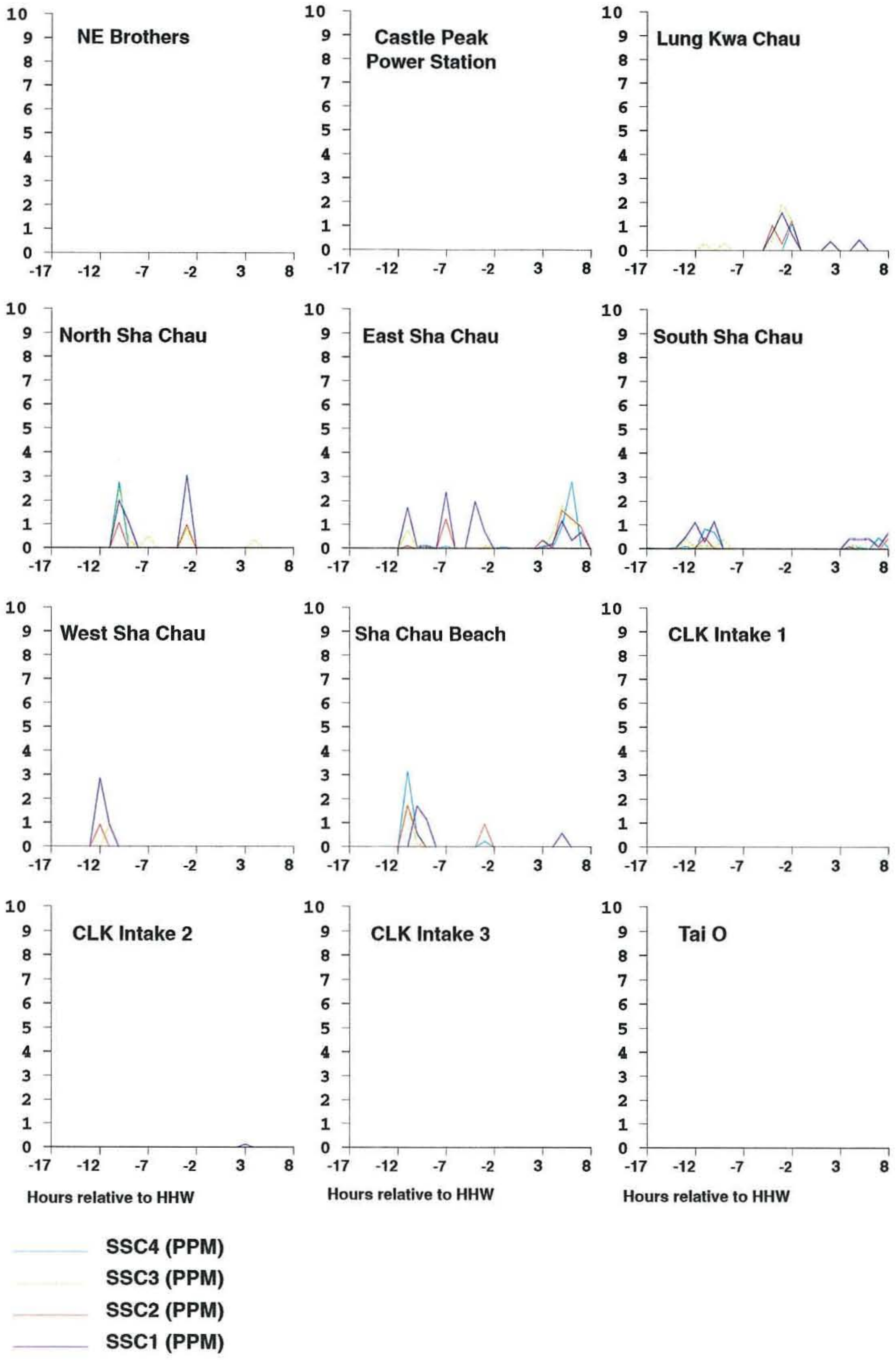

FIGURE L2 - SCENARIO 9: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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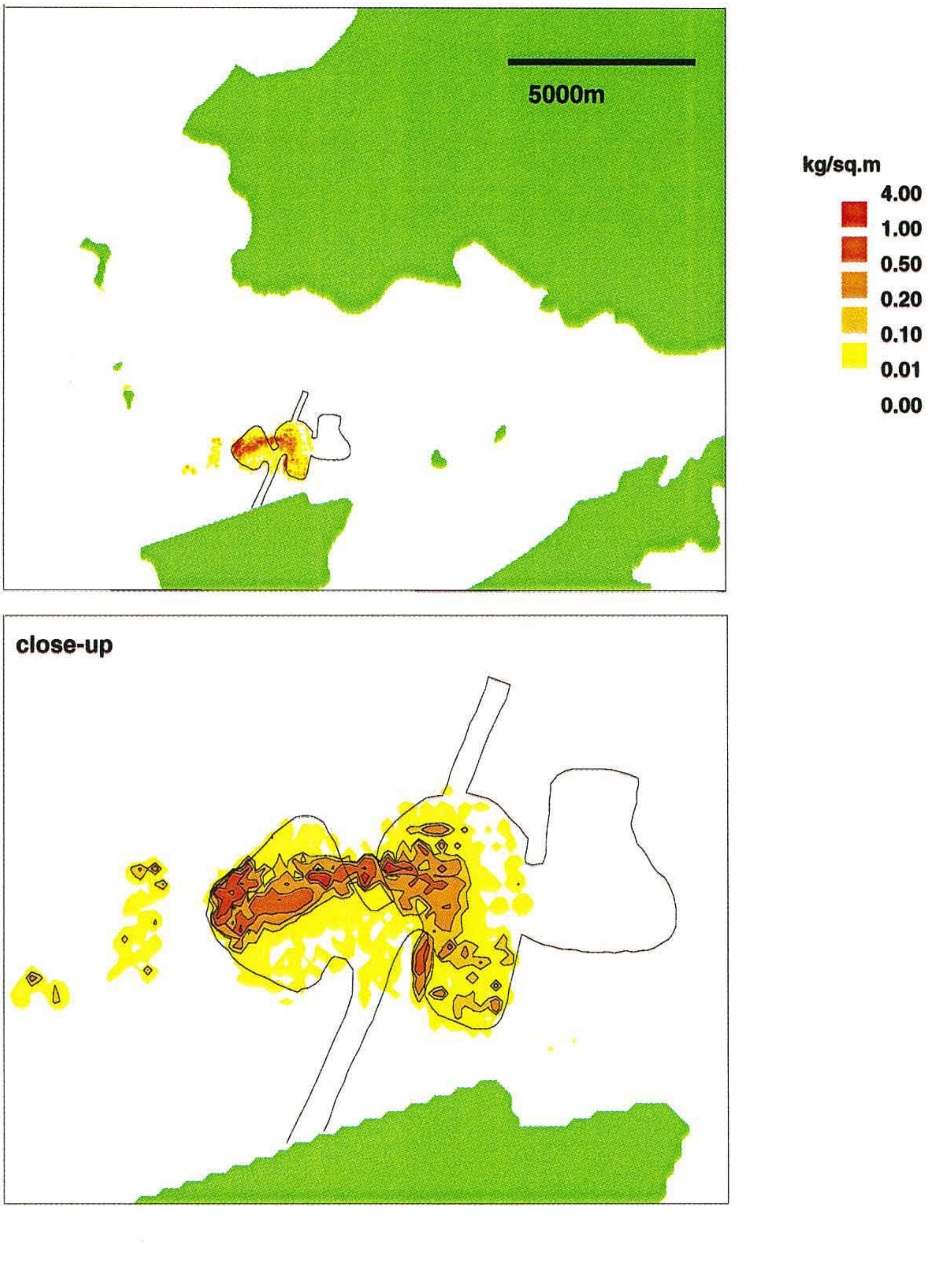

FIGURE L3 - SCENARIO 9: PREDICTED SEDIMENT DEPOSTION PER DAY

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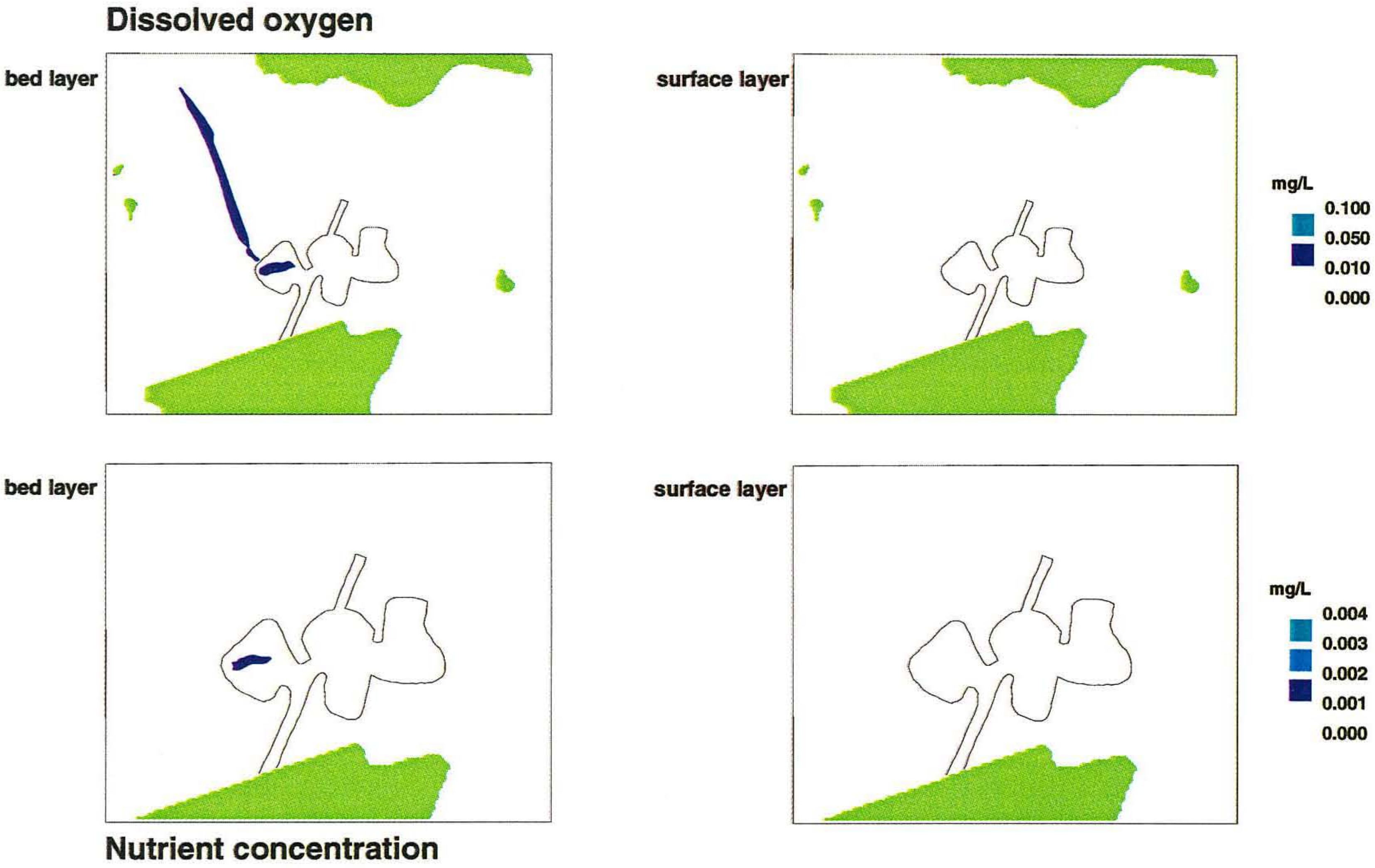

FIGURE L4 - SCENARIO 9: PREDICTED DISSOLVED OXYGEN DEPLETION AND NUTRIENT ELEVATION

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Annex M

Water Quality Modelling Results for Scenario 10

Scenario 10 Results (Annex M)

Scenario 10 consisted of a backfilling rate of 16,000 m^3day^{-1} of trailer dredged material at full Pit C on the dry season spring tide. Suspended sediment concentrations are higher in this scenario than in the comparable case of Scenario 4, which differed only in having a disposal location in Pit A rather than Pit C. This arises because current speeds are higher in the vicinity of Pit C, which is closer to the deep water channel between Urmston Road and Ma Wan and further from the relatively slack area north of the airport where the current streams divide. On the flood, peak concentrations are in the range 20-30 mg l^{-1}, occurring immediately to the north of Pit A in the near bed layer. On the ebb, there is a small area where concentrations exceed 50 mg l^{-1}, with all values being less than 150 mg l^{-1}. There is less difference in concentrations between the surface and bed layers than in Scenario 4, due to the higher average current speeds experienced by the sediment plume.

Net sediment deposits over one tidal cycle are shown. The deposition rate is lower than for disposal scenarios involving Pit A, and show most deposition occurring in the northern part of Pit B, with patches of deposits in and to the west of Pit A and around the Brothers. The depletion of dissolved oxygen is predicted to occur mainly to the east of CMP IV with a maximum of 0.05 mg l^{-1}. The maximum increase in nutrient concentrations is in the range 0.001-0.002 mg l^{-1}.

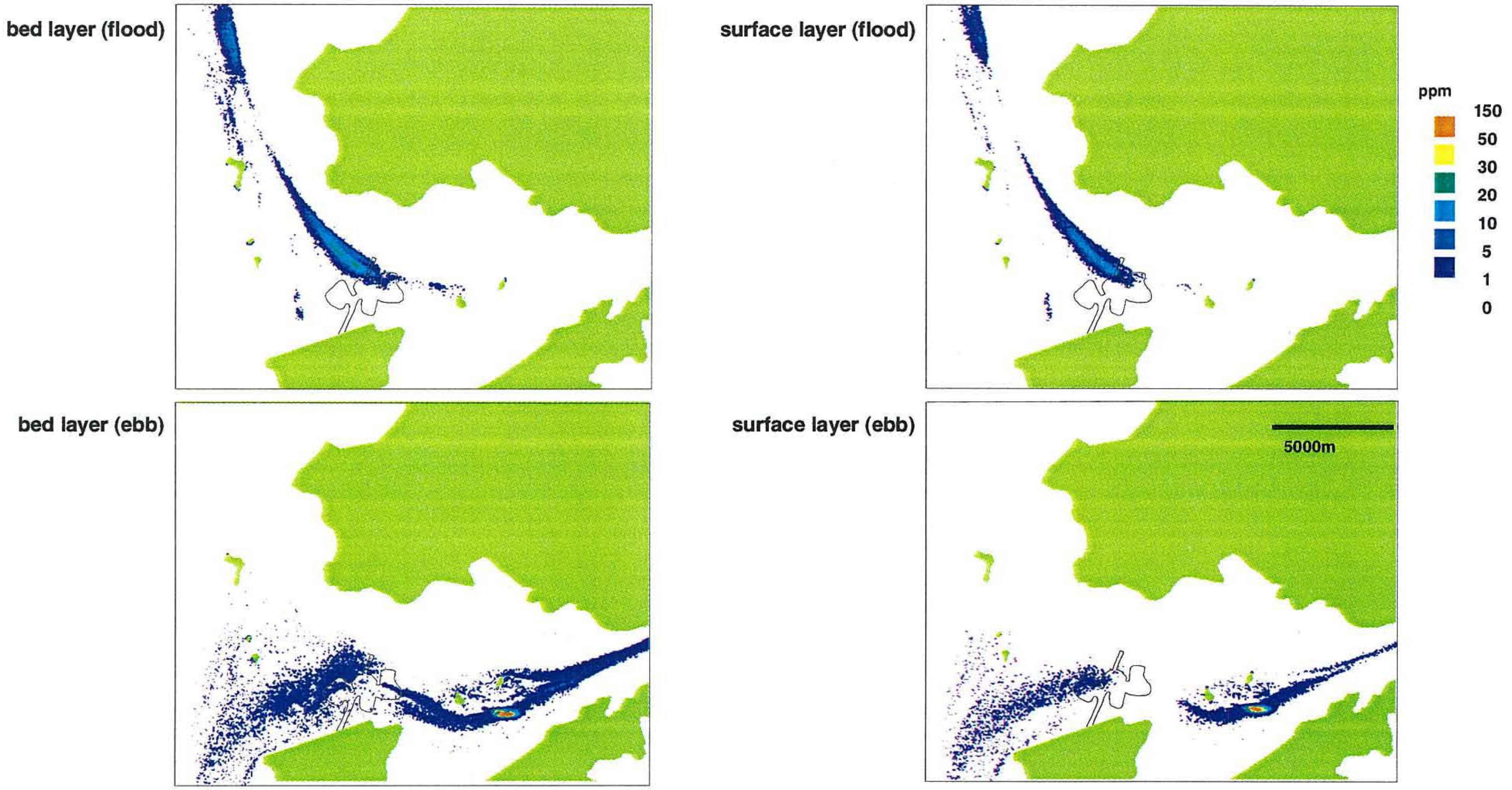

FIGURE M1 - SCENARIO 10: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS AT PEAK EBB AND PEAK FLOOD TIDES

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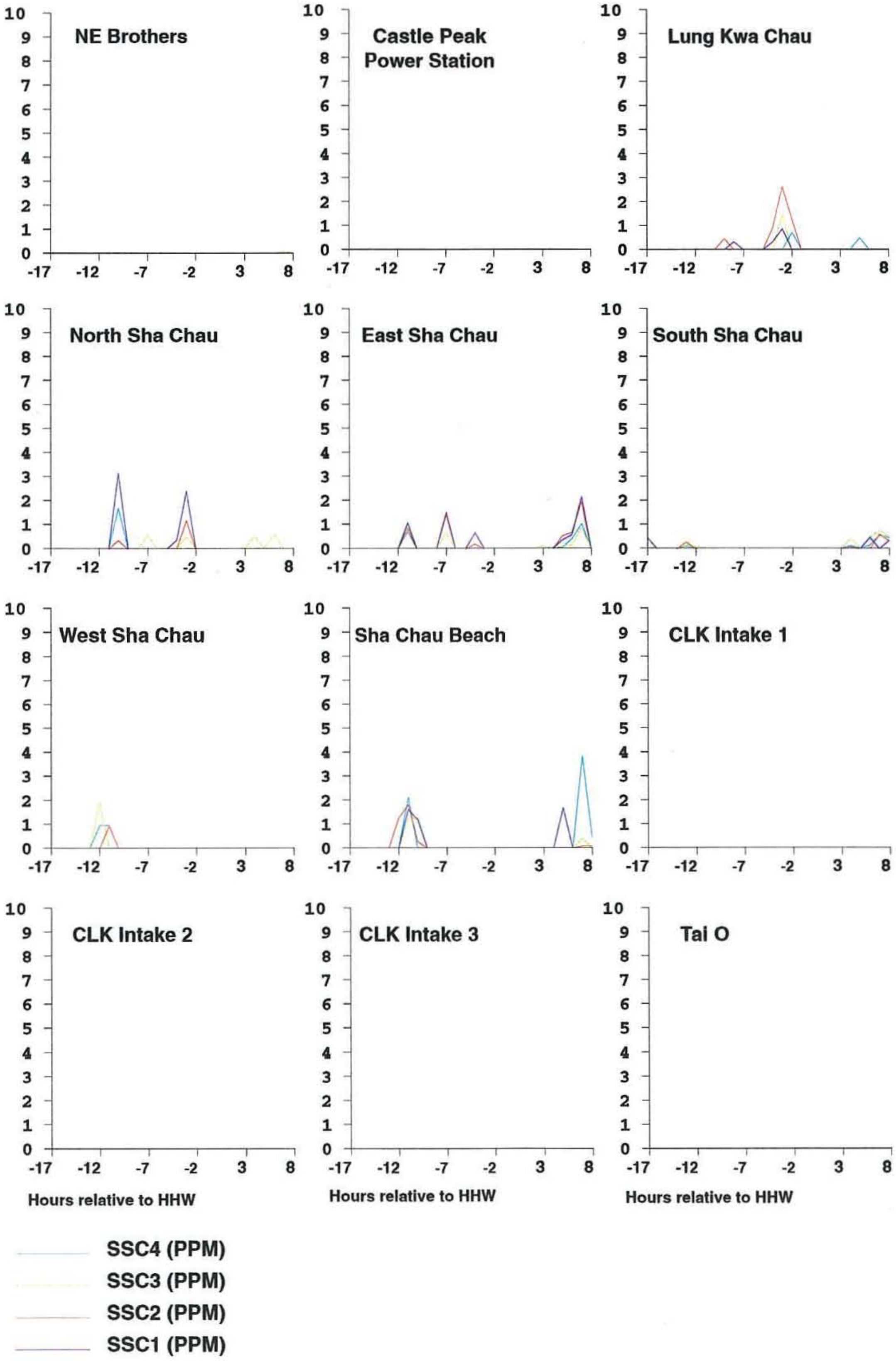

FIGURE M2 - SCENARIO 10: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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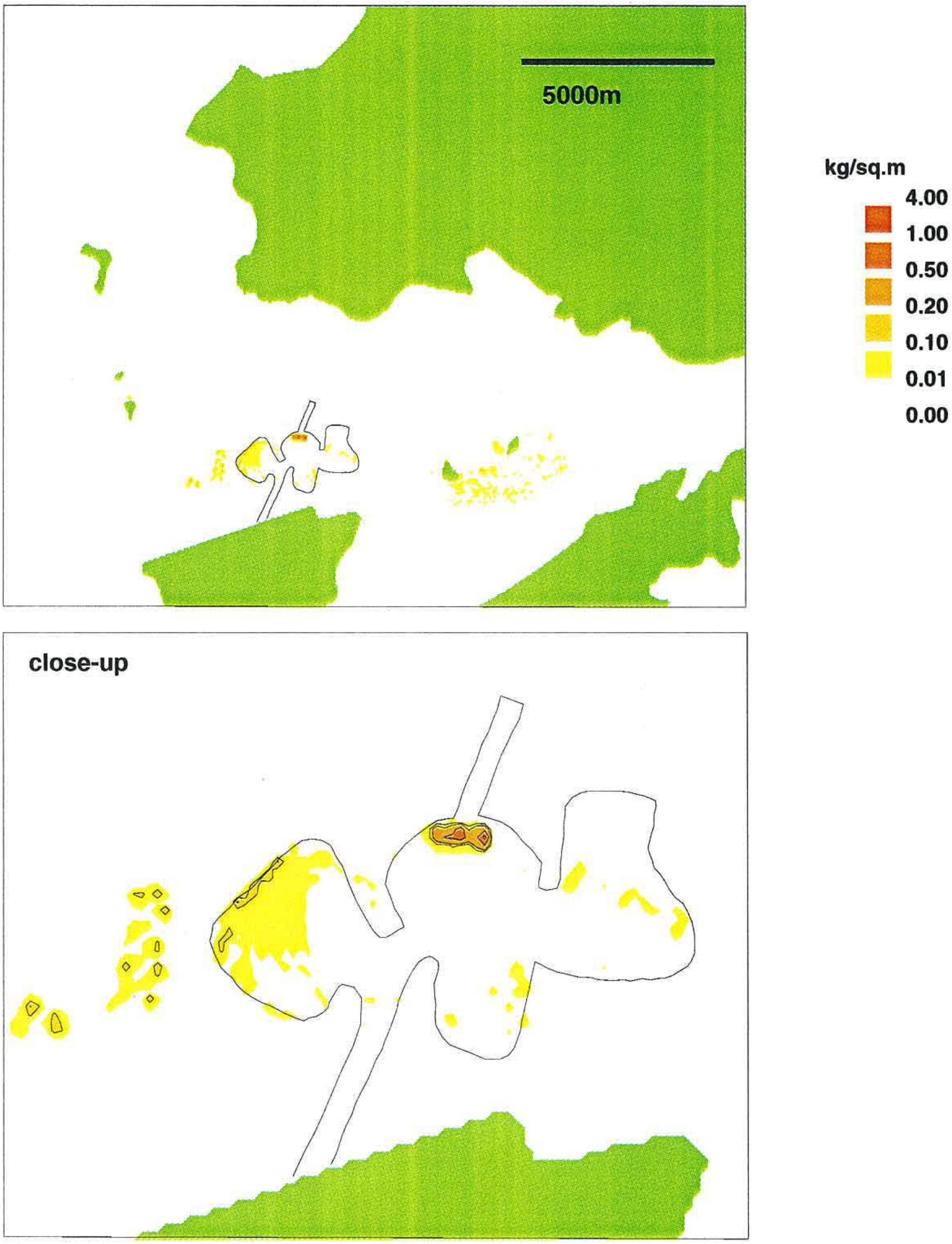

FIGURE M3 - SCENARIO 10: PREDICTED SEDIMENT DEPOSTION PER DAY

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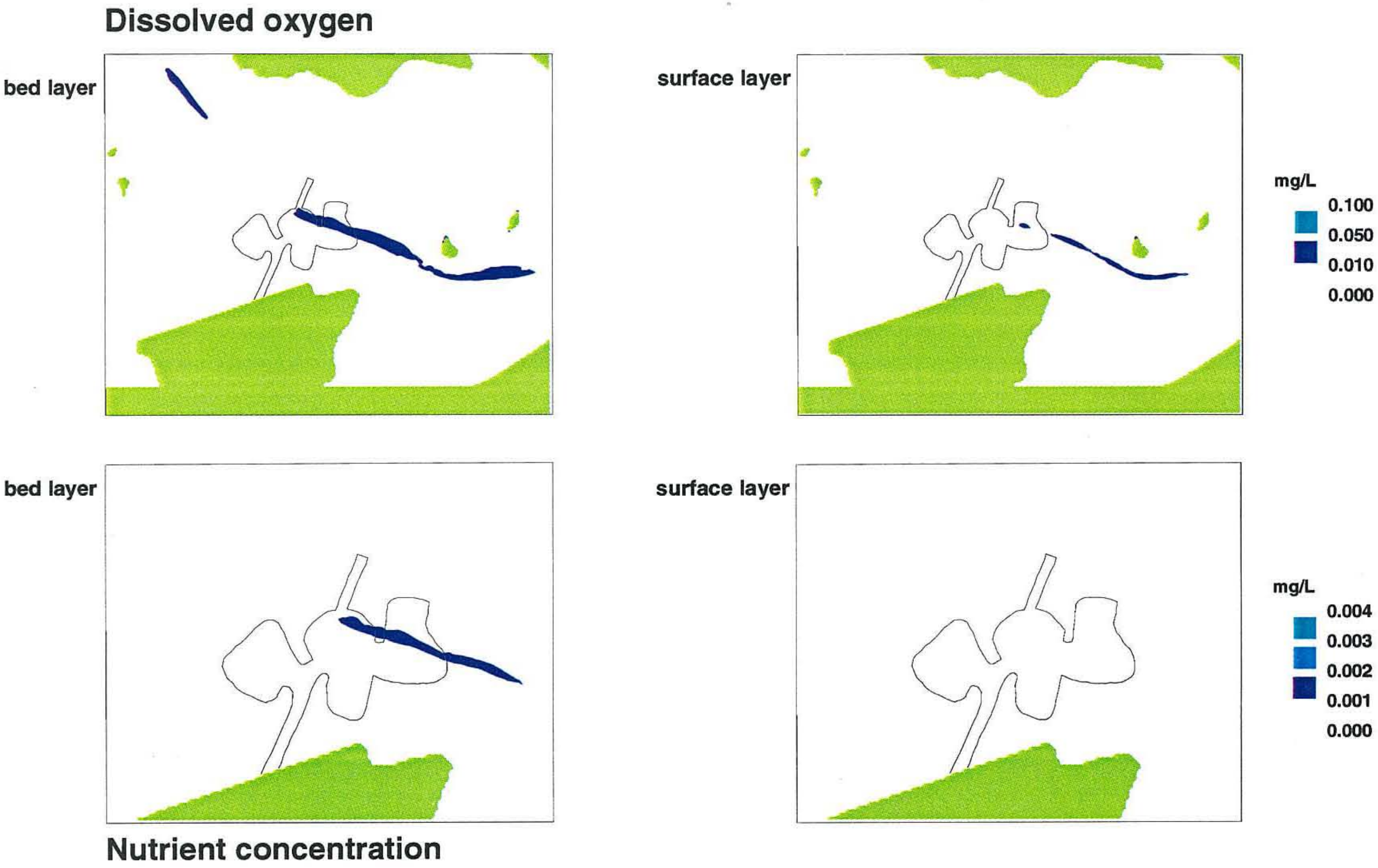

FIGURE M4 - SCENARIO 10: PREDICTED DISSOLVED OXYGEN DEPLETION AND NUTRIENT ELEVATION

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Annex N

Water Quality Modelling Results for Scenario 11

Scenario 11 Results (Annex N)

Scenario 11 consisted of a backfilling rate of 16,000 m^3 day^{-1} trailer dredged material in empty Pit C on the dry season spring tide. The pattern of suspended sediment concentrations for Scenario 11 is similar to that of Scenario 10, but concentrations are generally lower, because more deposition occurs in Scenario 11, particularly in Pit B. Peak concentrations on the flood phase of the tide are in the range of 10-20 mg l^{-1} and on the ebb phase in the range of 50-150 mg l^{-1}.

The majority of sediment deposition occurs in Pit B, with less rapid deposition in Pit A and in small patches around the Brothers. The peak deposition rate is less than 4 kgm^2 day^{-1}. Dissolved oxygen and nutrient impacts are greatest, and occur mainly in the bed layer, in Pit C and past the southern side of the Brothers. The DO depletion has a maximum value in the range of 0.01-0.05 mg l^{-1}. The increase in nutrient concentrations has a peak of less than 0.002 mg l^{-1}.

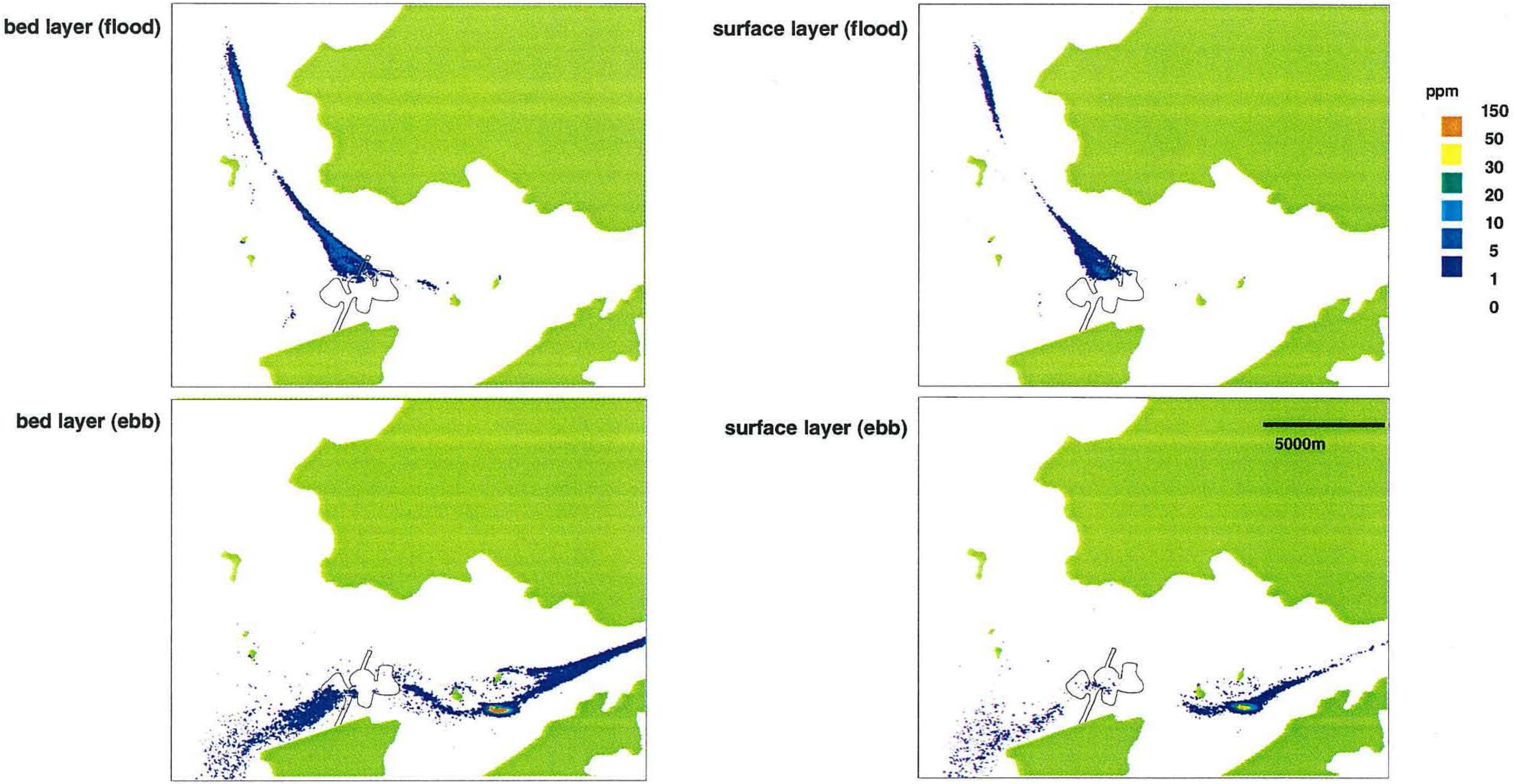

FIGURE N1 - SCENARIO 11: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS AT PEAK EBB AND PEAK FLOOD TIDES

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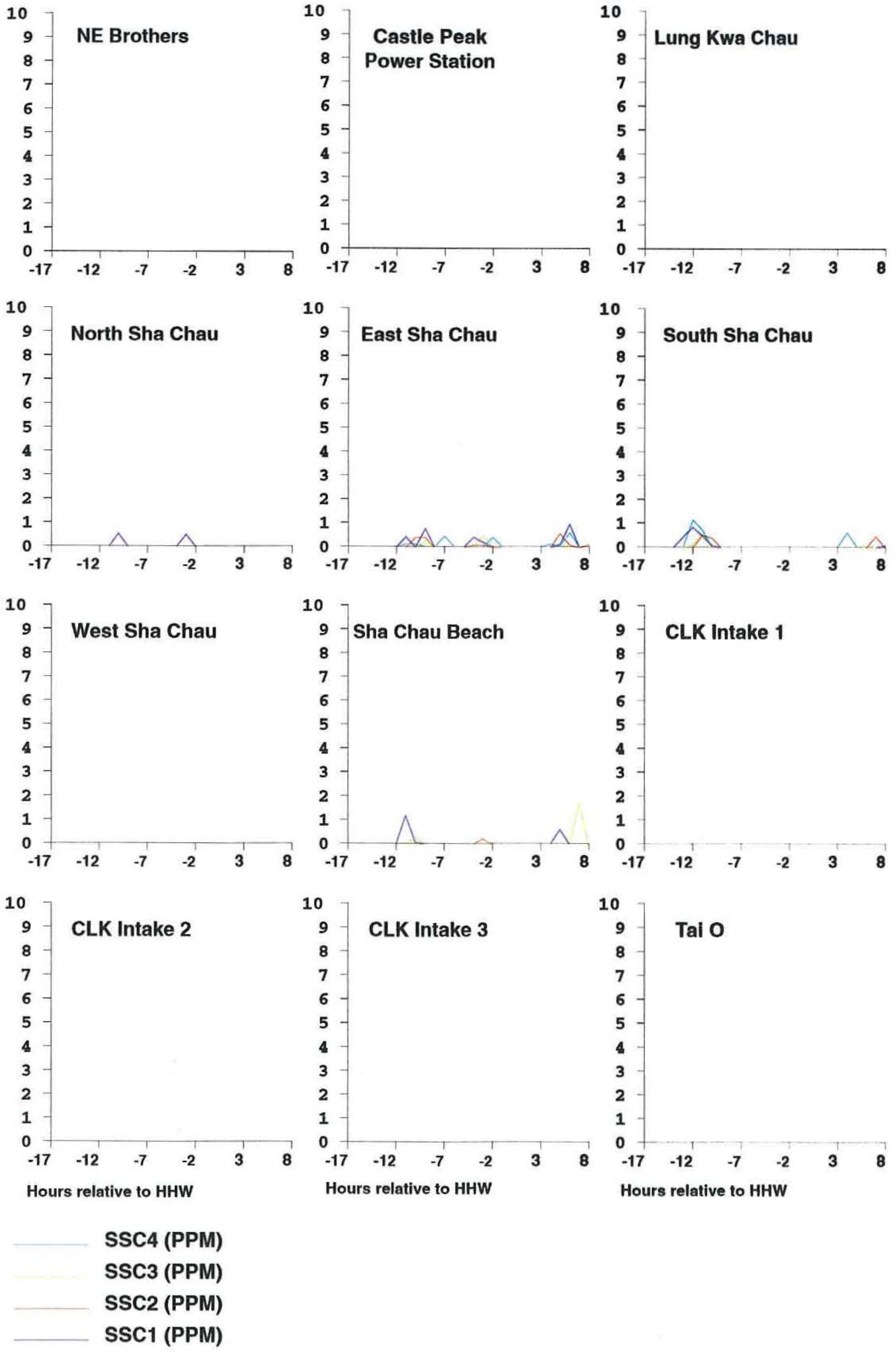

FIGURE N2 - SCENARIO 11: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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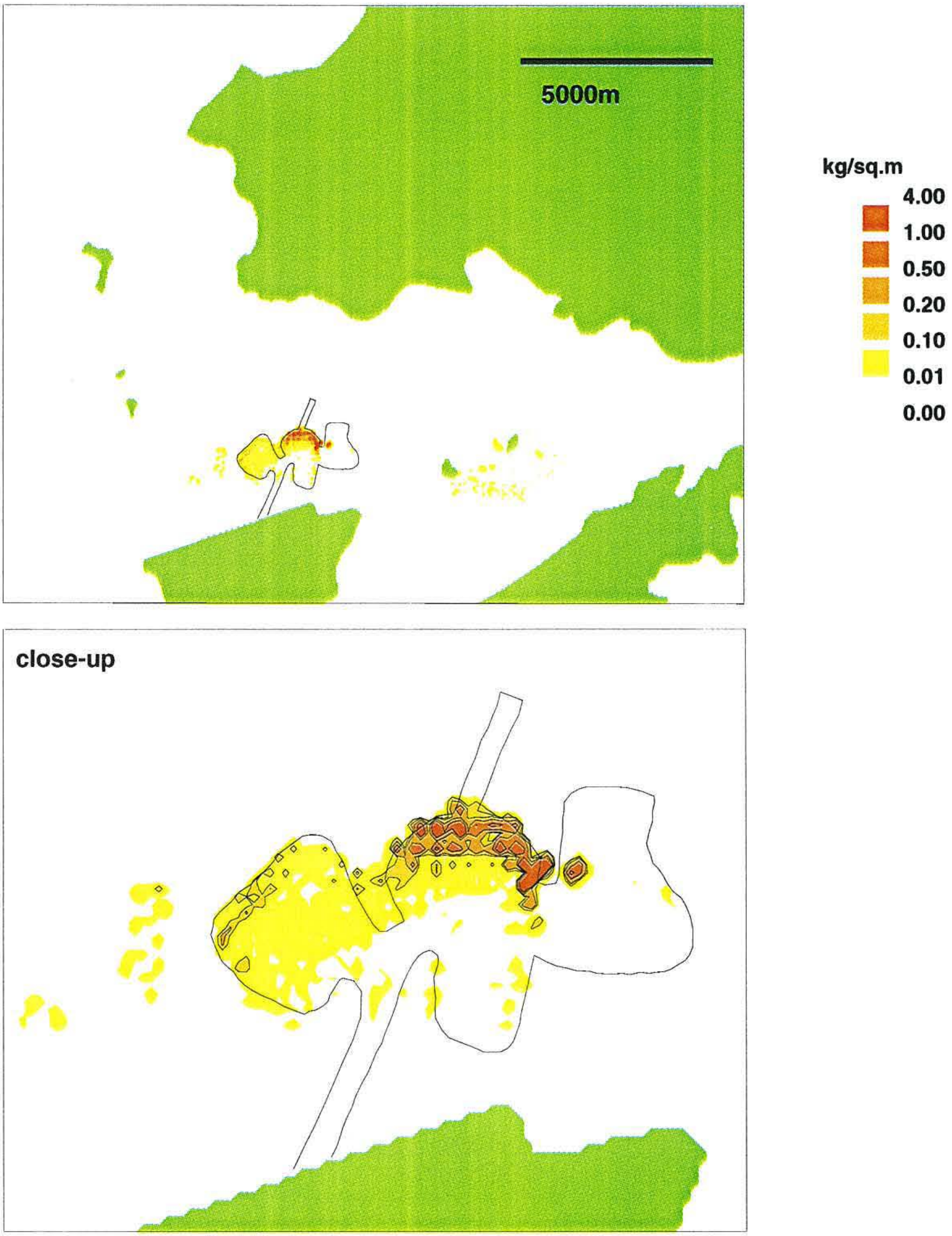

FIGURE N3 - SCENARIO 11: PREDICTED SEDIMENT DEPOSTION PER DAY

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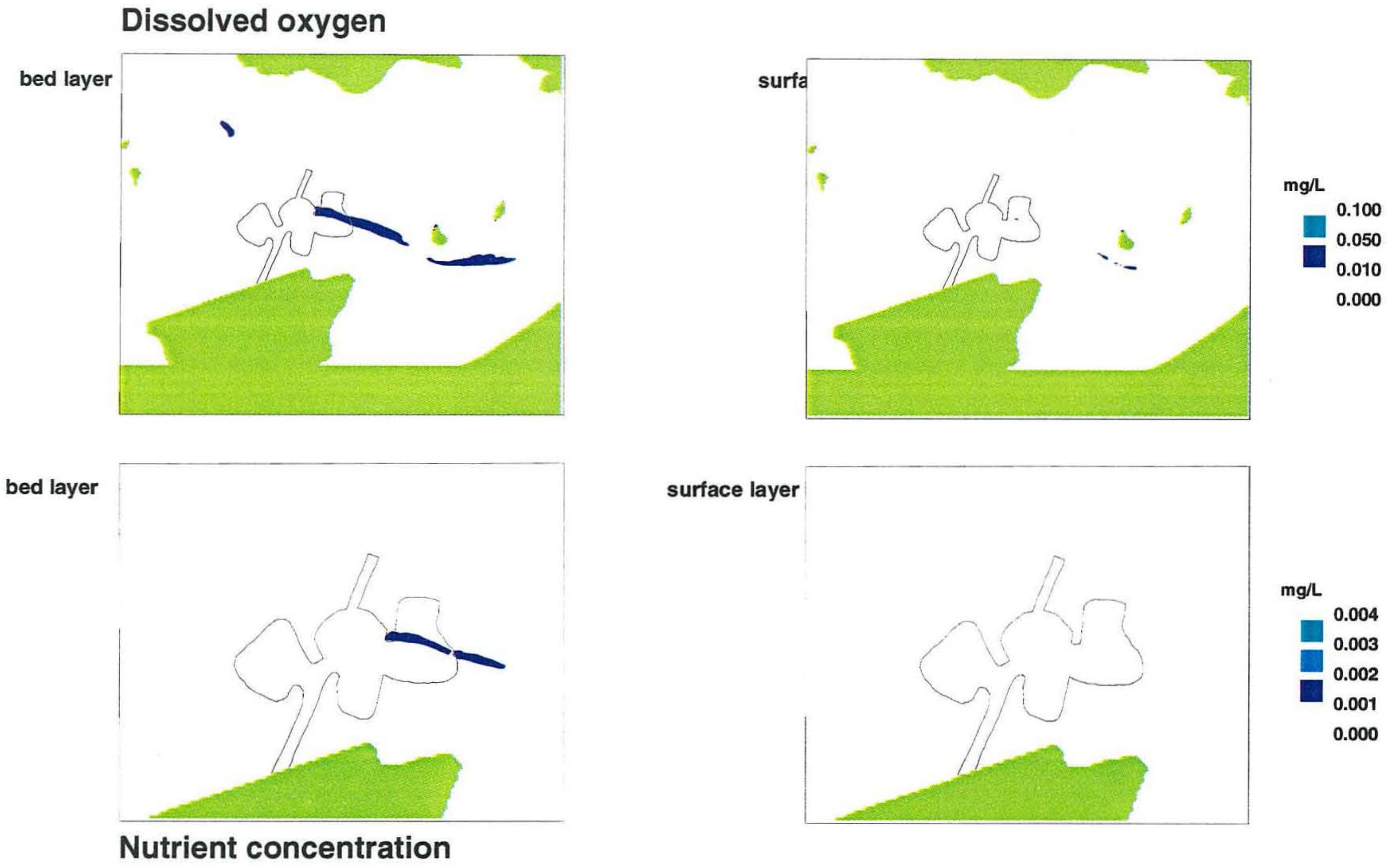

FIGURE N4 - SCENARIO 11: PREDICTED DISSOLVED OXYGEN DEPLETION AND NUTRIENT ELEVATION

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Annex O

Mixing Zone Plots

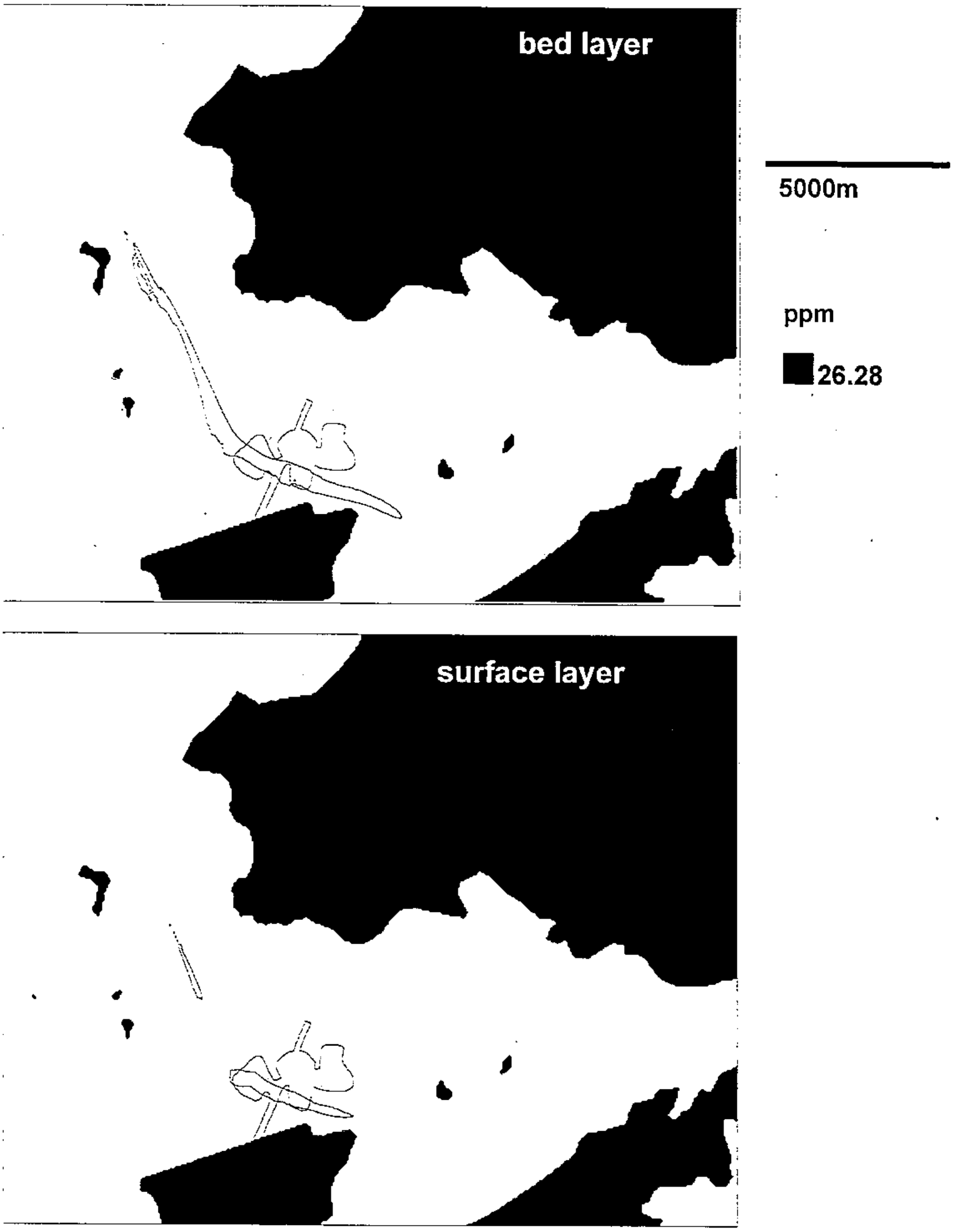

FIGURE O1 - SCENARIO 4: AREA WITHIN WHICH ALL SUSPENDED SEDIMENT WQO EXCEEDANCES WILL BE CONTAINED DURING ONE TIDAL CYCLE AFTER DISPOSAL IN THE DRY SEASON (WQO=26.28mg 1-1)

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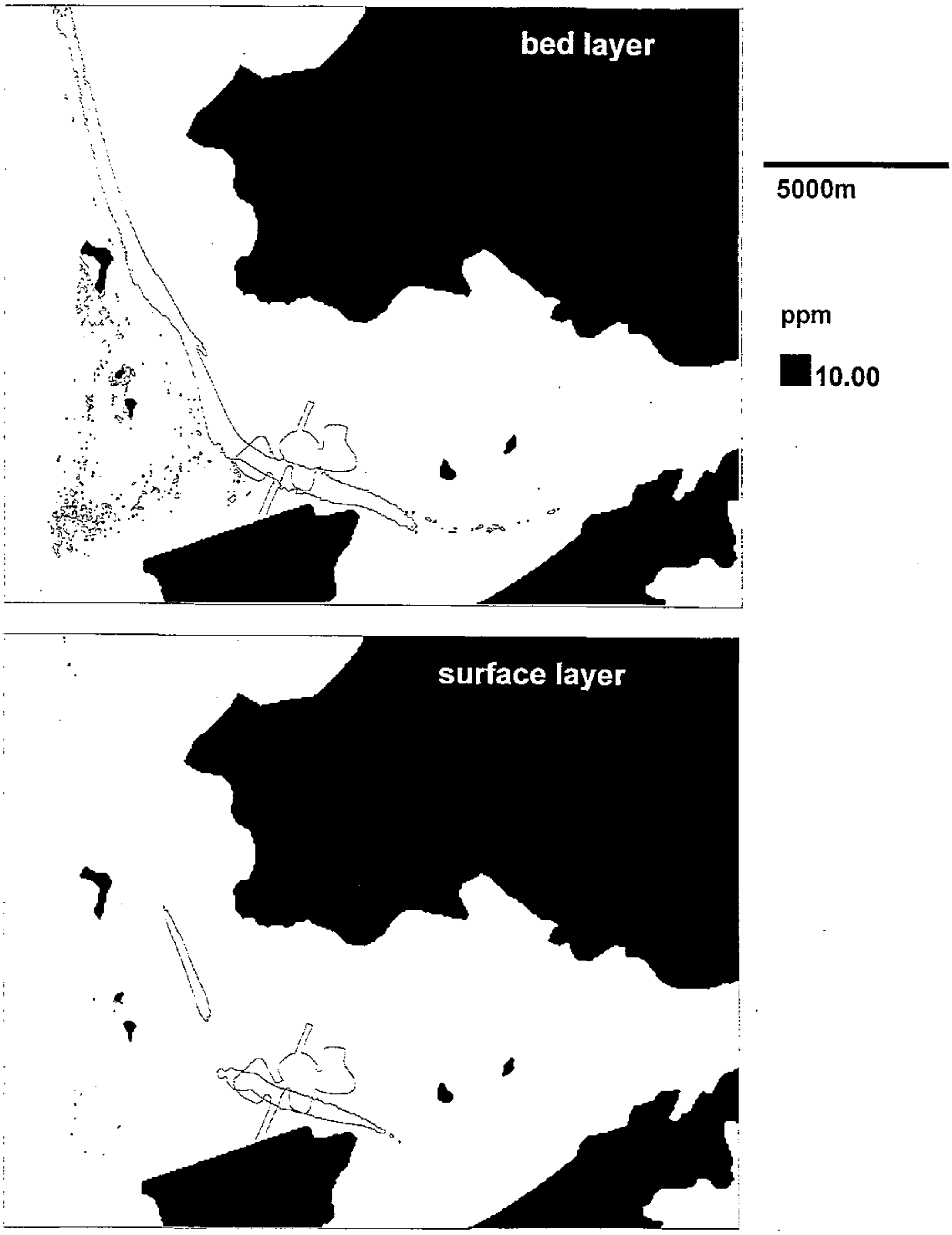

FIGURE O2 - SCENARIO 4: AREA WITHIN WHICH ALL SUSPENDED SEDIMENT WQO EXCEEDANCES WILL BE CONTAINED DURING ONE TIDAL CYCLE AFTER DISPOSAL IN THE DRY SEASON (WQO=10mg 1^{-1})

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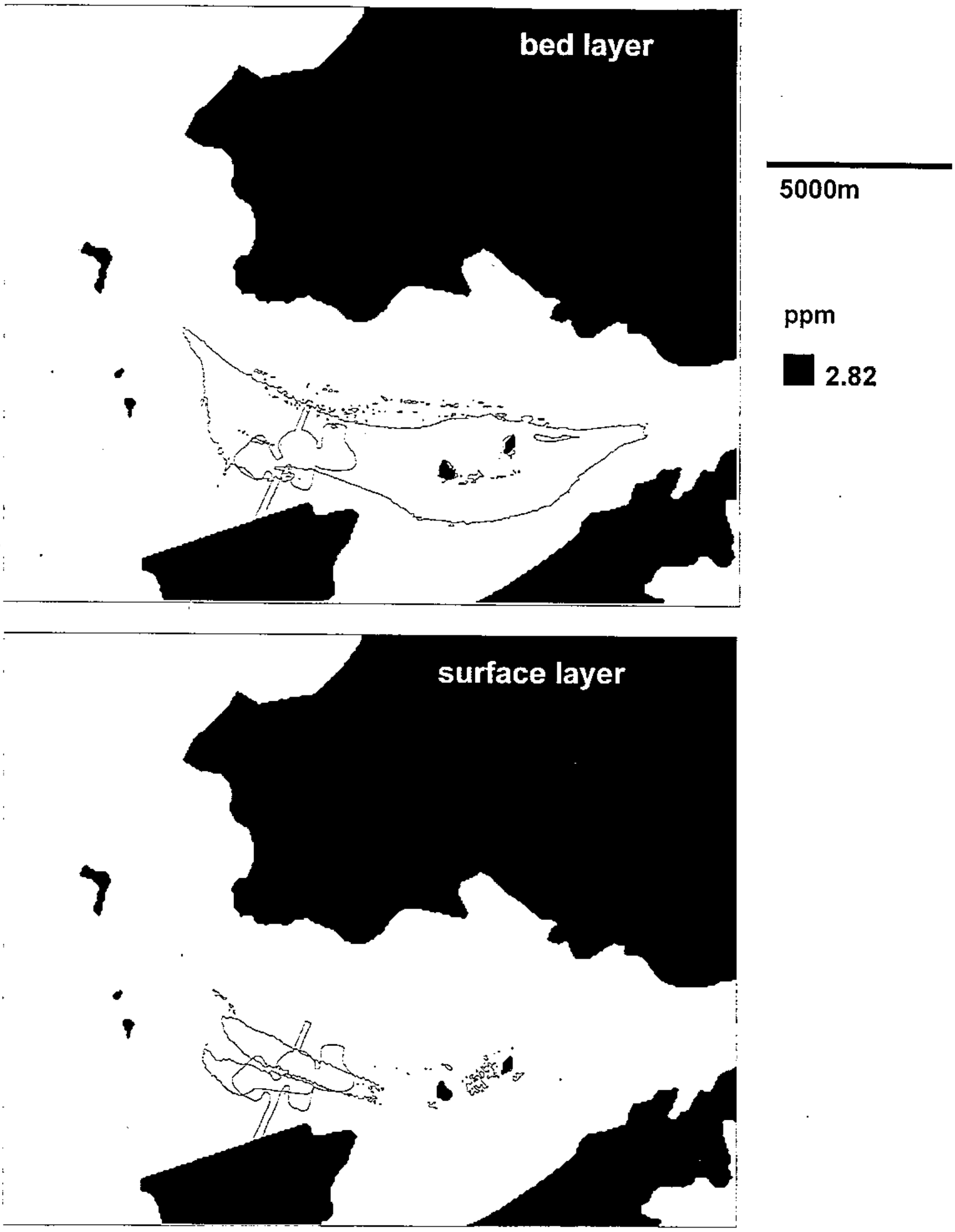

FIGURE O3 - SCENARIO 4: AREA WITHIN WHICH ALL SUSPENDED SEDIMENT WQO EXCEEDANCES WILL BE CONTAINED DURING ONE TIDAL CYCLE AFTER DISPOSAL IN THE WET SEASON (WQO=2.82mg 1-1)

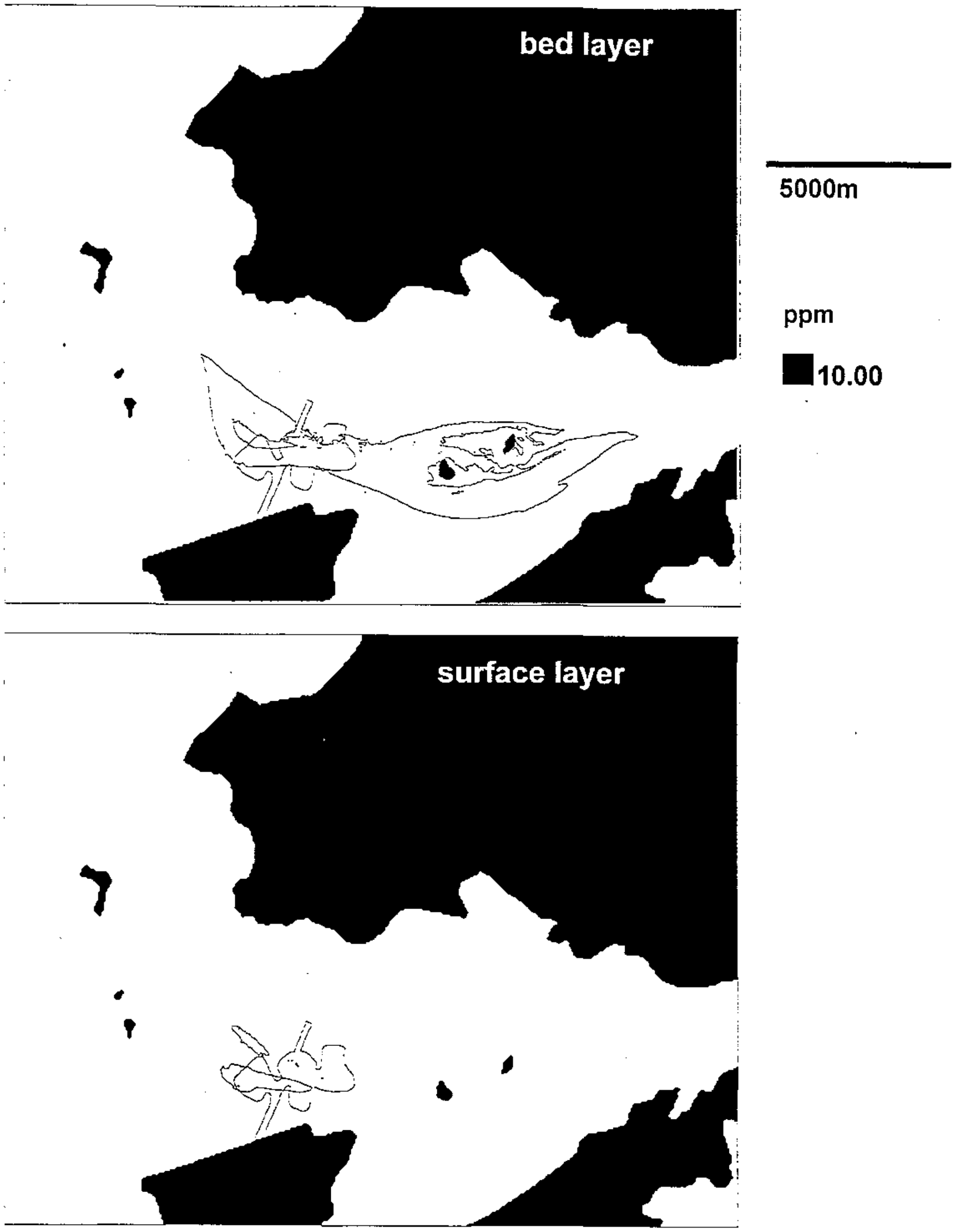

FIGURE O4 - SCENARIO 4: AREA WITHIN WHICH ALL SUSPENDED SEDIMENT WQO EXCEEDANCES WILL BE CONTAINED DURING ONE TIDAL CYCLE AFTER DISPOSAL IN THE WET SEASON (WQO=10mg l-1)

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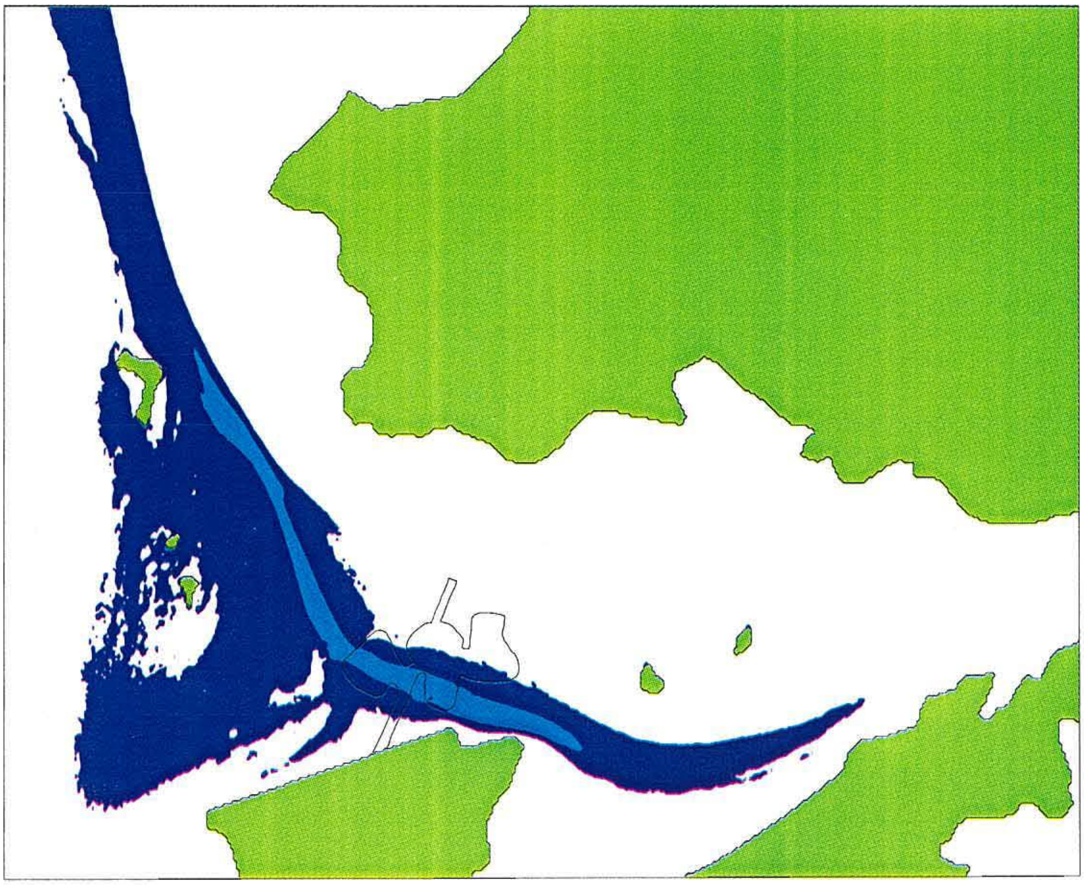
Annex P

Results of Contaminants Modelling

Cadmium (mg/l)	Copper (mg/l)	Lead (mg/l)	Mercury (mg/l)	Nickel (mg/l)	Zinc (mg/l)
1.5×10^{-5} 🟩	6.5×10^{-4} 🟩	7.5×10^{-4} 🟩	1.5×10^{-7} 🟩	4.0×10^{-4} 🟩	2.0×10^{-3} 🟩
1.5×10^{-6} 🟦	6.5×10^{-5} 🟦	7.5×10^{-5} 🟦	1.5×10^{-8} 🟦	4.0×10^{-5} 🟦	2.0×10^{-4} 🟦
1.5×10^{-7} ■	6.5×10^{-6} ■	7.5×10^{-6} ■	1.5×10^{-9} ■	4.0×10^{-6} ■	2.0×10^{-5} ■
Acenaphthylene(mg/l)	Phenanthrene(mg/l)	Fluoroanthene(mg/l)	Benzo(a)pyrene(mg/l)	Total PCBs (mg/l)	Chromium (mg/l)
4.4×10^{-7} 🟩	2.4×10^{-6} 🟩	6.0×10^{-6} 🟩	4.3×10^{-6} 🟩	2.27×10^{-7} 🟩	8.0×10^{-4} 🟩
4.4×10^{-8} 🟦	2.4×10^{-7} 🟦	6.0×10^{-7} 🟦	4.3×10^{-7} 🟦	2.27×10^{-8} 🟦	8.0×10^{-5} 🟦
4.4×10^{-9} ■	2.4×10^{-8} ■	6.0×10^{-8} ■	4.3×10^{-8} ■	2.27×10^{-9} ■	8.0×10^{-6} ■

FIGURE P1 - PREDICTED MEAN ADSORBED CONCENTRATIONS OF METALS AND ORGANICS IN THE SURFACE LAYER



Cadmium (mg/l)	Copper (mg/l)	Lead (mg/l)	Mercury (mg/l)	Nickel (mg/l)	Zinc (mg/l)
1.5×10^{-5} 🟩 1.5×10^{-6} 🟦 1.5×10^{-7} ■	6.5×10^{-4} 🟩 6.5×10^{-5} 🟦 6.5×10^{-6} ■	7.5×10^{-4} 🟩 7.5×10^{-5} 🟦 7.5×10^{-6} ■	1.5×10^{-7} 🟩 1.5×10^{-8} 🟦 1.5×10^{-9} ■	4.0×10^{-4} 🟩 4.0×10^{-5} 🟦 4.0×10^{-6} ■	2.0×10^{-3} 🟩 2.0×10^{-4} 🟦 2.0×10^{-5} ■
Acenaphthylene(mg/l)	Phenanthrene(mg/l)	Fluoroanthene(mg/l)	Benzo(a)pyrene(mg/l)	Total PCBs (mg/l)	Chromium (mg/l)
4.4×10^{-7} 🟩 4.4×10^{-8} 🟦 4.4×10^{-9} ■	2.4×10^{-6} 🟩 2.4×10^{-7} 🟦 2.4×10^{-8} ■	6.0×10^{-6} 🟩 6.0×10^{-7} 🟦 6.0×10^{-8} ■	4.3×10^{-6} 🟩 4.3×10^{-7} 🟦 4.3×10^{-8} ■	2.27×10^{-7} 🟩 2.27×10^{-8} 🟦 2.27×10^{-9} ■	8.0×10^{-4} 🟩 8.0×10^{-5} 🟦 8.0×10^{-6} ■

FIGURE P2 - PREDICTED MEAN ADSORBED CONCENTRATIONS OF METALS AND ORGANICS IN THE BED LAYER

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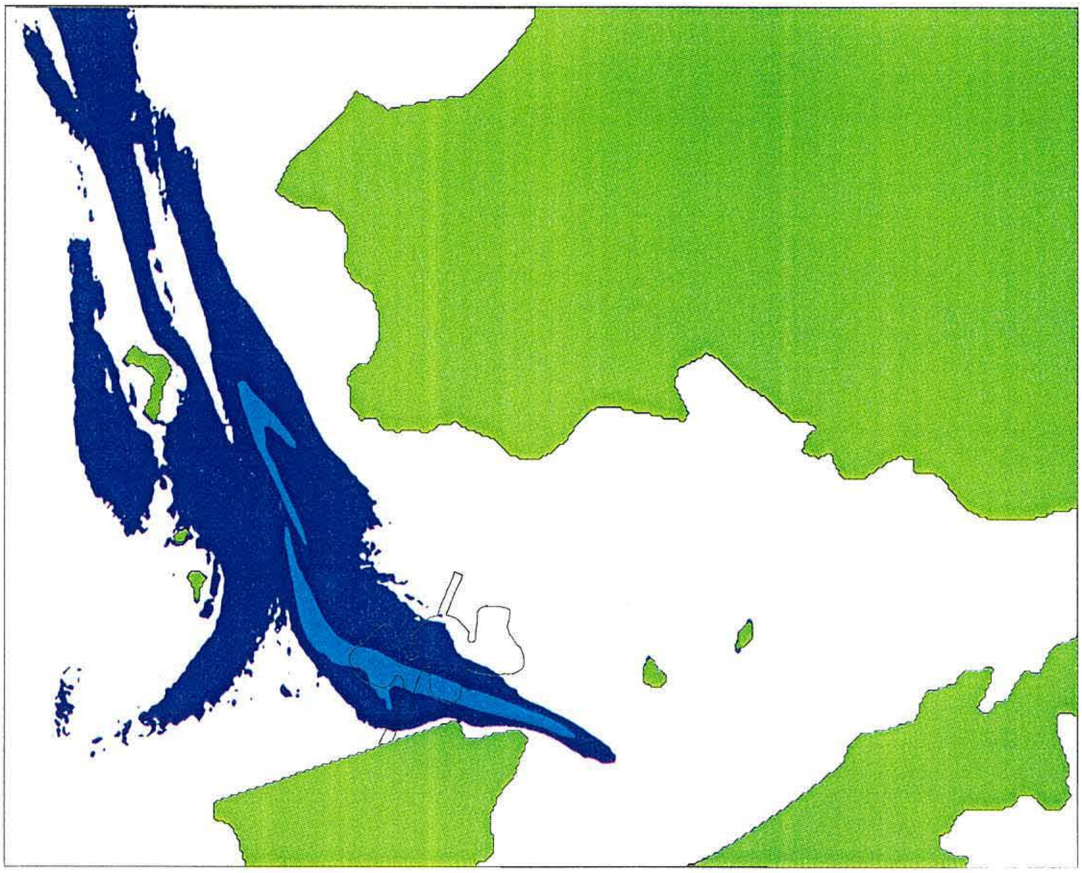
Hong Kong

ERM



Cadmium (mg/l)	Copper (mg/l)	Lead (mg/l)	Mercury (mg/l)	Nickel (mg/l)	Zinc (mg/l)
3.1x10^{-7}-7.6x10^{-6} 🟩 3.1x10^{-6}-7.6x10^{-7} 🟦 3.1x10^{-9}-7.6x10^{-8} ■	1.3x10^{-5}-1.2x10^{-4} 🟩 1.3x10^{-6} -1.2x10^{-5} 🟦 1.3x10^{-7} -1.2x10^{-6} ■	1.5x10^{-6}-1.5x10^{-5} 🟩 1.5x10^{-7}-1.5x10^{-6} 🟦 1.5x10^{-8}-1.5x10^{-7} ■	3.1x10^{-9}-3x10^{-8} 🟩 3x10^{-10} -3x10^{-9} 🟦 3x10^{-11}-3x10^{-10} ■	2.5x10^{-5} -7.5x10^{-5} 🟩 2.5x10^{-6} -7.5x10^{-6} 🟦 2.5x10^{-7}-7.5x10^{-7} ■	4.1x10^{-5}-3.8x10^{-4} 🟩 4.1x10^{-6}-3.8x10^{-5} 🟦 4.1x10^{-7}-3.8x10^{-6} ■
Acenaphthylene(mg/l)	Phenanthrene(mg/l)	Fluoroanthene(mg/l)	Benzo(a)pyrene(mg/l)	Total PCBs (mg/l)	Chromium (mg/l)
9.1x10^{-7} 🟩 9.1x10^{-8} 🟦 9.1x10^{-9} ■	3.7x10^{-6} 🟩 3.7x10^{-7} 🟦 3.7x10^{-8} ■	6.0x10^{-6} 🟩 6.0x10^{-7} 🟦 6.0x10^{-8} ■	5.3x10^{-8} 🟩 5.3x10^{-9} 🟦 5.3x10^{-10} ■	4.7x10^{-10} 🟩 4.7x10^{-11} 🟦 4.7x10^{-12} ■	N/A 🟩 N/A 🟦 N/A ■

FIGURE P3 - PREDICTED MEAN DESORBED CONCENTRATIONS OF METALS AND ORGANICS IN THE SURFACE LAYER

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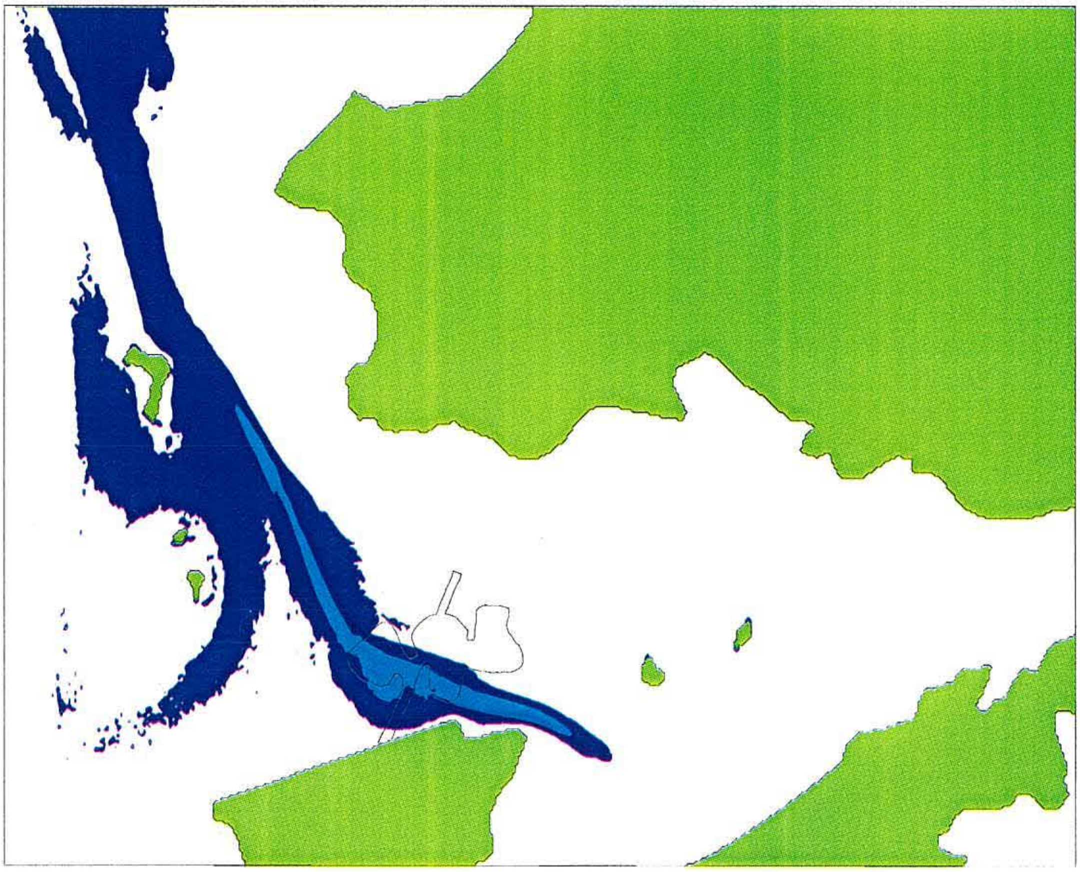
Hong Kong



Cadmium (mg/l)	Copper (mg/l)	Lead (mg/l)	Mercury (mg/l)	Nickel (mg/l)	Zinc (mg/l)
$3.1x10^{-7}$-$7.6x10^{-6}$ 🟩	$1.3x10^{-5}$-$1.2x10^{-4}$ 🟩	$1.5x10^{-6}$-$1.5x10^{-5}$ 🟩	$3.1x10^{-9}$-$3x10^{-8}$ 🟩	$2.5x10^{-5}$ -$7.5x10^{-5}$ 🟩	$4.1x10^{-5}$-$3.8x10^{-4}$ 🟩
$3.1x10^{-6}$-$7.6x10^{-7}$ 🟦	$1.3x10^{-6}$ -$1.2x10^{-5}$ 🟦	$1.5x10^{-7}$-$1.5x10^{-6}$ 🟦	$3x10^{-10}$ -$3x10^{-9}$ 🟦	$2.5x10^{-6}$ -$7.5x10^{-6}$ 🟦	$4.1x10^{-6}$-$3.8x10^{-5}$ 🟦
$3.1x10^{-9}$-$7.6x10^{-8}$ ■	$1.3x10^{-7}$ -$1.2x10^{-6}$ ■	$1.5x10^{-8}$-$1.5x10^{-7}$ ■	$3x10^{-11}$-$3x10^{-10}$ ■	$2.5x10^{-7}$-$7.5x10^{-7}$ ■	$4.1x10^{-7}$-$3.8x10^{-6}$ ■
Acenaphthylene(mg/l)	Phenanthrene(mg/l)	Fluoroanthene(mg/l)	Benzo(a)pyrene(mg/l)	Total PCBs (mg/l)	Chromium (mg/l)
$9.1x10^{-7}$ 🟩	$3.7x10^{-6}$ 🟩	$6.0x10^{-6}$ 🟩	$5.3x10^{-8}$ 🟩	$4.7x10^{-10}$ 🟩	N/A 🟩
$9.1x10^{-8}$ 🟦	$3.7x10^{-7}$ 🟦	$6.0x10^{-7}$ 🟦	$5.3x10^{-9}$ 🟦	$4.7x10^{-11}$ 🟦	N/A 🟦
$9.1x10^{-9}$ ■	$3.7x10^{-8}$ ■	$6.0x10^{-8}$ ■	$5.3x10^{-10}$ ■	$4.7x10^{-12}$ ■	N/A ■

FIGURE P4 - PREDICTED MEAN DESORBED CONCENTRATIONS OF METALS AND ORGANICS IN THE BED LAYER

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