FINAL REPORT

Civil Engineering Department

Environmental Impact Assessment of Backfilling Marine Borrow Areas at East Tung Lung Chau

11 February 1998

ERM-Hong Kong, Ltd
6/F Hecny Tower
9 Chatham Road, Tsimshatsui
Kowloon, Hong Kong
Telephone (852) 2722 9700
Facsimile (852) 2723 5660

ERM

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Reference C1412

For and on behalf of ERM-Hong Kong, Ltd

Approved by: S.M. LAISTER

Signed: SM Laister

Position: Executive Director

Date: 11th February 1998

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1 INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Sand from two Marine Borrow Areas (MBAs) situated adjacent to East Tung Lung Chau has been excavated primarily for the West Kowloon reclamation. As sand extraction is complete (as of July 1996), in accordance with the policy of the Fill Management Committee (FMC), it is proposed to backfill the MBAs and restore the seabed to an environmentally acceptable level. This restoration is expected to produce several benefits including the potential reinstatement of the natural hydrodynamic regime and recolonization of normal benthic assemblages. Backfilling would also provide much needed additional disposal capacity, above that supplied by the open-seafloor disposal sites at South Cheung Chau and East of Ninepins, for uncontaminated marine mud.

The East Tung Lung Chau MBAs (hereafter referred to as the ETLC MBAs) consist of two pits: a deep and distinct borrow pit to the west of the Ninepins Islands and a large, less well-defined area of shallow sand extraction located to the southeast of Tung Lung Chau (*Figure 1.1a*). The deeper, more defined MBA has been excavated to a maximum depth of approximately -47 mPD from a natural sea bed level in this area of approximately -27 mPD. In the larger MBA near Tung Lung Chau, up to 5 metres of sand have been removed in water depths of around -25 to -30 mPD. It is estimated, from bathymetry surveys conducted by the Civil Engineering Department Geotechnical Engineering Office (CED GEO), that the ETLC MBAs collectively have a potential backfilling capacity of over 31 Mm^3. However, since further limited sand extraction may take place in one of the MBAs before backfilling commences, potential backfilling capacities are anticipated to increase.

This Environmental Impact Assessment (EIA) Study for the Backfilling of Marine Borrow Areas (MBAs) at East Tung Lung Chau is prepared by ERM Hong Kong Ltd in association with Dredging Research Ltd, and Hydraulic and Water Research (Asia) Ltd.

1.2 OBJECTIVE OF THE EIA STUDY

The objective of the EIA is to provide information on the nature and extent of environmental impacts arising from the proposed backfilling and to design an environmentally acceptable operations plan. The findings of this Study will contribute to decisions on the overall acceptability of environmental impacts likely to arise as a result of the backfilling activities. The findings will determine operational conditions and requirements including the optimum backfilling levels and rates for the MBAs, to avoid excessive loss of material and impacts to sensitive receivers. The Study will also assess the acceptability of residual impacts after the proposed mitigation measures are implemented. The goal of the Study is to develop a practical and workable approach to resolving key environmental issues, and to allow backfilling to proceed within the proposed time frame without unacceptable environmental impacts.

1.3 *Initial Assessment Report (IAR) Findings*

The IAR for the proposed backfilling was released in November 1995. The overall purpose of the IAR element of the EIA Study was to perform a review of the environmental acceptability of the proposed backfilling operations at the MBAs, and to outline practical and cost-effective mitigation measures to minimize adverse environmental impacts.

The IAR described the existing environment within the study area, including baseline air, noise, water quality and marine ecological conditions. It provided an initial assessment and evaluation of the potential environmental impacts that may arise from the proposed backfilling project. Six possible backfilling scenarios for the MBA were modelled to identify potential impacts requiring mitigation.

The IAR concluded that as there are unlikely to be any insurmountable environmental impacts, backfilling operations at the ETLC MBA are considered environmentally feasible. Key issues warranting further assessment in the EIA were identified and further analyses such as modelling studies, desktop assessments to address remaining data gaps, and design of an appropriate, environmentally-acceptable Operations Plan were proposed.

At the first Study Management Group (SMG) meeting held on 5 June 1996, the SMG agreed that the IAR provides an acceptable basis upon which to proceed to the EIA stage and that the acceptability of the project would be evaluated through this process. The SMG highlighted the importance of further investigation of water quality and sediment transport issues, potential cumulative impacts, and environmental monitoring and audit requirements.

1.4 *Scope of the EIA*

This EIA recommends an Operations Plan for the proposed backfilling project which will maximise use of the MBAs and minimise environmental impacts by incorporating appropriate mitigation measures. The residual impacts resulting after the implementation of these mitigation measures are assessed and the project's overall feasibility determined.

In this EIA, potential environmental impacts that may arise from the proposed backfilling activities are evaluated in terms of water quality and sediment transport, marine ecology, noise and air quality. In order to provide a detailed assessment of the key issues identified in the IAR and highlighted by the SMG, additional information is presented on erosion and deposition, and the marine ecology of the study area. Other detailed assessments conducted for the EIA include modelling of a greater range of possible backfilling scenarios to provide definition of operational design factors to minimise sediment loss. The EIA recommends practical and cost-effective mitigation measures, where necessary, to reduce predicted impacts to acceptable levels. Environmental monitoring and audit (EM&A) requirements necessary to ensure the implementation and effectiveness of these measures are also presented.

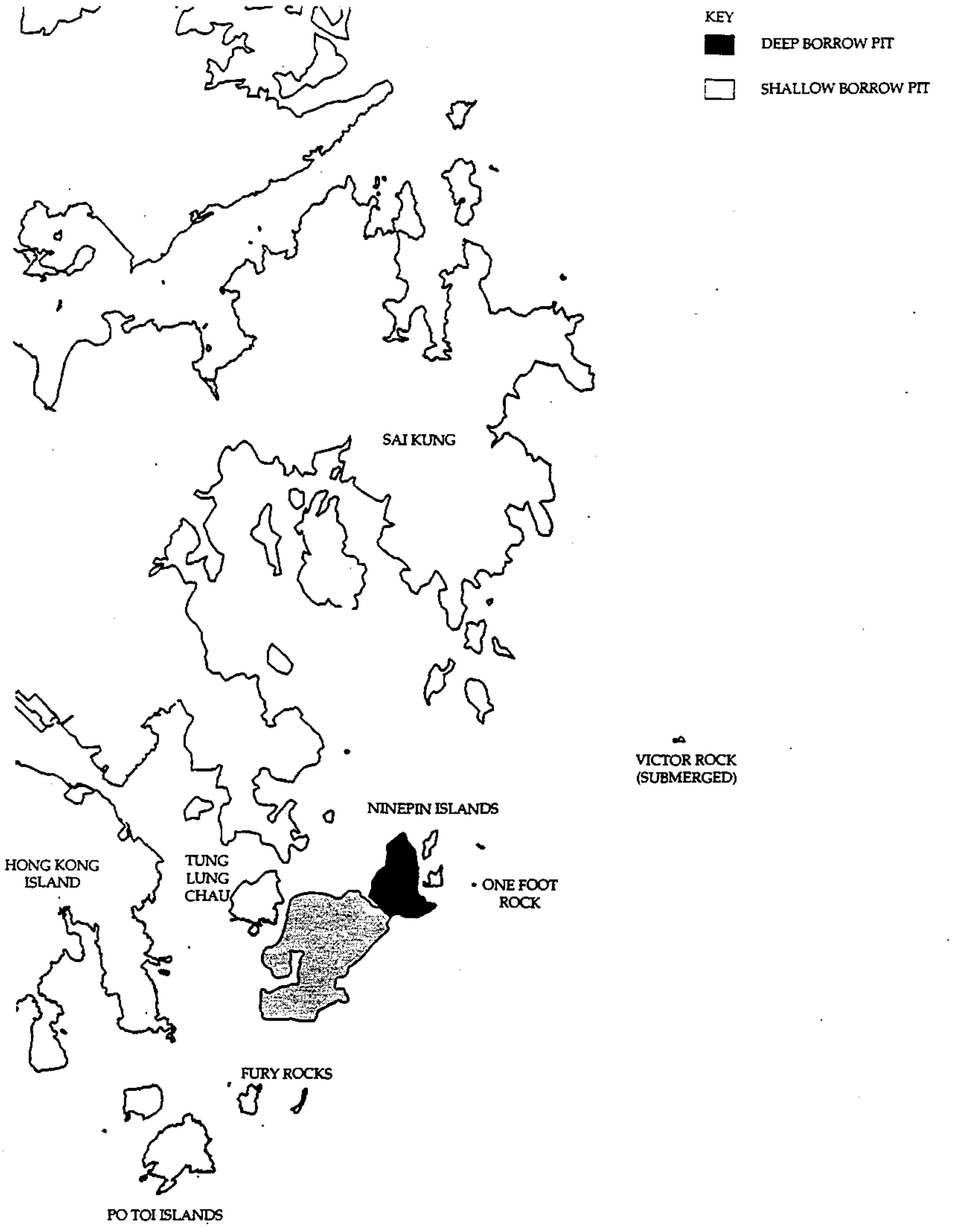

FIGURE 1.1a - LOCATION OF THE EAST TUNG LUNG CHAU MARINE BORROW AREA

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1.5 *STRUCTURE OF THE REPORT*

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

- *Section 2* describes the location of the East Tung Lung Chau MBA, and the proposed project programme, including backfilling methods and engineering requirements;

- *Sections 3, 4, 5 and 6* define and assess potential environmental impacts which may arise from backfilling operations with respect to water quality and sediment transport, marine ecology, noise, and air quality, respectively. These sections also outline possible mitigation measures and environmental monitoring and audit requirements;

- *Section 7* summarises the findings of the EIA study and describes the mitigation measures necessary for the project to proceed in an environmentally-acceptable manner.

2 PROJECT DESCRIPTION

2.1 INTRODUCTION

This section describes the engineering design of the proposed backfilling of the ETLC MBAs. The following information is presented:

- a description of the site, including its location, area, bathymetry and dredging history;
- the methods used for the transport and disposal of dredged material;
- the projects in Hong Kong that will generate surplus mud during the period January 1998 to January 2001 and which are potential sources of backfill material;
- an Operations Plan based on the results of the IAR which will be evaluated in the remainder of this report.

2.2 SITE DESCRIPTION AND HISTORY

The ETLC MBAs cover an area of 18 km^2 and comprise of a series of shallow depressions in the sea bed at the southwestern end and one deep pit at the northern end. The MBAs extend from the western side of the Ninepins Group to the seaward end of the Tathong Channel. Natural seabed levels in this area are typically in the range of -27 to -30 mCD (CD is 0.146 metres below PD).

The majority of the southwestern MBA was dredged to exploit surface sands, principally for the West Kowloon Reclamation, and the depth of dredging has extended to between 1 and 5 m. Close to the Ninepins, there exist two conjoined pits, which form the northeastern (deep) pit and which have been dredged to a maximum depth of approximately -47 mCD. The total combined area of these pits is a little over 2 km^2.

Figure 2.2a shows the location and bathymetry of the proposed backfill area. The bathymetry is based on several surveys carried out during 1993-1994, which were compiled by the Fill Management Committee (FMC) in February 1995. This bathymetry is an accurate representation of the present condition of the MBAs. For the purposes of this EIA it has been assumed that backfilling will only take place within areas bounded by closed contours, ie fully-enclosed depressions in the seabed. These may be divided into three areas with the following void volumes:

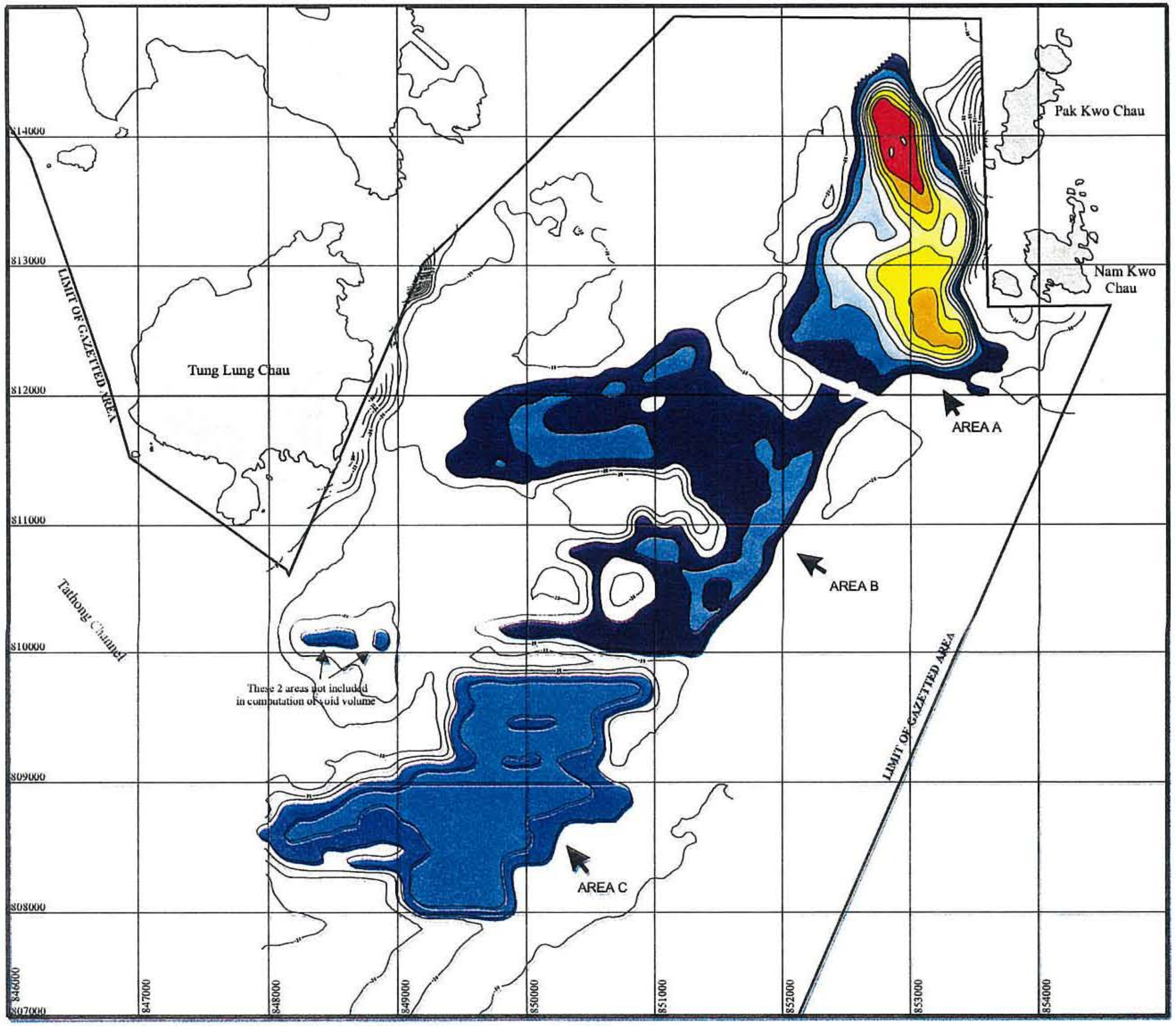
- Area A, the conjoined deep pits adjacent to the Ninepins, has a void volume of 17.9 Mm^3;
- Area B, the area of surface dredging east of Tung Lung Chau has a void volume of 6.6 Mm^3; and
- Area C, the area of surface dredging southeast of Tung Lung Chau has a void volume of 7.0 Mm^3.

As the physical characteristics of Areas B and C are similar, and therefore, the environmental impacts associated with backfilling the two areas are likely to be similar, for the purposes this study Areas B and C are considered together as one large pit, hereafter referred to as the southwest, or shallow, MBA. The present void volume for the southwest MBA is thus approximately 13.6 Mm^3 but may increase in the future if the dredging of sand for Tseung Kwan O reclamation progresses. A detailed breakdown of pit volumes is given below in *Table 2.2a*. The potential backfill volumes are given at one-metre intervals below - 30 mCD. The volumes have been calculated by considering the areas of closed contours and assuming a 1 m thick layer at each contour.

Table 2.2a *Potential Backfilling Volumes of Areas A, B and C in the ETLC MBA*

Level m-CD	**Volumes**				**%**
	Area A	Area B	Area C	Total	
30	2,542,265	3,602,715	2,853,484	8,998,464	28.56
31	2,282,275	2,425,717	2,332,224	7,040,216	22.34
32	2,018,443	539,831	1,761,014	4,319,288	13.71
33	1,808,402	49,949	64,036	1,922,387	6.10
34	1,623,975			1,623,975	5.15
35	1,476,691			1,476,691	4.69
36	1,287,142			1,287,142	4.08
37	1,109,119			1,109,119	3.52
38	952,229			952,229	3.02
39	820,953			820,953	2.61
40	676,230			676,230	2.15
41	461,066			461,066	1.46
42	345,799			345,799	1.10
43	205,238			205,238	0.65
44	162,654			162,654	0.52
45	103,739			103,739	0.33
46	4,483			4,483	0.01
TOTALS	17,880,703	6,618,212	7,010,758	31,509,673	100

As shown in *Table 2.2a*, the total void volume of the MBAs is approximately 31.5 Mm^3. Despite the considerable depth of the two conjoined pits adjacent to the Ninepins (Area A), more than 50% of the present pit volume lies above - 32.0 mCD. It should be noted that the volumes given in *Table 2.2a* are smaller than the volume which has been dredged from the area since a large proportion of the dredged volume was removed from a gentle bathymetric high which extended southwest from the Ninepins, only traces of which now remain.



SEABED LEVEL (metres below CD)

- 30 - 32
- 32 - 34
- 34 - 36
- 36 - 38
- 38 - 40
- 40 - 42
- 42 - 44
- 44 - 46
- Deeper than - 46 mCD

Levels above -30 mCD as indicated on drawing.

This plan is based on bathymetric data provided by GEO, acquired during various surveys undertaken in 1993-4.

The bathymetry is believed to be a fair representation of the present situation except in the TKO allocation where dredging is still in progress.

2,000 metres

Approximate void volumes:
Area A: 17.9 M cubic metres
Area B: 6.6 M cubic metres
Area C: 7.0 M cubic metres

FIGURE 2.2a - LOCATION PLAN AND BATHYMETRY OF THE EAST TUNG LUNG CHAU MARINE BORROW AREAS

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Tsimshatsui, Kowloon
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2.3 *Backfill Material, Transport and Disposal*

In Hong Kong dredging is typically conducted using either grab dredgers, which load barges for transport to the disposal site, or trailing suction hopper dredgers which are able to transport the dredged material directly. In a limited number of cases, cutter suction dredgers have been used to load barges or to pump mud to re-handling pits where it is has been dredged later by trailer dredgers. The source of material is discussed in *Section* 2.4.

2.3.1 *Trailer Dredgers*

Trailer dredgers are self-propelled, sea-going vessels. They comprise a large hold (hopper) for the storage and transport of dredged material. They dredge by lowering suction pipes to the seabed and pumping the material into the hopper as a dilute soil-water slurry while slowly moving forwards. The majority of trailers are equipped with two suction pipes, one on each side of the vessel, and the pipes terminate in a large, hinged, rectangular draghead which ensures good contact with the seabed. The dredging pumps are usually mounted inboard but some trailers have an additional pump mounted on the suction pipe in order to improve efficiency when working at great depths. Trailers come in a wide variety of sizes ranging from a hopper capacity of a few hundred cubic metres up to 17,500 m^3. The majority of trailers which have worked in Hong Kong in recent years have been in the range of 5,000-10,000 m^3 hopper capacity. When fully loaded, the dredger sails to the disposal area or to the reclamation site. The dredged material is normally discharged by dumping through doors or valves in the bottom of the hold.

A limited number of trailer dredgers have the ability to place material through one or both suction pipes. The pipe can be lowered so that the draghead lies on, or just below, the seabed and the dredged material is slowly released by controlled pumping. In this case, the pump is used as a brake to slow the discharge rate.

2.3.2 *Grab Dredgers and Barges*

Grab dredgers comprise a pontoon-mounted crane equipped with a four-point anchoring system. The material is excavated using a grab bucket and discharged into a barge moored alongside the dredger. Grab dredgers are common in Hong Kong and are generally classified according the volume of the grab, with 8-10 m^3 the most frequently used size. The barges used to transport the dredged material to the disposal area usually range in size between 400 and 1,000 m^3 hopper capacity. The barges normally used in Hong Kong are towed by a tug but self-propelled barges are common elsewhere. The barges discharge through a series of doors in the bottom or by splitting the full length of the hull.

An alternative discharging procedure, but one which is slow, difficult and costly, is to unload the barge using a grab and to discharge the material through a tremie pipe extending down to the seabed. This is not considered to be a practical proposition at the ETLC MBAs because the proposed backfilling area is exposed and subject to sea swell which would lead to damage if barges were to be moored alongside the unloading barge.

2.3.3 *Backfilling Methods*

The three main potential backfilling methods are thus:

- simple bottom-dumping from trailer dredgers;
- controlled discharge through the suction pipe(s) from trailer dredgers;
- simple bottom-dumping from barges.

In all cases it has been assumed that disposal vessels will be moving at a speed of 2-3 knots while dumping.

2.4 *PROJECT PROGRAMME*

The programme for backfilling operations will depend on the rate at which surplus uncontaminated mud is generated and the maximum rate at which disposal can occur without unacceptable environmental impact. A list of projects which will produce surplus muds within a 4 year period beginning January 1998 is presented in *Table 2.4a*. The table shows that the demand for mud disposal sites from identified projects will be greatest at the beginning of this period. Demand for disposal in later years may increase as additional projects are conceived and developed.

If the ETLC MBAs are approved as a disposal site for uncontaminated materials, materials which are currently being disposed of at the East of Ninepins open seafloor disposal site will be diverted to the ETLC MBAs. The current rate of disposal at the East of Ninepins site is 10 Mm^3year^{-1}. This equates to daily disposal rates of approximately 27,000 m^3 which is considerably below the combined rates proposed in the Operations Plan detailed in *Section 2.5.4* of 50,000 m^3 for the northeastern (Area A) and southwestern (Area B) parts of the MBAs and 25,000 m^3 for the central part of the MBAs (Area C). At this rate, the backfilling of the MBA could be completed in approximately three and a half years.

The relative proportions of grab dredged material and trailer dredged material cannot be estimated for the above projects at this time. However, it can reasonably be assumed that small inshore projects will use grab dredgers, while larger projects, over approximately 200,000 m^3, will involve both grab and trailer dredgers.

Table 2.4a ***Uncontaminated Mud Disposal Requirements for the period January 1998 to December 2001***

Project	**Surplus Uncontaminated Mud Volumes (Mm^3)**			
	1998	**1999**	**2000**	**2001**
Container Terminal No. 9 (CT9)	6.27	6.27	6.84	
Dredging Area of Kellett Bank for 6 Government Moving Buoys	1	0.4		
Kau Hui Development - Engineering Works, Area 16, Yuen Long		0.02	0.03	0.01
Kowloon Point Development				0.15
Lantau Port Development	11.79	15.39	8.79	0.79
Main Drainage Channel& Poldered Village Protection Scheme for San Tin	0.08			
Main Drainage Channels for Fanling, Sheung Shui & Hinterland	0.29	0.52	0.63	0.47
Mainland North Division Maintenance Contract	0.01			
Maintenance& Repairs to Seawalls, Piers & Other Port Works	0.25			
Maintenance Dredging of Yau Ma Tei Anchorage	0.6			
Ngau Tam Mei Drainage Channel	0.06	0.12	0.11	0.07
North Lantau Development (NON ACP)	0.05			3.00
Peng Chau Development PKG3, Stage I (PWP NO. 112CL/A)	0.02			
Peng Chau Development PKG4 (PWP No. 193CL/B)	0.07			
Peng Chau Typhoon Shelter		1	3.5	2.1
Regulation of Shenzhen River, Stage II Remaining Work	1	1	0.35	
Sham Tseng Sewerage Treatment & Disposal Facilities	0.01			
Shek Wu Hui Development, Package 4, Engineering. Works	0.09	0.1	0.05	
Shenzhen River Improvement works, Stage II Advance Work	1	1	0.35	
Siu Lam Typhoon Shelter		2.5	0.3	
Tseung Kwan O Development	0.92	0.4	0.54	0.71
Tseung Kwan O Port Development Area 137 Stage I	1.16			
Tuen Mun Area 38 Special Industries Area Reclamation	0.11			
Tung Chung Development Phase IIA - Infrastructure & Reclamation	0.05			
Village Flood Protection for Yuen Long, Kam Tin & Ngau Tam Mei	0.01			
West Kowloon Reclamation (South)			0.21	
Yuen Long (SW) Extension - Site Formation RD & Drain. work	0.05	0.3	0.03	0.01
Yuen Long / Kam Tin Drainage Channels	0.07	0.06	0.06	0.03
Yuen Long East Comprehensive Development Area	0.02	0.02		
Total	25.0	29.1	21.8	7.3

Source: Fill Management Development Committee Database of Fill Requirements and Surpluses August 1996

2.5 DESIGN OF THE OPERATIONS PLAN

2.5.1 *Introduction*

The impacts of backfilling operations can be mitigated by controlling the following factors:

- daily disposal rates;
- the location of disposal according to the prevailing seasonal current direction;
- the type of material (barge or trailer) to be disposed in a given area; and,
- the level to which the MBAs are filled.

During the IAR three disposal scenarios simulating a range of rates and disposal locations in both wet and dry seasons were modelled. The first scenario simulated disposal of 100,000 m^3day^{-1} of material into the northeast corner of the MBAs (Area A) under wet and dry season conditions on spring tides. The second scenario was the same as the first except that the disposal rate was halved to 50,000 m^3day^{-1}. The third scenario was the same as the second except that it also included disposal of 50,000 m^3day^{-1} in the southwest MBA (Area B/C). Results indicated the following:

- there are seasonal trends in the transport of suspended sediments corresponding to seasonal changes to the current regime;
- elevations of suspended sediments at sensitive receivers occur to the northeast of the pit during the first scenario;
- depletions of DO and elevations of nutrients are negligible in comparison to background levels.

An Operations Plan was developed based on these results with the objective of backfilling as much of the MBAs as possible at a rate which would not cause unacceptable environmental impacts. The plan specifies the rate and location that backfilling can occur according to the season and the type of material for disposal. The rationale behind the development of the Operations Plan is described below.

2.5.2 *Disposal Locations*

Experience gained at South Cheung Chau and East of Ninepins disposal sites shows that as long as disposal contractors are given a reasonably-sized area in which to dispose of spoil, out-of-area disposal is minimal. Disposal areas of approximately 800 m to 1000 m by 350 m to 500 m are in use at these sites, and similar sized areas are envisaged for East Tung Lung Chau. These areas are presented in *Figure 2.5a*. Note that none of these areas are within 150 m of the edge of the pits (see *Section 3.5.3*) and that they are all at a considerable distance from the boundary of the gazetted area.

The direction and strength of currents in the study area influences the impacts of disposal operations as they determine where suspended sediments are transported and hence which sensitive receivers are affected. As a result, the

FIGURE 2.5a - PROPOSED MUD DISPOSAL AREAS IN THE ETLC MBAs
Source: FMC/344, Civil Engineering Dept

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environmental impact of backfilling operations can be mitigated by specifying the location of disposal according to the prevailing currents (which are described in greater detail in *Section 3.3.1*).

During the dry season currents typically flow to the southwest. By restricting disposal operations to the northeast MBA (Area A) at this time, the transport of suspended sediments from the MBA to the northeast, which could result in impacts to sensitive receivers around the Ninepins Group, can be avoided as the plume generated by the disposal activities will be carried southwest over the MBAs. By the time the plume crosses the southwestern boundary of the MBAs the suspended sediment concentration will have decreased markedly and impacts to sensitive receivers lying southwest of the MBA will be unlikely.

Conversely, during the wet season currents typically flow to the northeast. By restricting disposal operations to the southwest MBA (Area C) at this time, the transport of suspended sediments from the MBA to the southwest can be avoided as the plume generated by the disposal activities will be carried northeast over the MBAs. By the time the plume crosses the northeastern boundary of the MBAs the suspended sediment concentration will have decreased markedly and impacts to sensitive receivers to the northeast will be unlikely.

In between the wet and dry seasons are transition periods during which currents may change direction. It is therefore more difficult to optimise disposal locations in the MBAs during these periods. The frequency throughout the year at which wet (NE) season and dry (SW) season currents occur and the velocities of these currents are presented in *Table 2.5a*. These data were derived from measurements from long term (July 1992 to July 1993) seabed ADCP deployments in the Eastern Waters of Hong Kong. The data show that for a significant part of the year (mid-March to mid-May and mid-August through September) the currents are in a transitional state during which rapid switching (perhaps as frequently as daily) from wet to dry season conditions can take place. As it is not possible to predict the direction of the currents during these periods, it is proposed that disposal is confined to the central part of the MBA, approximately equidistant from the sensitive receivers and that the disposal rates are reduced from the maxima allowed at either end of the MBA.

In order to avoid mounding (inadvertent backfilling above pre-existing seabed levels), only trailer dredged material will be disposed in the southwestern (shallow) MBA. Grab dredged materials, which following disposal can sustain higher repose angles than trailer dredged material and is thus more prone to mounding, will be restricted to disposal in the northeastern (deep) MBA. Periodic bathymetric monitoring, which will be conducted as part of the EM&A programme, will be used to confirm that mounding and excessive loss of fluid mud do not occur.

Table 2.5a *Offshore Current Set and Maximum Speeds - Eastern Waters*

Set	Percentage of time current sets in a particular direction & approximate maximum current speed.											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
015	-	-	3% 0.8kt	11% 1.2kt	9% 1.2kt	5% 1.2kt	5% 1.2kt	5% 1.2kt	8% 1.2kt	1% 0.4kt	-	-
045	-	-	6% 0.8kt	16% 1.2kt	19% 1.2kt	31% 1.2kt	67% 1.6kt	19% 1.2kt	14% 1.2kt	1% 0.4kt	1% 0.4kt	-
075	-	-	8% 0.8kt	11% 1.2kt	24% 1.2kt	45% 1.2kt	28% 1.6kt	20% 1.2kt	13% 1.2kt	1% 0.4kt	-	-
105	-	-	2% 0.8kt	2% 0.8kt	7% 0.8kt	6% 1.2kt	-	-	5% 1.6kt	2% 0.4kt	-	-
135	1% 0.8kt	1% 0.8kt	2% 0.4kt	1% 0.8kt	3% 0.8kt	-	-	-	3% 1.2kt	1% 0.4kt	1% 0.4kt	1% 0.4kt
165	2% 0.8kt	1% 0.4kt	-	1% 0.8kt	-	1% 0.8kt	-	3% 1.2kt	1% 0.6kt	1% 0.4kt	3% 0.8kt	-
195	5% 0.8kt	7% 1.2kt	6% 0.8kt	2% 0.8kt	1% 0.4kt	1% 0.8kt	-	6% 1.2kt	3% 0.6kt	7% 0.8kt	7% 0.8kt	8% 0.8kt
225	29% 1.2kt	31% 1.6kt	24% 1.2kt	8% 1.2kt	3% 0.8kt	4% 1.2kt	-	15% 1.2kt	10% 1.2kt	31% 1.2kt	30% 1.6kt	30% 1.2kt
255	59% 1.6kt	53% 1.6kt	38% 1.2kt	30% 1.6kt	13% 1.2kt	5% 1.6kt	-	21% 1.6kt	22% 1.6kt	44% 1.2kt	48% 1.6kt	50% 1.6kt
285	4% 1.2kt	7% 1.2kt	6% 1.2kt	10% 1.2kt	10% 1.2kt	-	-	5% 1.2kt	8% 1.2kt	5% 0.8kt	8% 1.2kt	8% 1.2kt
315	-	-	2% 0.4kt	4% 0.8kt	6% 0.8kt	2% 0.8kt	-	4% 0.8kt	5% 1.2kt	4% 0.4kt	2% 0.8kt	3% 0.8kt
345	-	-	6% 0.8kt	4% 0.8kt	5% 0.8kt	-	-	2% 0.8kt	6% 1.2kt	2% 0.4kt	-	-

Notes: Shaded areas show percentages exceeding 20.
Source: Data derived from a seabed-mounted ADCP at a station located due east of the Ninepins and just outside the boundary of the waters of the SAR.

2.5.3 *Disposal Rates*

During the IAR, in consultation with CED GEO, backfilling rates of 100,000 m^3day^{-1} and 50,000 m^3day^{-1} (*in situ* volume) were selected for the initial modelling. Following the IAR, the maximum rate proposed for disposal in the northeastern part of the MBA (Area A) was reduced to 50,000 m^3day^{-1}. The same rate of 50,000 m^3day^{-1} was proposed in the southeast MBAs (Area C) and a reduced rate of 25,000 m^3day^{-1} was proposed for the central portion of the MBAs (Area B). Simulations of these disposal rates have been conducted using mathematical modelling and the results are presented in *Section 3.8* and *Annexes D* to *F*.

The rates quoted above are based on hopper volumes. These volumes are higher than the *in situ* volume of material which is dredged because of the dilution which takes place during the dredging process. There is wide variation in the density of marine mud but, at most sites, the bulk density at the surface is of the order of 1.4 Mg m^{-3} rising to about 1.6 Mg m^{-3} at a depth of 10 m[1][2][3]. For trailer dredgers, the density of mud which is delivered to the hopper depends partly on the *in situ* density and partly on factors such as the degree of confinement of the site, whether Lean Mixture Over Board (LMOB) systems are used, and the sea conditions during dredging. Hopper densities are generally found to lie in the range 1.2 - 1.4 Mg m^{-3} [4][5][6]. For grab-dredged material loaded into barges, the degree of dilution is generally low and therefore hopper densities for grab dredged material are typically higher than hopper densities for trailer dredged material.

2.5.4 *The Operations Plan*

The Operations Design, given in *Table 2.5b* below, is based on the disposal location and disposal rate information presented in *Sections* 2.5.2 and 2.5.3.

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(3) Guildford C M and Chan H C (1969) Some Aspects of the Plover Cove Dam Proc of the 7th Intl Conference on Soil Mechanics and Foundation Engineering Mexico City Vol 2 291-299

(4) Engineering Geology, Ltd (1988) Tin Shui Wai Development Bottom Dumping of Borrow Area Overburden: Report and Assessment of the Wiesbaden Dumping Trials Report to Bilfinger and Berger Dredging BV

(5) Binnie Consultants, Ltd (1993) Report on Surveys and Dumping Experiments undertaken in the Redundant Marine Borrow Pits of Blackpoint in Urmston Road Report to GEO/CED under Fill Management Study - Phase II

(6) Dredging Research, Ltd (1996) Measurements of Sediment Transport after Dumping from Trailing Suction Hopper Dredgers in the East Tung Lung Chau Marine Borrow Area Report to GEO/CED under Agreement CE2/93

Table 2.5b *Operational Design including Disposal Rates, Material Requirements and Location by Season*

Season	Maximum total daily disposal (m^3 in hopper)	Disposal Areas for Grab-Dredged Material[(a), (b)]	Disposal Areas for Trailer-Dredged Material[(a)]
Dry season: beginning of October to mid-March (5.5 months)	50,000	1,2 only	1,2,3 only
Wet season: mid-May to mid-August (3 months)	50,000	none	7,8,9 only
Transitional seasons: mid-March to Mid-May (2 months) mid-August to end of September (1.5 months)	25,000	none	4,5,6 only

(a) Disposal Areas referred to are presented in *Figure 2.5a*

(b) Disposal of grab-dredged Material is only proposed for the northeast deep MBAs due to concerns associated with mounding of grab-dredged material in the southwest shallow MBAs

In addition to the operational design features presented above, the Operations Plan includes the following conditions on backfilling activities:

- backfilling operations at ETLC MBAs will be prohibited during dredging and or backfilling in the Eastern Waters Marine Borrow Area;
- backfilling at ETLC MBAs prohibited during dredging in the Tathong Channel and West/East Po Toi MBAs and during reclamation activities at Tseung Kwan O;
- backfilling of the ETLC MBAs and concurrent disposal at the East of Ninepins Disposal Site will not be authorised since the former is intended to replace the latter;
- trailer dredgers shall be stationary while dumping and shall not wash out their hoppers after dumping;
- the level to which the MBAs are backfilled will be controlled to avoid mounding above the surrounding seabed in the MBAs and to ensure the deposited material will remain stable (see *Section* 3.9 for details);
- to minimise the erosion of unconsolidated material in the MBAs, backfilling operations should cease upon the hoisting of the Typhoon Signal 3 (see *Section 3.9* for details).
- in order to avoid disruption to fishing activities, if a fishing vessel is working at the disposal location, the disposal vessel will be required to wait until the fishing vessel has left the disposal area (ie moved more than 1 km away from the area). A mechanism to deal with complaints and non-compliance cases will be developed and implemented.

The Operations Plan may be modified according to the results of environmental monitoring during backfilling operations to incorporate further environmental impact mitigation measures, which may include alternative limits on the volume of disposal, the backfill level, spatial and temporal restrictions, the rate of disposal, and marine traffic restrictions in addition to plant maintenance and working method measures.

2.5.5 *Control of Backfilling Operations*

The success of measures incorporated in the Operations Plan to mitigate the environmental impact of disposal operations will depend on the effectiveness of control of disposal rates and disposal locations. FMC Allocations, EPD Dumping Permits and the EPD black box vessel position recording system are proposed to achieve this control. Similar arrangements, administered jointly by FMC and EPD, are in place at the South Cheung Chau and East of Ninepins open seafloor disposal sites, where they are operating smoothly and effectively.

2.5.6 *Flexibility of Backfilling Operations*

Because the ETLC MBAs are intended to be just one of Hong Kong's several disposal sites for uncontaminated mud, there will be alternative disposal facilities available should unexpected problems arise with the use of ETLC MBAs. This flexibility will serve to provide additional reassurance until there are sufficient EM&A results to demonstrate the acceptability of the operations.

2.6 *MARINE TRAFFIC*

The Marine Department advises that, with the exception of the extreme southwestern part of the ETLC MBAs, which is at the end of the Tathong Channel Traffic Separation Scheme, the proposed backfilling area is not frequented by large vessels. Fishing boats are the most numerous users of the area but they are generally in transit to more distant fishing grounds. There is a steady flow of small coastal freighters en route to and from Hong Kong which pass over the area from northeast to southwest (and vice versa). Informal observations made by team members made during recent surveys of the area (unconnected with this Study) suggest that approximately 10-15 such vessels cross the area per hour, including a limited number of towed barges. Marine Department expect that such traffic will increase in the future as the Port of Yantian, at the head of Mirs Bay, increases in importance. In addition, pleasure craft, both powered and under sail, use this area. The majority of this traffic is confined to the western side of the MBAs, near Tung Lung Chau, but occasional visits are made to the Ninepins Group.

The Marine Department has indicated that no particular problems concerning navigation issues are foreseen during the proposed backfilling at the rates which have been considered in this EIA. The backfilling will, in essence, be the reverse of the original dredging operation which created the pits, during which it is understood that no problems arose. Even if the backfilling is eventually undertaken using barges, the net effect will be a simple diversion of an existing traffic flow to and from the East of Ninepins disposal site and no difficulties are expected to arise. However, Marine Department have asked to be consulted again on these matters if larger traffic flows are expected to be generated by any significantly increased rate of backfilling.

3 WATER QUALITY

3.1 INTRODUCTION

This section presents an assessment of potential water quality impacts associated with proposed backfilling operations at the ETLC MBAs. The objective is to predict the extent, magnitude and acceptability of the potential impacts, and to test the effectiveness of mitigation measures identified during the Initial Assessment Report (IAR).

Predictions of the effects of backfilling operations have been made using hydrodynamic and water quality mathematical modelling. The results are presented with a discussion of the acceptability of predicted potential impacts. Information on the existing hydrodynamic, water quality and sediment quality characteristics of the Study Area is presented as background information. In addition, the stability of deposited material has been assessed under various tidal and wave (storm) conditions and a suitable levels for backfilling are recommended.

3.2 STATUTORY REQUIREMENTS AND EVALUATION CRITERIA

The acceptability of water quality impacts will be determined through comparisons with statutory requirements. Under the Water Pollution Control Ordinance, Hong Kong waters are subdivided into 10 Water Control Zones (WCZs). Each WCZ has a designated set of statutory Water Quality Objectives (WQOs).

The ETLC MBAs proposed for backfilling are situated within the Mirs Bay WCZ (MBWCZ) and therefore the WQOs for the MBWCZ are applicable as evaluation criteria for assessing water quality impacts resulting from backfilling operations. In addition, initial modelling results conducted for the IAR indicated that sensitive receivers which are located within the Southern Water Control Zone (SWCZ) and the Eastern Buffer Water Control Zone (EBWCZ) may be impacted by backfilling operations. Therefore, the WQOs for these two zones are also applicable as evaluation criteria for sensitive receivers located within these WCZs. The locations of the MBAs and the WCZs are presented in *Figure 3.2a*. Since only sediment classified as uncontaminated, according to applicable regulation criteria, will be disposed at the ETLC MBAs, the WQOs for suspended solids (SS), dissolved oxygen (DO) and nutrients will be of greatest relevance in assessing compliance with statutory requirements. These criteria are as follows for the three WCZs of interest:

- Suspended Solids (SS): Marine activities must not raise the natural ambient SS level by 30% or cause the accumulation of SS which may adversely affect aquatic communities (MBWCZ, SWCZ and EBWCZ);

- Dissolved Oxygen (DO): DO within 2 m 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 (not less than 5 mg l^{-1} for fish culture zones) (MBWCZ, SWCZ and EBWCZ);

- Nutrients: Nutrients shall not be present in quantities that cause excessive algal growth. Annual mean depth averaged inorganic nitrogen should not exceed 0.3 mg l^{-1} (MBWCZ), 0.1 mg l^{-1} (SWCZ) and 0.4 mg l^{-1} (EBWCZ).

3.3 *BASELINE CONDITIONS*

3.3.1 *Hydrodynamics*

The hydrodynamic characteristics of the Study Area are largely determined by the interaction of offshore wind driven oceanic currents and inshore tidal currents. The ETLC MBAs lie in the transition zone between the two, and although oceanic currents predominate, tidal currents are sufficient to cause changes in current magnitude and direction. In addition, currents are affected by short term weather fluctuations including storm surges and typhoons, and on rare occasions the influence of the Pearl River discharge can reach the Study Area.

Surface oceanic currents follow the prevailing winds and flow predominantly in a north-easterly direction in the wet season and south-westerly in the dry season. Wet season conditions are generally stable only during the months of mid-May to mid-August. Dry season currents are reasonably stable during the period October to mid-March. Outside of these times, in the months of March/April/May and August/September, are transitional periods during which time the currents may vary between wet and dry season conditions. These semi-predictable seasonal currents are presented in *Figures 3.3a* and *3.3b*. As shown in *Table 2.5a*, dry season current speeds are slightly higher than wet season current speeds.

The influence of tidal currents increases westward from the MBAs. West of the Ninepins Group, the tide may play a dominant role in current patterns, with tidal reversals in current direction commonly occurring. The flood tide flows generally to the west-southwest between the Ninepins Group and Basalt Island, and along the coast to the southwest toward Cape D'Aguilar. Minor, weak currents flow up into Port Shelter and Rocky Harbour Bays. Strong currents flow around the south side of Tung Lung Chau and into the Tathong Channel of Victoria Harbour. On the ebb tide this flow pattern is reversed as water moves out of Victoria Harbour along the Tathong Channel, slowly eastward and northeastward along the coast, slowly eastward out of the bays, and easterly through the Ninepins and Basalt Island.

Tidal divergence and convergence in the Study Area immediately southwest of the Ninepins result in areas of slower current movement (<0.1 m s^{-1}). These slower surface currents, in the vicinity of the northeast (deep) MBA, tend to promote sediment deposition, and vary with season and depth as well as tidal flows. These currents compare with moderate to faster moving surface currents (0.3 - 0.5 m s^{-1}) immediately east-southeast of Tung Lung Chau in the southwest (shallow) MBA. In this part of the Study Area, seasonal ocean circulation patterns apparently play a larger role in the development of currents. As stated previously, dry season currents are relatively greater than wet season currents, but tidal influences play an increasingly dominant role in inshore areas.

In coastal waters, conditions can vary from being well mixed in the winter dry season to being highly stratified in the summer wet season when a layer of brackish water introduced from various stream and river sources overlies the denser, more saline oceanic waters near the seabed.

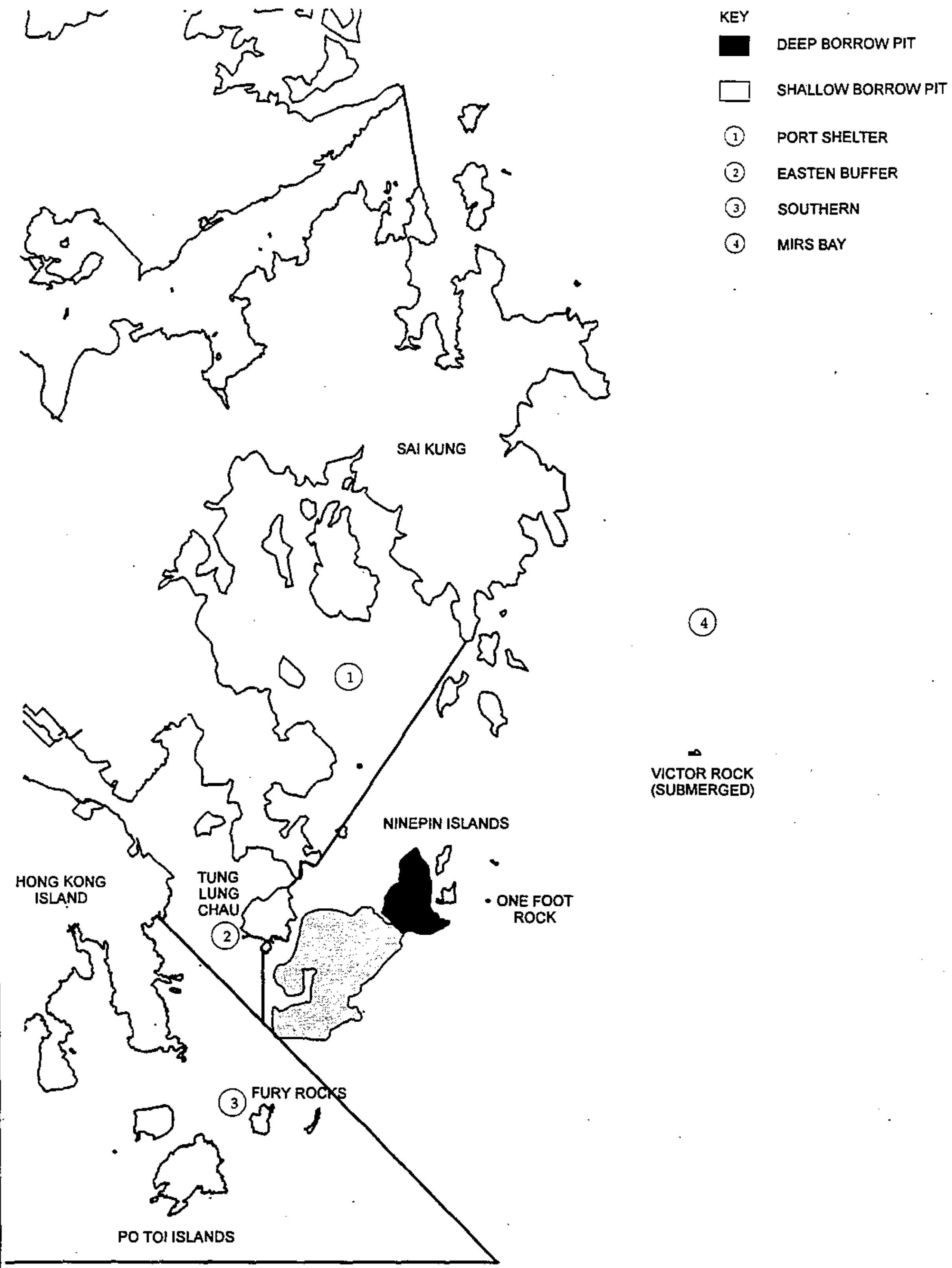

FIGURE 3.2a - LOCATION OF WATER CONTROL ZONE THE EAST TUNG LUNG CHAU MARINE BORROW AREA

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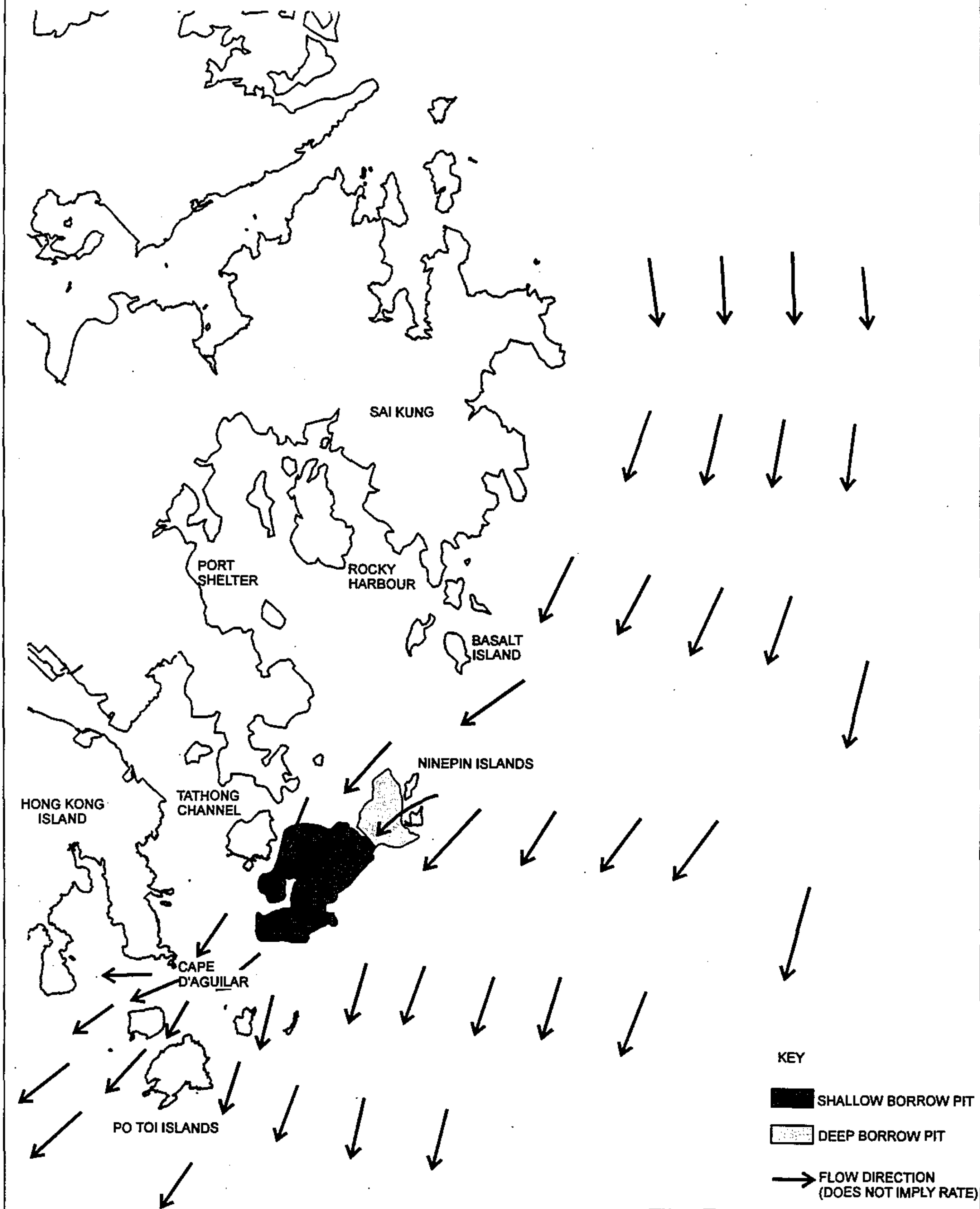

FIGURE 3.3a - APPROXIMATE FLOW DIRECTION, SURFACE LAYER, DRY SEASON (DOES NOT INCLUDE TIDAL VARIATIONS)
Source: N Evans of GEO CED

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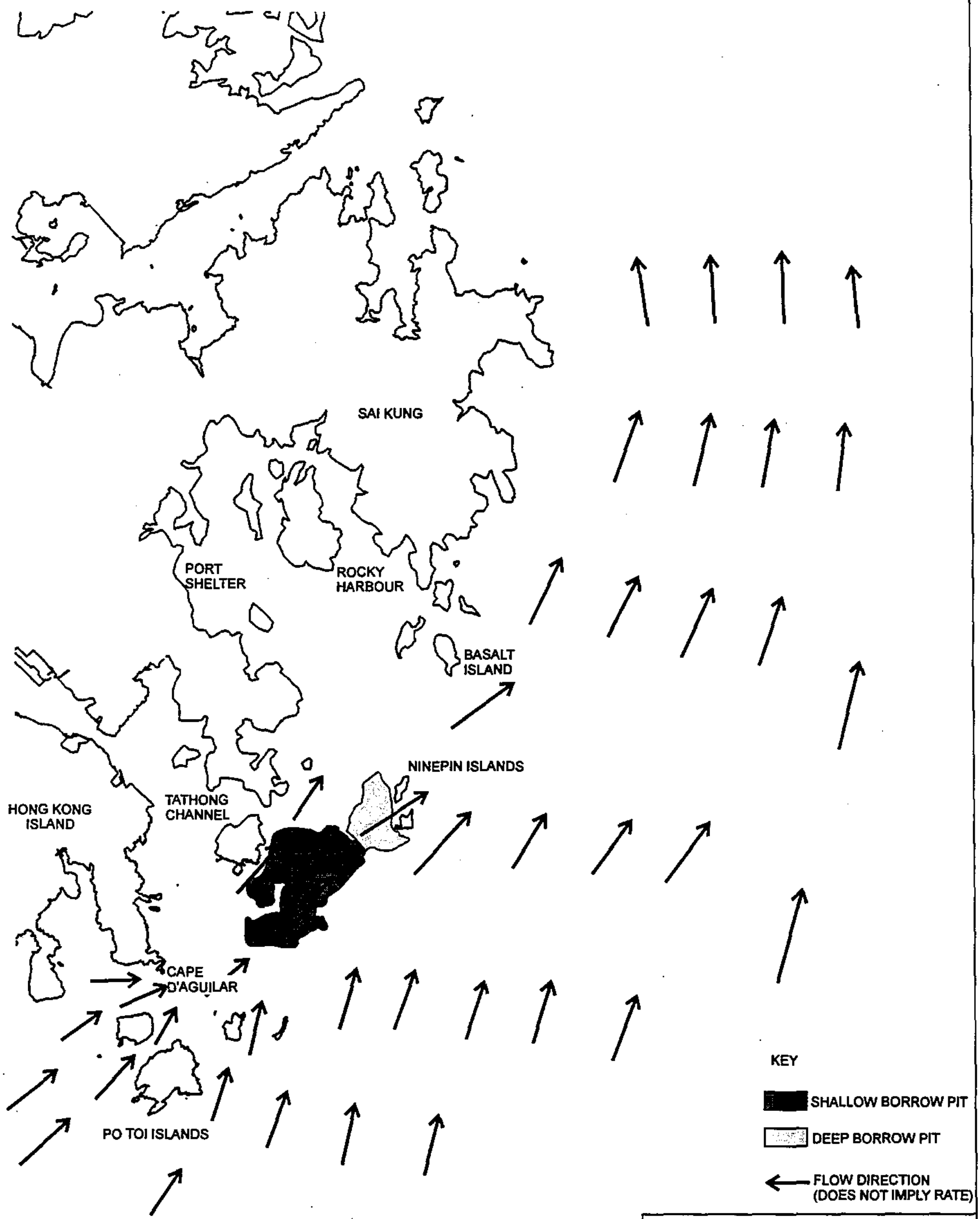

FIGURE 3.3b - APPROXIMATE FLOW DIRECTION, SURFACE LAYER, WET SEASON (DOES NOT INCLUDE TIDAL VARIATIONS)
Source: N Evans GEO CED

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3.3.2 *Water Quality*

Water quality monitoring is regularly undertaken by EPD in the three WCZs relevant to this study at the stations shown in *Figure 3.3c*. These data provide an indication of baseline water quality conditions within the study site and are summarised for stations MM8, EM3 and SM19 in *Table 3.3a*, below.

The MBWCZ, which is the largest within Hong Kong waters, is the least influenced by the Pearl River. Water quality is characterised by low SS concentrations, low turbidity, low BOD concentrations and high DO levels. Low turbidity results in high light penetration, low nutrient concentrations and low *E. coli* counts. During the summer, stratification occurs with a thin layer of less dense, fresh water overlying deeper, denser saline water and this is associated with changes in DO with depth. Particularly in the southern part of the MBWCZ, the waters are some of the cleanest in Hong Kong. However, the water quality in the southern MBWCZ may be affected by dredging and disposal activities at number of MBAs and the East of Ninepins Dredged Material Disposal Site.

Table 3.3a ***Summary Statistics of 1995 Water Quality in the Vicinity of the MBAs***

Determinant		Mirs Bay WCZ (Station MM8)	Southern WCZ (Station SM19)	Eastern Buffer WCZ (Station EM3)
Number of samples		9	6	12
Temperature (°C)	Surface	23.6 (17.2 - 27.6)	22.7 (15.1 - 28.9)	22.8 (15.0 - 30.2)
	Bottom	22.9 (17.3 - 27.5)	21.5 (15.0 - 27.3)	22.0 (15.0 - 31.2)
Salinity (ppt)	Surface	32.7 (29.0 - 33.8)	30.7 (21.7 - 34.2)	32.0 (28.4 - 33.7)
	Bottom	33.9 (33.2 - 34.4)	33.5 (32.4 - 34.2)	32.9 (30.2 - 34.4)
DO (% satn)	Surface	84.7 (43.3 - 102.0)	101.2 (74.4 - 120.1)	82.0 (4.6 - 101.5)
	Bottom	77.4 (43.4 - 91.4)	82.8 (56.6 - 100.2)	87.1 (65.7 - 101.7)
pH		8.2 (8.0 - 8.3)	8.2 (8.1 - 8.4)	8.1 (8.0 - 8.4)
Secchi Disc (m)		3.7 (2.0 - 5.0)	2.2 (1.2 - 2.8)	2.4 (1.5 - 4.0)
Turbidity (NTU)		3.9 (0.8 - 6.3)	5.6 (1.4 - 9.1)	5.9 (1.3 - 28.4)
SS (mg l^{-1})		2.5 (0.9 - 5.7)	7.3 (2.7 - 15.0)	7.7 (2.3 - 17.6)
BOD_5 (mg l^{-1})		0.4 (0.3 - 0.6)	0.7 (0.2 - 1.8)	0.6 (0.3 - 1.3)
Total Inorganic N (mg l^{-1})		0.05 (0.02 - 0.08)	0.09 (0.04 - 0.18)	0.11 (0.04 - 0.20)
Total N (mg l^{-1})		0.14 (0.07 - 0.24)	0.24 (0.14 - 0.44)	0.36 (0.11 - 0.58)
PO_4 - P (mg l^{-1})		0.03 (0.01 - 0.12)	0.01 (0.01 - 0.02)	0.03 (0.01 - 0.04)

Determinant	Mirs Bay WCZ (Station MM8)	Southern WCZ (Station SM19)	Eastern Buffer WCZ (Station EM3)
Total P (mg l^{-1})	0.06 (0.03 - 0.12)	0.06 (0.03 - 0.08)	0.08 (0.04 - 0.15)
Chlorophyll-a (µg l^{-1})	1.13 (0.37 - 1.83)	3.51 (0.47 - 15.33)	2.36 (0.33 - 7.10)
E. coli (no. per 100 ml)	1 (1 - 3)	4 (1 - 29)	98 (8 - 3067)

Notes: Except as specified, data presented are depth averaged data
Data presented are annual arithmetic means except for *E. coli* data which are annual geometric means.
Data enclosed in brackets indicate the ranges.
Source: Marine Water Quality in Hong Kong for 1995 (EPD 1997)

Ambient conditions for SS, DO and Total Inorganic Nitrogen have been calculated for each of the WCZs for both wet and dry seasons and these data are presented in *Table 3.3b*, *Table 3.3c* and *Table 3.3d*. In each case the stations were selected in accordance with EPD guidance and the period from which the data were analysed was chosen, again with EPD guidance, to avoid any possible effects of dredging activities. Graphs of each of these parameters over the same time period are presented in *Annex A*. They show the effect of seasonal changes on some of the parameters.

Table 3.3b ***Mirs Bay Water Control Zone(Stations MM 8, 9, 14 & 15): Baseline Conditions for SS, Total Inorganic Nitrogen and DO over the period January 1991 to December 1992***

Parameter and Layer	Dry Season		Wet Season	
	Mean	SD	Mean	SD
SS (mg l^{-1})				
Surface	3.8 (0.5 -15)	3.3	2.5 (0.5 -14.5)	2.7
Middle	3.8 (0.5 -10)	2.5	2.7 (0.5-17)	3.3
Bottom	4.1 (0.5 -14)	3.2	6.0 (1-17)	4.6
Total Inorganic Nitrogen [a] (mg l^{-1})				
Surface	0.12 (0.03 -0.3)	0.08	0.07 (0.009 -0.25)	0.06
Middle	0.10 (0.03 -0.3)	0.08	0.05 (0.012 -0.17)	0.04
Bottom	0.09 (0.022 -0.28)	0.07	0.05 (0.01 -0.192)	0.05

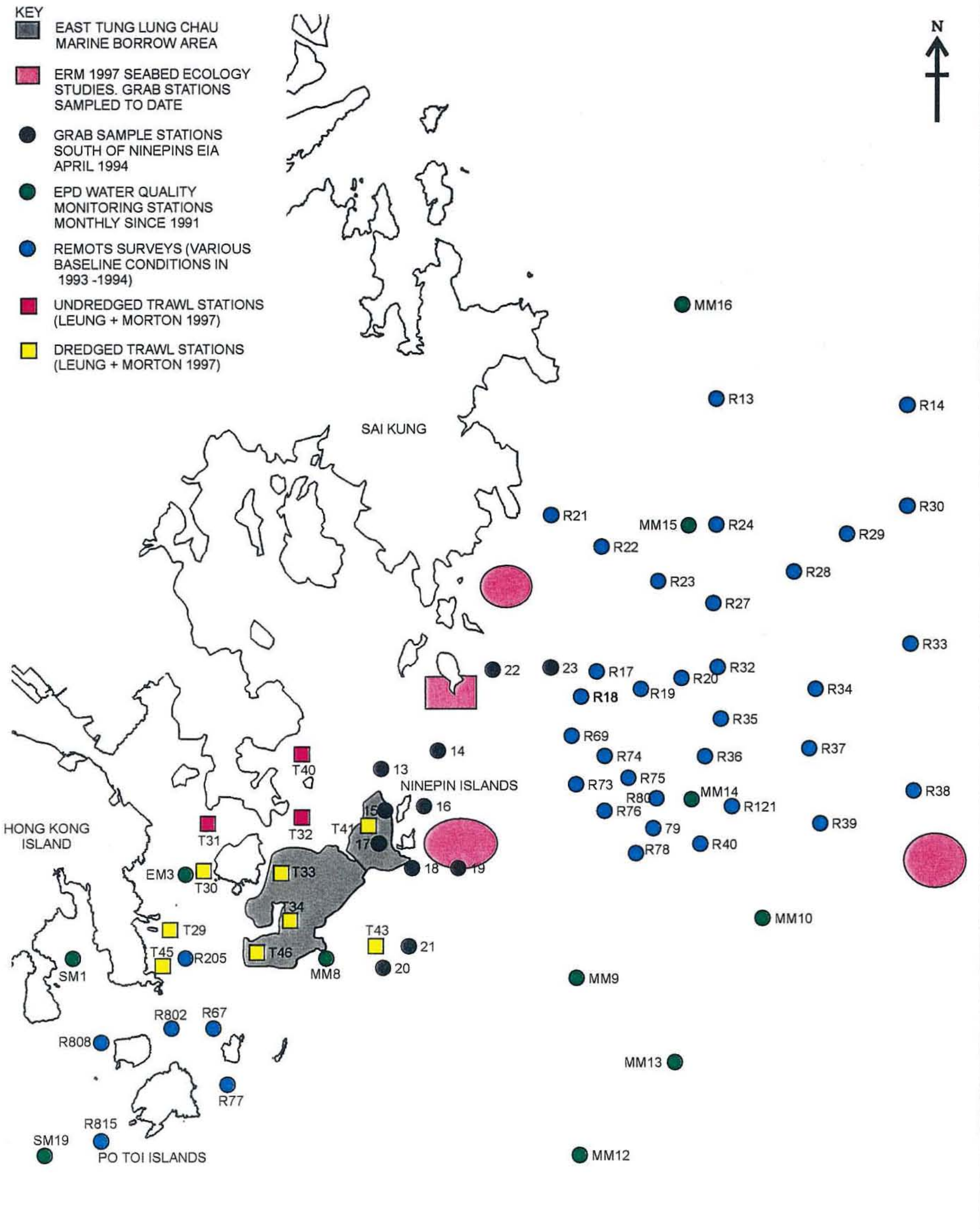

FIGURE 3.3c - SAMPLING STATIONS OF WATER QUALITY AND ECOLOGICAL DATA COLLECTED IN THE STUDY AREA

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Parameter and Layer	Dry Season		Wet Season	
	Mean	SD	Mean	SD
DO (mg l^{-1})				
Surface	7.8 (6.3 -9.5)	0.86	7.02 (5.8 -10.13)	0.85
Middle	7.6 (5.3 -10.2)	1.2	6.2 (4.55 -7.8)	0.75
Bottom	7.4 (4.7 -9.8)	1.2	5.7 (2.93 - 7.4)	1.1

Note [a] Total Inorganic Nitrogen is the sum of NH_4, NO_3 and NO_2

Table 3.3c ***Southern Water Control Zone (Stations SM 18, & 19): Baseline Conditions for SS, Total Inorganic Nitrogen and DO over the period January 1991 to December 1992***

Parameter and Layer	Dry Season		Wet Season	
	Mean	SD	Mean	SD
SS (mg l^{-1})				
Surface	6.2 (0.5 - 28)	6.3	3.4 (0.5 - 16)	3.5
Middle	4.9 (0.5 - 18)	4.1	3.4 (0.5 - 20)	4.1
Bottom	5.5 (0.5 - 23)	5.8	5.9 (0.5 - 39)	7.7
Total Inorganic Nitrogen [a] (mg 1^{-1})				
Surface	0.1 (0.02 - 023)	0.06	0.18 (0.02 - 0.53)	0.14
Middle	0.1 (0.02 - 0.21)	0.05	0.10 (0.02 - 0.29)	0.06
Bottom	0.1 (0.03 - 0.22)	0.05	0.09 (0.02 - 0.33)	0.07
DO (mg l^{-1})				
Surface	7.94 (5.65 -11.70)	0.92	7.65 (4.95 - 9.26)	0.93
Middle	7.84 (1 - 13.74)	2.64	5.78 (1 -7.90)	1.60
Bottom	7.27 (1 - 16.34)	2.89	5.62 (2.92 - 11.22)	1.95

Note [a] Total Inorganic Nitrogen is the sum of NH_4, NO_3 and NO_2

Table 3.3d *Eastern Water Control Zone (Station EM3): Baseline Conditions for SS, Total Inorganic Nitrogen and DO from the period January 1991 to December 1992*

Parameter and Layer	Dry Season		Wet Season	
	Mean	SD	Mean	SD
SS ($mg\ l^{-1}$)				
Surface	4.1 (0.5 - 11)	3.1	2.6 (0.5 - 11)	2.2
Middle	4.7 (0.5 - 23)	5.0	3.2 (0.5 - 9.5)	2.2
Bottom	4.8 (0.5 - 14)	3.4	3.9 (0.5 - 14)	3.4
Total Inorganic Nitrogen [a] ($mg\ l^{-1}$)				
Surface	0.16 (0.02 - 0.47)	0.11	0.13 (0.01 - 0.4)	0.09
Middle	0.14 (0.01 - 0.42)	0.09	0.1 (0.02 - 0.4)	0.09
Bottom	0.14 (0.01 - 0.40)	0.09	0.09 (0.01 - 0.18)	0.05
DO ($mg\ l^{-1}$)				
Surface	7.54 (4.67 - 12.77)	1.62	6.58 (4.01 - 9.06)	1.22
Middle	7.36 (4.68 - 11.32)	1.27	5.61 (1 - 7.76)	1.33
Bottom	7.46 (5.5 - 11.72)	1.34	5.46 (3.33 - 8.65)	1.23

Note [a] Total Inorganic Nitrogen is the sum of NH_4, NO_3 and NO_2

Calculation of Water Quality Objectives for SS

The WQO for SS which is defined in full in *Section* 3.2, is an elevation of 30% over ambient concentrations. Ambient concentrations presented *Tables 3.3b, 3.3c* and *3.3d* are very low. Consequently elevations of 30% above these levels are also very low and in practice are on the same order as the sensitivity of the SS analytical techniques. Following discussion with EPD, a 10 $mg\ l^{-1}$ elevation above ambient was agreed as an appropriate assessment criterion against which to measure the acceptability of predicted elevations in SS. This assessment criterion is consistent with the EIAs for the proposed Eastern Waters MBA and for Disposal of Contaminated Mud in the East Sha Chau MBA.

3.3.3 *Bathymetry Conditions*

As detailed in *Section 2*, the ETLC MBAs consist of a northeast (deep) pit and much larger southwest (shallow) pit (see *Figure 2.2a*). In the southwest shallow pit dredging has typically removed between 1 and 5 m of material. The deeper northeastern pit has been dredged for marine sand and excavated to a maximum depth of around -47 mPD. As indicated on *Figure 2.2a*, the seabed outside the MBAs is approximately level, with a mean depth of -27 mPD to -30 mPD.

3.3.4 *Sediment Quality*

Baseline sediment conditions are provided by EPD's routine sediment monitoring programme, which includes stations ES2 (in the same location as water quality monitoring station EM3, described above) and MS8 (in the same location as water quality monitoring station MM8). Sediment quality data are summarised in *Table 3.3e* and *Table 3.3f*.

Table 3.3e ***Summary Statistics of 1995 Sediment Quality at Stations ES2 (Tathong Channel) and MS8 (North of Waglan Island): Physical Characteristics, Organic Content and Nutrients***

Parameter	ES2	MS8
Particle size distribution (%<63 μm)	70 - 89	>90
Eh (-mV)	150 - 199	<100
Total Organic Carbon (%w/w)	0.5 - 0.8	0.5 - 0.8
Total Nitrogen (mg kg dry solids^{-1})	400 - 500	600 - 700
Total Phosphorus (mg kg dry solids^{-1})	150 - 200	150 - 200

Note: The values quoted are the ranges quoted by EPD.
Source: EPD Routine Monitoring Data 1995.

These data indicate that sediment near the ETLC MBAs is composed of fine particles, and is relatively well aerated with less negative Eh values than other stations. The organic and nutrient concentrations in the sediment are higher at station MS8 (and other stations further offshore from this), however the reason for this is not known.

Table 3.3f *Sediment Quality at Stations ES2 (Tathong Channel) and MS8 (North of Waglan Island): Heavy Metals, PAHs and PCBs*

Station/Parameter (mg kg^{-1})	Particle size fraction	Minimum	Maximum	Mean	SD
ES2					
Cd	<63μm	0.01	0.5	0.35	0.21
	Bulk	0.1	0.5	0.36	0.2
Cr	<63μm	33	46	38.66	3.74
	Bulk	7	49	31.44	43.4
Cu	<63μm	13	64	34.66	14.74
	Bulk	9	32	23.55	7.46
Hg	<63μm	0.05	0.11	0.06	0.02
	Bulk	0.05	0.07	0.05	0.007
Ni	<63μm	22	37	27.22	4.52
	Bulk	9	31	21	7.93
Pb	<63μm	26	44	32.11	6.27
	Bulk	18	52	29.77	10.04
Zn	<63μm	75	240	107.56	51.19
	Bulk	28	94	69.55	89.2
Total PAHs	<63μm	41	41	41	0
	Bulk	39	73	49	11.4
Total PCBs	<63μm	5	5	5	0
	Bulk	5	7	5.42	0.78
MS8					
Cd	Bulk	0.01	44	3.02	9.85
Cr	Bulk	0.5	41	30.61	6.79
Cu	Bulk	14	36	20.35	5.45
Ni	Bulk	20	30	24	2.9
Pb	Bulk	16	110	40.87	19
Zn	Bulk	23	110	81.16	16.6

Source: EPD Routine Monitoring Data 1993

These data are presented to provide a full picture of the baseline conditions. No changes in ambient heavy metal or organic contaminant concentrations are expected as a result of backfilling at ETLC MBAs since the material proposed for disposal will be uncontaminated.

3.4 *SENSITIVE RECEIVERS*

There are a number of sensitive receivers within the Study Area which could potentially be affected by changes in water quality resulting from backfilling activities. These have been identified below in accordance with the HKPSG, which provides guidelines for identifying environmental factors influencing development planning. Facilities and sites which are sensitive to changes in water quality are identified on *Figure 3.4a*. As changes in water quality will impact ecological resources, these are also indicated on *Figure 3.4a*, and will be discussed in detail in *Section 4*.

Sensitive receivers have been considered in water quality modelling to predict potential increase in SS concentrations at each location resulting from backfilling the ETLC MBAs. Results are discussed in *Section 3.7*. Descriptions and locations of sensitive receivers that have been identified are provided below.

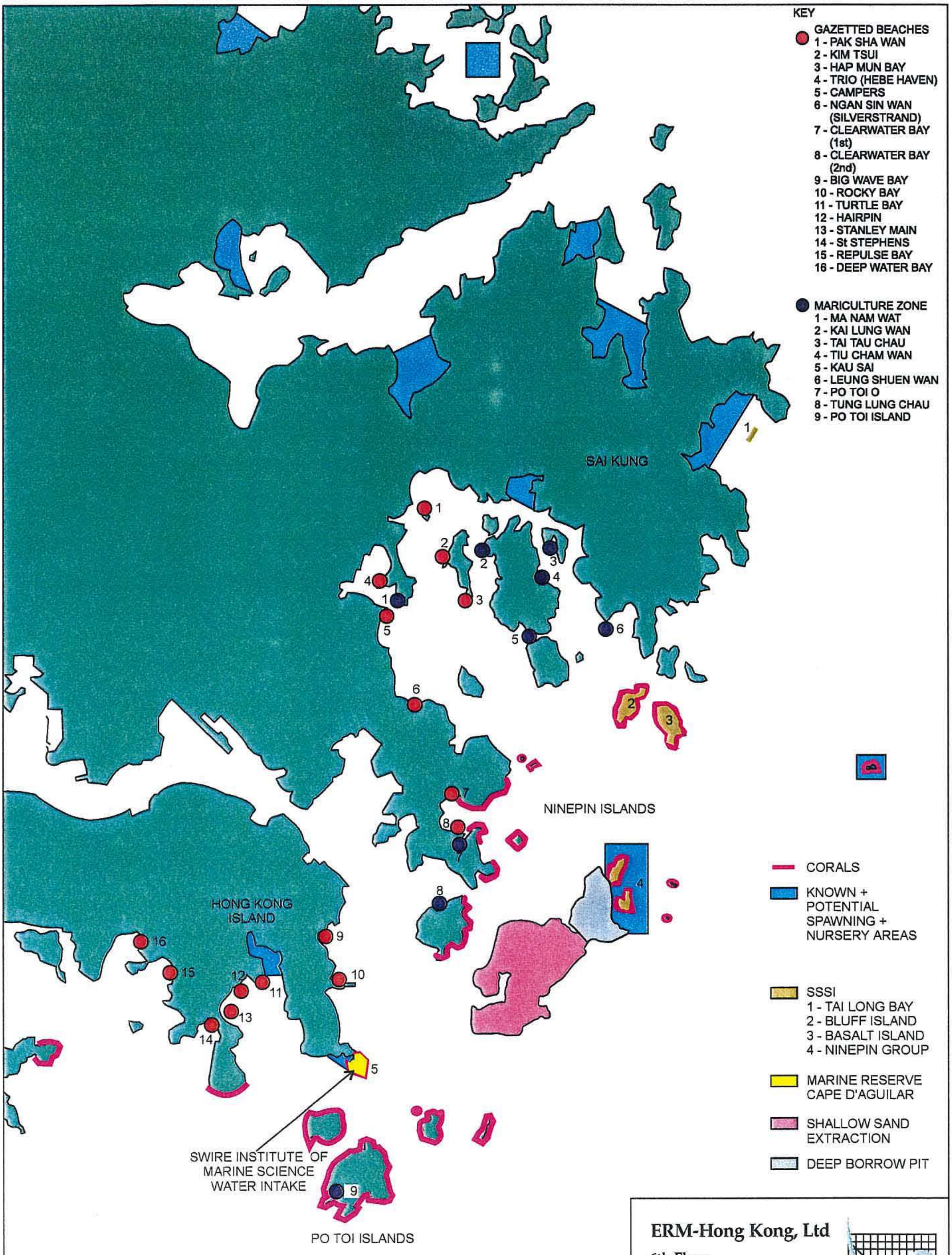

FIGURE 3.4a - WATER AND ECOLOGICAL SENSITIVE RECEIVERS IN THE STUDY AREA

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3.4.1 *Bathing Beaches*

A number of gazetted bathing beaches which are located along the eastern shores of Hong Kong Island, Clearwater Bay, and Port Shelter coastlines, may be affected by backfilling at the ETLC MBAs. These are Pak Sha Wan, Kim Tsui, Hap Mun Bay, Trio, Campers, Silverstrand, Clearwater Bay 1st and 2nd, Big Wave Bay, Rocky Bay, Turtle Bay, Hairpin, Stanley Main, St Stephens, Repulse Bay and Deep Water Bay bathing beaches. Hong Kong Grid Coordinates of beaches included in modelling simulations are presented in *Table 3.4a*.

Table 3.4a *Names and Locations of Gazetted Beaches within the Study Site*

Beach	Easting	Northing
Clearwater Bay 1st	848100	816950
Clearwater Bay 2nd	847750	815750
Big Wave Bay	843550	811900
Rocky Bay	844050	810500
Turtle Bay	840950	810050
Hairpin	840500	809700
Stanley Main	840250	809160
St Stephens	839800	808800

3.4.2 *Water Intakes*

The Swire Institute of Marine Science (SWIMS) on Cape D'Aguilar has water intakes for a desalinator and for aquaria. However the SWIMS has advised that they have no specific criteria for these intakes other than the regional requirements set for the WCZ. The SWIMS is also an ecological sensitive receiver as coral is located there and it has Site of Special Scientific Interest (SSSI) status.

3.4.3 *Mariculture Areas and Ecological Resources*

Nine Fish Culture Zones (FCZs) are situated close to the Study Area, they are: Ma Nam Wat, Kai Lung Wan, Tai Tau Chau, Tiu Cham Wan, Kau Sai, Leung Shuen Wan, Po Toi O, Tung Lung Chau and Poi Toi Island.

There are also a number of sensitive water bodies containing coral heads and outcrops. These outcrops are on all sides of Bluff Island and Basalt Island, around the entire coast of the Ninepins Group of islands (Pak Kwo Chau, Nam Kwo Chau and Tung Kwo Chau), Victor Rock, headlands of Clearwater Bay (Tat Tong Kok, Po Toi O South and Tai Wan Tsai), the west side of Ching Chau (Steep Island), the southeastern shores of Tung Lung Chau (Fat Tong Mun and Nam Tong Mei, respectively), and around the Po Toi Islands. Hong Kong Grid coordinates for the ecological sensitive receivers used in the modelling simulations are presented in *Table 3.4b*.

Table 3.4b *Names and Locations of Ecological Sensitive Receivers within the Study Site, including Corals, SSSIs, Fisheries and Mariculture Areas*

Sensitive Receiver	Easting	Northing
Tung Lung Chau FCZ	847650	812900
Po Toi O FCZ	848350	815000
Nam Tong Mei	847900	811050
Fat Tong Mun	848600	812600
Tat Tong Kok	849600	814250
Steep Island	850300	815400
Po Toi O South	849250	815650
Tai Wan Tau	849250	816750
Sung Kong N	848050	805750
Sung Kong S	847850	804750
Sung Kong W	847500	805150
Pak Kwo Chau E	854300	814700
Pak Kwo Chau W	853600	814500
Nam Kwo Chau E	854450	813400
Nam Kwo Chau W	853900	812750
Tung Kwo Chau N	855550	814200
Tung Kwo Chau S	855850	813950
Bluff Island	853800	819300
Basalt Island	855550	819200
Victor Rock	862725	818000
Swire Institute	844650	807550

3.5 GENERAL IMPACT PROCESSES

The extent of potential water quality impacts resulting from backfilling activities at the ETLC MBAs will depend upon a number of factors including:

- the physical and chemical nature of backfill material;
- the dispersion characteristics of the receiving water body;
- the rate of backfilling operations (ie the quantity of spoil to be disposed per day); and
- the number, nature and proximity of sensitive receivers.

Brief discussions of the physical and chemical effects of spoil disposal, as well as factors affecting spoil loss to suspension or erosion are provided below.

3.5.1 *Physical Effects*

Water quality impacts resulting from marine backfilling arise directly from the increased concentration of suspended sediment in the water column. This leads to a reduction in light penetration and increased heat retention. Physical effects can also occur in the form of smothering of marine organisms through obstruction or irritation of gill filaments and other membranes. The extent of physical effects will depend on the amount of material put into suspension during backfilling operations and the dispersive forces acting on the suspended material.

3.5.2 *Chemical Effects*

As the proposed disposal material at the ETLC MBAs is uncontaminated marine mud, resulting chemical effects are expected to be confined to associated with decreases in DO and increases in nutrient concentrations.

Material with high oxygen demand can cause substantial decreases in DO. In addition, an increase in solids in the water column reduces light penetration, and subsequently diminishes photosynthesis except in the immediate surface layer. This, therefore, reduces the rate at which oxygen is produced in the water column. The effects of suspended sediment on temperature, as described above (*Section 3.5.1*), also act to reduce DO levels since the solubility of oxygen in water decreases with increasing temperature.

Increased concentrations of nutrients released from backfilling activities may promote algal growth in the upper layers of the water column (ie those which receive sufficient light to enable photosynthesis). Increased nutrient concentrations can lead to algal blooms which can in turn cause DO depletion as dead algae fall through the water column and decompose on the bottom. Anoxic conditions may result if DO concentrations are already low or are not replenished.

The extent of chemical effects associated with proposed backfilling operations will depend on the oxygen demand and nutrient content of the disposed material and the degree of interaction with the physical effects described above.

3.5.3 *Behaviour of Disposed Sediments*

Sediment losses due to backfilling operations can occur either through:

- losses to suspension during and immediately following backfilling (ie caused by entrainment into the water column as the sediment descends to the seabed and as a result of the generation of an impact cloud as the sediment contacts the seabed and any previously disposed material); and

- losses if disposed sediments are disturbed during storms by wave-induced currents and transported from the MBAs by tidal currents.

Losses during and immediately following backfilling, which result in considerably higher suspended sediment concentrations than erosion of deposited material, are described in the rest of this section.

Factors Influencing Loss to Suspension

Losses during backfilling operations will be determined by factors influencing sediment entrainment in the water column and those forces acting to transport these entrained sediments. The loss of sediments to the water column during the disposal process occurs in two stages:

- fine material is stripped off as backfilling material descends through the water column;

- fine material is stripped off any radially expanding bottom density surge which may develop as the backfilling material arrives at the seabed.

Disposal Trials

In order to investigate the degree to which stripping occurs, a disposal trial was conducted in September 1995[1] to investigate the specific behaviour of marine mud disposed at the ETLC MBAs. Details of the methodology of the trial and the results are provided in *Annex B*, however, no evidence was found of fluid mud and this is taken as evidence that the radially-expanding bottom density surge was largely confined by the sides of the pit. These results are in accordance with various field measurements undertaken during other dumping trials[2] in Hong Kong. Data from these studies, other field measurements and energy density budget analyses[3][4][5] suggest that provided discharge takes place 100 metres away from the foot of a slope, a density surge would be comfortably retained in a pit with a slope of only 2 metres height (irrespective of its angle). If discharge takes place at more than 150 metres from the slope (as will happen during backfilling at ETLC MBAs because the disposal areas presented in *Figure 2.5a* are at a greater distance than this from the edge of the MBA), it is likely that most surges would have insufficient energy even to reach the slope. As bottom density surges are not expected to contribute substantially to sediment losses the remainder of this discussion will focus on stripping as the sediment mass descends through the water column.

Density and Composition of Sediments

The density and composition of the sediment influence the rate at which stripping occurs. Both vary according to the extraction method used.

During dredging by hydraulic methods (ie trailer dredgers), mud becomes diluted due to the limitations of the pumping system. The degree of dilution depends on the *in situ* characteristics of the material: soft, semi-fluid mud may not be diluted to as great an extent as cohesive mud. In addition, the frequency of dredger turning can also contribute to dilution since when the dredger turns it must raise the draghead and thus increase the ratio of water to sediment.

Mechanical dredging methods (ie grab dredging) involve much less remoulding and dilution of sediments. In this case, the dredged material comprises large lumps (≥ 1 m^3) of remoulded but generally intact material with a relatively small amount of slurry. Much higher barge densities and lower bulking factors can be achieved than is usual with hydraulic dredging methods.

Dilution

Sediment undergoes considerable dilution during dumping from both trailer-dredgers and barges. The degree of dilution is a function of the size of the barge openings, the speed of discharge and the water depth. The dilution decreases as the speed of discharge increases and as the size of the hopper or barge openings increases. During descent the material undergoes considerable dilution as a

(1) Dredging Research Limited (1996) *op cit*

(2) Engineering Geology, Ltd (1988) *op cit*

(3) Bokuniewicz H (1985) Energetics of Dredged Material Disposal Wastes in the Ocean Vol 6 Nearshore Waste Disposal Wiley Interscience New York

(4) Davies P G J (1986) Ervaringen met de Grondverbetering Stormvloedkering in de Oosterschelde Polytechnisch Tijdschrift: Bouwkunde, Wegen- en Waterbouw

(5) Ogawa H (1969) Dispersion of Dumped Sand from a Hopper Barge Trans JSCE Vol 1 PT 1

result of axial spreading of the jet and entrainment of ambient water. Two types of dilution can be distinguished:

- slurrified dredged material (eg, the slurry component of trailer dredged mud), is diluted reducing the concentration of the slurry;
- lumpy material which comprises large softened lumps of mud with a relatively small slurry component as is generated during mechanical dredging, is diluted as the lump fraction spreads out during descent.

Loss Rates

Accurately estimating the amount of sediment lost to suspension during disposal events is critical to the assessment of potential impacts associated with sediment plumes. The loss rate assumed for the EIA was derived from field data collected at the disposal trials. During the trials suspended sediment was monitored using acoustic techniques for six disposal events from two trailer dredgers: the Krankeloon and the Pacifique. Dumps from the Krankeloon resulted in losses of 0.9 to 2.1% which is considerably lower than loss rates from the Pacifique which ranged from 5.3 to 8.7%. Neither dredger is considered to be typical and a value of 5% was assumed for this Study which was applied for both trailers and barges during modelling. In practice loss rates during dumping from barges are lower than from trailers because barge dredged material is typically of higher density than trailer dredged material. Loss rates of 5% and below are expected to be achieved by trailers for two reasons. Firstly it is in the commercial interest of the dredging operator to maintain high hopper densities and high hopper densities result in low loss rates. Secondly, the same trailer dredgers that are used for disposal operations at the East Sha Chau Marine Borrow Pit are very likely to be used for backfilling at the ETLC MBAs. It is proposed that trailer loss rates be measured in the field at the East Sha Chau Marine Borrow Pit and if the loss rate for a particular trailer is higher than 5%, an alternative method of placement, such as disposal down the trailer arm may be required. Similar controls will be applied at the ETLC MBAs and the procedures for verifying loss rates will be documented in the EM&A Manual.

3.6 WATER QUALITY MODELLING: BACKGROUND

The behaviour of suspended sediment in the water column during disposal operations at the ETLC MBAs has been simulated using mathematical modelling. This section describes the models used for sediment transport and for the prediction of water quality.

During backfilling a proportion of fine sediment becomes suspended in the water column and is transported and dispersed by seasonal and tidal currents. The suspended sediment tends to flocculate at a rate which is dependent on the concentration of sediment, forming larger particles which sink under gravity. At the seabed, if the current speed is sufficiently low the sediment is deposited and it begins to consolidate. At higher current speeds the sediment continues to be transported. Transport continues until the current speed drops to the point at which sediment is deposited.

The processes of transport, dispersion and settling of suspended sediment have been simulated using the WAHMO hydrodynamic model and the MUDFLOW and SEDPLUME sediment transport models. For the IAR, three disposal scenarios were simulated with MUDFLOW and results for these scenarios are described briefly in detail in the IAR and briefly in *Section 2.5.1*. Following revisions to the Operations Plan a further nine scenarios were modelled for the EIA using SEDPLUME. MUDPLUME was not used in accordance with guidance given by EPD to sub-consultants during the EIA for the proposed Eastern Waters MBA. Results for the nine scenarios are presented in *Section 3.8*.

3.6.1 *Flow Model Description*

Hydrodynamic predictions are generated by the WAHMO tidal model which has been widely used in Hong Kong to predict the effects of marine operations and developments. The model divides the water column into two discrete layers which allows the simulation of variations in current velocity and salinity through the depth of the water column. The model bathymetry has been updated in accordance with recent changes to the Hong Kong coastline and includes the following reclamations: Tseung Kwan O, Black Point Power Station, Chek Lap Kok airport platform, Tung Chung, North Lantau, Container Terminal 8, West Kowloon, and Central-Wanchai.

WAHMO is well established and has been fully calibrated and validated using extensive data sets collected in 1988, 1990 and 1993. Details of this calibration and validation exercise are provided in Strategic Sewage Disposal Scheme Stage II: Oceanic Outfall and Oceanographic Surveys and Modelling Reports R7a and R7b[6].

Examples of WAHMO flow model out up are presented in *Annex C* as part of the description of the calibration of the SEDPLUME model.

3.6.2 *Sediment Transport Model Description*

Sediment transport for the nine EIA disposal scenarios was simulated with the SEDPLUME model which simulates the process of sediment transport, deposition and re-erosion for plumes generated in activities such as backfilling. SEDPLUME uses hydrodynamic predictions generated by the WAHMO tidal model to represent tidal advection and a random walk technique to represent the dispersion of sediment.

Particle Tracking

The plume model simulates the loss of sediment to suspension by introducing particles into the model area at specified three dimensional locations (x, y and z coordinates). The movement of the particles is simulated by tracking particles as they are transported by currents and dispersion, and as they sink at a rate which is dependent on the concentration of suspended sediment in the immediate vicinity. When the depth coordinate (z) of a particle reaches the depth of the seabed, (which is stored as a bathymetry file), the particle is not permitted to sink further. At this point, if the current speed is below a critical magnitude, settlement of the particle is assumed and transport ceases. If the current speed then increases above the critical magnitude, the point at which the critical bed shear stress is exceeded, erosion of the particle is simulated and the particle is again transported by advection and dispersion.

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(6) Strategic Sewage Disposal Scheme Stage II: Oceanic Outfall Oceanographic Surveys and Modelling Reports R7a and R7b, SOM Consultants, September 1994.

Nutrient Levels

Sediment plume model predictions of suspended sediment concentrations were used to derive predictions of nutrient levels resulting from disposal events. Elevations of nutrient concentrations resulting from release of dredged material are calculated from the predicted suspended sediment concentration by assuming that all nutrients associated with the sediment are lost to suspension, and are transported and diluted at the same rate as the sediment in suspension.

Dissolved Oxygen Levels

The effect of disposal events on dissolved oxygen levels were predicted from predicted suspended sediment concentrations in two ways.

The tidally averaged DO depletion at any point in time over a 24 hour period was predicted using the average suspended sediment elevation over 24 hours and 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 mg O_2 kg^{-1} sediment
	K	=	daily oxygen uptake factor = 0.23

The analysis does not allow for re-aeration but this is expected to be a minor factor in the above relationship and thus have a negligible effect on the results. Note that because average SS concentrations over 24 hours are highest closest to the dump site, the tidally averaged rate of depletion resulting from SS elevations are predicted to be highest close to the dump site.

The absolute DO depletion in each plume (resulting from individual disposal events) was predicted by integrating DO depletion rates over the life time of a plume. DO depletion rates were calculated from predicted suspended sediment concentrations within the plume at a number of intervals throughout the lifetime of the plume. The predictions were based on the following relationship:

$$DO_n = DO_{n-1} + k\, d^{-1}(DO_{sat} - DO_{n-1})\Delta t - K\, SOD\, C\, \Delta t$$

where	DO_n	=	dissolved oxygen concentration at time n
	DO_{n-1}	=	dissolved oxygen concentration at time n-1
	k	=	re-aeration rate
	d	=	water depth
	DO_{sat}	=	saturated dissolved oxygen concentration
	Δt	=	time interval
	K	=	rate of oxygen uptake = 0.23 day^{-1}
	SOD	=	sediment oxygen demand
	C	=	average suspended sediment concentration at the centre of a plume at time n

Note that because the absolute DO level is progressively depleted as the plume is transported away from the disposal site, the highest absolute DO depletion occurs away from the disposal site. This is in contrast to the tidally averaged DO depletion predictions. Further details of this methodology are presented in *Annex G*.

Model Input

The model requires the following key input data:

- hydrodynamic data;
- bathymetry data;
- the time of the start of the simulation relative to high water;
- the length of the time step which determines how often the model recalculates the position of the particles;
- the frequency at which disposal events occur; and
- the mass of mud released into suspension.

In addition, the following factors and functions are used by the model and can be modified during model calibration:

- the loss rate which determines what percentage of the disposed material becomes suspended in the water column;
- the bed friction and the critical bed shear stress which together determine the current speed at which material is deposited onto, and eroded from, the seabed;
- the area over which the disposal occurs and the depth at which the particles are introduced; .
- the concentration to sink rate function which determines how quickly particles sink;
- the rate at which material is dispersed which is represented in the model by the length of the random walk step.

Model Output

At periodic time intervals (the storage interval) throughout model simulation the number of particles in suspension and the number of particles that have settled in specified cells are stored. This data can then be manipulated and presented in the following ways:

- snap shots which show the simulated concentration (the concentration is a function of the area of the cell and the depth of the water column) of sediment in each of the cells at a particular moment in the period over which the model is run;

- maximum concentration plots which show the maximum concentration that is predicted in any cell during the simulation period;

- time history plots which show the concentration of suspended sediments at designated sensitive receiver locations throughout the duration of the simulation;

- tidal averages which show the average concentration from all the snap shots taken over the period during which the model is run;

- sediment deposition plots which show the number of particles deposited in a cell over the period during which the model is run;

- water quality predictions for nutrients (or any other potential pollutant) which show the tidal average of predicted concentration of nutrients which is calculated from the tidal average of the suspended sediment and the proportion of nutrient to SS in the backfill material;

- water quality predictions for DO which show the 24 hour average of the oxygen deficit which is calculated from the tidal average of SS and a function of the oxygen demand associated with sediment.

SEDPLUME Calibration

SEDPLUME was calibrated and validated during this Study using field data collected at disposal trials at the ETLC MBAs in September 1995. Field measurements of SS were undertaken following disposal events using Acoustic Doppler Current Profilers (ADCP). The resulting data were used to determine the optimum value for the loss rate, the maximum length of the random walk step, the concentration to sink rate relationship and the area and depth over which material is introduced into the water column. During the disposal trials, currents were observed to flow both in northeasterly and southwesterly directions and this enabled calibration of the model for both wet and dry season tidal conditions. Further details of the disposal trials and the calibration exercise are given in *Annexes B* and *C*.

3.7 WATER QUALITY MODELLING: MODEL SET UP

3.7.1 Modelling Scenarios

During the IAR three disposal scenarios were simulated to predict the impact of backfilling on water quality. The results, which are briefly described in *Section 2.5.1*, predicted limited elevations in suspended sediment at sensitive receivers to the northeast of the MBAs. Various mitigative measures were introduced into the Operations Plan (described in *Section 2.5*) to reduce these elevations and an additional set of nine disposal scenarios was generated and modelled.

Table 3.7a presents the nine new scenarios, which were chosen to represent the latest planned combinations of disposal locations and seasonal conditions, and the three original scenarios.

Table 3.7a *Parameters for Modelled Scenarios*

Scenario Number	Season	Tide	Disposal Rate ($m^3\ day^{-1}$)	Disposal Interval (hours)	Vessel Type	Disposal Area[a]	Disposal Site[b]
Modelling Scenarios Conducted for the IAR							
1a	Dry	Spring	100,000	1.92	Trailer	A	NA[c]
1b	Wet	Spring					
2a	Dry	Spring	50,000	3.84	Trailer	A	NA[c]
2b	Wet	Spring					
3a	Dry	Spring	100,000	1.92	Trailer	A, B & C[d]	NA[c]
3b	Wet	Spring					
Modelling Scenarios Conducted for the EIA							
1	Dry	Spring	50,000	0.384	Barge	A	1
2	Dry	Spring	50,000	3.84	Trailer	A	1
3	Dry	Spring	50,000	0.384	Barge	A	2
4	Dry	Spring	50,000	3.84	Trailer	A	2
5	Transition	Spring	25,000	7.68	Trailer	B	6
6	Transition	Spring	25,000	7.68	Trailer	B	4/5
7	Wet	Spring	50,000	3.84	Trailer	C	7/8
8	Dry	Neap	50,000	0.384	Barge	A	1
9	Dry	Neap	50,000	3.84	Trailer	A	1

Notes : (a) Disposal Areas are presented in *Figure 2.2a* and *Figure 2.5a*
(b) Disposal Sites are presented in *Figure 2.5a*
(c) NA = Not Applicable
(d) In this scenario 50,000 m^3 of material was released at two points, one of which was in Area A and the other in various locations in Areas B and C

3.7.2 *Values Used for Modelling Variables*

Rate of Introduction of Sediment into the Water Column

The rate at which sediment becomes suspended in the water column depends on the disposal rate, the density of the material and the loss rate. They have been derived as follows:

- Disposal rates which are presented in *Table 3.7a*, were selected on the basis of the results of the IAR. Actual disposal rates will typically be lower, at approximately the same rates as the current disposal at East of Ninepins from where material will be diverted (see *Section 2.4*). The frequencies of disposal events were derived from the assumed rate of disposal per day, an assumption of 24 hour dumping, a volume of material carried by trailers of 8,000 m^3 and, a volume of material carried by barges of 800 m^3. The volume of material carried by barges is derived from assumptions of hopper capacity of 1000 m^3 and hopper fill levels of 80% capacity.

- Material dry densities of 556 kg m^{-3} and 662 kg m^{-3} were assumed for trailers and barges respectively in accordance with agreements with the FMC. These values are based on estimates of the *in situ* mud density prior to dredging and bulking factors during grab and trailer dredging. The *in situ* bulk density is assumed to be 1.4 to 1.5 tonnes m^{-3} (see *Section 2.5.3*), which corresponds to a dry density of 0.794 tonnes m^{-3}, and the bulking factor is assumed to be 1.2 for grab dredged material and 1.43 for trailer dredged material. These values are consistent with data published by Tavolaro[7].

- A conservative loss rate of 5% was assumed on the basis of disposal trials conducted at the ETLC MBAs as discussed in *Section 3.5*.

Disposal Locations

Nine potential disposal areas were identified by CED GEO for modelling of potential disposal operations as described in *Section 2.5* and presented in *Figure 2.5a*.

Release Area and Depth

The introduction of sediment into the model was simulated over a circle of a 60 metre radius and over the lower 75% of the depth on the bases of field data collected during the disposal trials. Further details of the derivation of these values are presented in *Annex C*.

Sediment Quality: Nutrient and Sediment Oxygen Demand

Model inputs for dissolved oxygen and nutrient assessments were derived from EPD data collected during routine monitoring in Victoria Harbour. A value of 40,000 mg kg^{-1} was used for SOD and a value of 500 mg kg^{-1} was used for Total Nitrogen (TN).

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[7] Tavolaro J F (1982) Sediment Budget Study for Clamshell Dredging and Disposal Activities. US Army Engineer District New York USA

Summary of Values used for Modelling Variables

A summary of model input parameters is provided in *Table 3.7b*.

Table 3.7b ***Summary of Model Input Parameters***

Parameter	Value for Trailers	Value for Barges
Rate of Disposal per Day	50,000 m^3 or 25,000 m^3	50,000 m^3
Frequency of Disposal Events	3.84 hours or 7.68 hours	23 minutes
Mass of Disposed Material per Dump	4,448 tonnes	529.6 tonnes
Percent Loss (to suspension in the water column)	5%	5%
Dry Density of Dredged Material in Barge	556 kg m^{-3}	662 kg m^{-3}
Mass of Solids Released per Disposal Event	222.4 tonnes	26.48 tonnes
Sediment Oxygen Demand	40,000 mg O_2 kg^{-1}	40,000 mg O_2 kg^{-1}
Sediment Nutrient Content	500 mg TN kg^{-1}	500 mg TN kg^{-1}

3.8 MODELLING RESULTS: EVALUATION OF POTENTIAL IMPACTS

This section describes modelling results for suspended sediment, sediment deposition, DO and nutrients with particular reference to WQOs, the assessment criterion for SS and elevations of suspended sediment concentration at sensitive receivers. Results for the scenarios simulated are presented in the form of contour plots of predicted suspended sediment concentrations, predicted sediment deposition, predicted oxygen depletion and predicted nutrient elevation. In all cases the plots represent concentrations and rates over ambient levels. Time history plots represent a cycle of predicted elevations which occur as suspended sediment plumes from consecutive disposal operations are simulated to pass sensitive receivers. Thus it is most meaningful to consider the maximum predicted concentrations as occurring at some point in the cycle rather than at specific time after disposal.

3.8.1 *Results of Dry Season Disposal Scenarios*

Scenarios 1 to 4, 8 and 9 simulated disposal events during the dry season in the northeastern (deep) MBA. Results of all these scenarios predict the transport of sediment by oceanic currents from the disposal sites to the southwest towards sensitive receivers on Sung Kong Island and Poi Toi Island. Impacts on water quality, including impacts at the sensitive receivers, are predicted to be small and vary with the location of the disposal event, the type of vessel used and the strength of the tidal currents which vary within the lunar cycle.

Disposal in Area 1

Scenarios 1, 2, 8 and 9 simulated the effects of disposal of 50,000 m^3 of material in Area 1 from barges and trailers under dry season, spring and neap tidal conditions. Modelling output for these Scenarios are presented in *Annex D*. The greatest impacts were predicted to occur under Scenario 9, the results of which are presented in *Figures D26* to *D30*. This worst case scenario, which simulated disposal from trailers on the neap tide, is described here to illustrate trends in the results from all the dry season scenarios.

Figure D26 shows the maximum concentration at any point throughout the tidal cycle in the top and bottom layers of the model. Concentration intervals have been selected to show the area over which the assessment criterion is exceeded. *Figure D27* shows a snap shot of the predicted transport of consecutive plumes from the disposal events (note that contours show suspended sediment concentration intervals below 10 mg l^{-1} in order to illustrate how plumes are predicted to be transported) and the predicted deposition of sediment from suspension. *Figure D28* shows predictions of the depletion of DO and elevation of nutrients resulting from the elevations in suspended sediment concentrations. In both cases, the effects of sediment disposal are greater in the lower layer reflecting the fact that sediment concentrations are predicted to be more elevated in the lower part of the water column.

Suspended sediment concentrations are predicted to be elevated over an area to the southwest of the disposal site for all dry season scenarios. The area is greater following disposal from trailers than following disposal from barges which is a result of the greater simulated loss of sediment to suspension per disposal event from trailers than from barges. This can be seen by comparing barge simulation results in *Figures D1* and *D2* with trailer simulation results in *Figures D5* and *D6*. Disposal events on spring tides result in a greater area over which sediment concentrations are elevated as a result of slightly higher maximum currents on the spring tide. This can be seen by comparing spring results for barge and trailer respectively in *Figures D1* and *D6* with neap results in *Figures D21* and *D26*. Elevations above the assessment criterion are restricted to within the MBAs with the exception of relatively small areas in the bottom layer of the model to the southeast of the gazetted boundary.

At sensitive receivers to the southwest of the disposal site elevations in suspended sediment concentration are predicted under all of scenarios 1, 2, 8 and 9 but at very low levels. The maximum elevation predicted was approximately 7 mg l^{-1} at Sung Kong South in the bottom layer of the model. However at the other sensitive receivers at which suspended sediment elevations are predicted - namely Sung Kong North, Sung Kong West, and the Swire Marine Laboratory - elevations of 1 between 1 and 2 mg l^{-1} are more typical.

Sediment deposition is predicted to be largely confined to a small area within the MBAs. Small areas of low deposition (<50 g m^{-2}) are also predicted around in a number of locations on the coastline of Sung Kong and Poi Toi Islands (eg. *Figure D2*). This deposition is likely to be due to low current speeds and relatively shallow water around the islands.

Tidally-averaged DO depletion and nutrient elevation simulations predict that only the area immediately surrounding the disposal locations will be affected by significant rates of DO depletions and nutrient elevation. Barge disposal is predicted to result in larger areas of tidally averaged DO depletion and nutrient elevation because of the increased frequency of disposal events. The maximum tidally averaged DO depletion is 0.6 mg l^{-1} which occurs at the dumping site itself. This decreases rapidly to around 0.1 mg l^{-1} and for all the scenarios the tidally averaged depletion decreases to below 0.03 mg l^{-1} by the time the plume reaches the boundary of the gazetted MBAs.

Absolute DO depletion predictions, within individual plumes as they are transported away from the disposal site, are small as detailed in *Annex G*. Because they are small and because the surrounding waters are well oxygenated (see *Tables 3.3a, 3.3b* and *3.3c*) exceedances of the WQO for DO (see *Section* 3.2) are not expected.

Disposal in Area 2

Scenarios 3 and 4 simulated the effects of disposal in Area 2 from barges and trailers of 50,000 m^3 of material under dry season spring tide conditions. Area 2 is in the northeast MBA slightly to the south of Area 1 (see *Figure 2.5a*). Results showed similar patterns to disposal simulations in Area 1. This is as would be expected because the disposal points simulated in Area 1 and Area 2 are close and all other aspects of the respective simulations were the same. Output from the two scenarios (3 and 4) are presented in *Figures D11* to *D15* and *Figures D16* to *D20*, respectively, in *Annex D*.

Suspended sediment concentrations are again predicted to be elevated over an area to the southwest of the disposal site and again the area predicted is greater following disposal from trailers than following disposal from barges. Elevations above the assessment criterion are predicted to occur within the MBAs and to the southeast of the MBAs over an area of similar size to that predicted for scenarios 1, 2, 8 and 9. However, in this case a larger proportion of the area, which is mostly in the lower layer of the model, falls outside of the gazetted boundary of the MBAs because Area 2 is closer to this boundary than Area 1.

At sensitive receivers to the southwest of the disposal site elevations in suspended sediment concentration are predicted under both scenarios. Marginally higher concentrations are predicted following disposal from barges than from trailers because of the greater frequency of barge disposal scenarios. As for scenarios 1, 2, 8 and 9, the maximum suspended sediment elevation predicted was at Sung Kong South in the bottom layer of the model but in this case it was lower at approximately 4 mg l^{-1}. Elevations of between 1 and 2 mg l^{-1} were also predicted to occur at Sung Kong North, Sung Kong West, and the Swire Marine Laboratory.

Sediment deposition is predicted to be largely confined to a small area within the MBAs. Small areas of low deposition (<50 g m^{-2}) are also predicted around a number of locations on the coastline of Sung Kong and Poi Toi Islands (eg *Figure D2*). This deposition probably is likely to be due to low current speeds and relatively shallow water around the islands.

Tidally-averaged DO depletion and nutrient elevation simulations predict that only the area immediately surrounding the disposal site will be affected and the respective DO depletions and nutrient elevations are very low in both cases.

Absolute DO depletion predictions, within individual plumes as they are transported away from the disposal site, are small as detailed in *Annex G*. Because they are small and because the surrounding waters are well oxygenated (see *Tables 3.3a, 3.3b* and *3.3c*) exceedances of the WQO for DO (see *Section* 3.2) are not expected.

3.8.2 *Results of Wet Season Disposal Scenario*

Scenario 7 simulated disposal events during the wet season in the southwest (shallow) MBA at the mid-point between areas 7 and 8. Results are presented in *Figures E1* to *E5* in *Annex E*. The maximum concentration plots presented in *Figure E1* show that sediment is transported from the disposal site predominantly to the northeast but also to the southwest reflecting the influence of tidal currents on the predominant oceanic flow. As a result of the tidal current changes and the generally low current speeds, suspended sediment is predicted to be largely restricted to within the gazetted area of the MBAs. No elevations in suspended sediment concentration are predicted at sensitive receivers and no elevations above of the SS assessment criterion are predicted outside the MBAs. Tidally averaged depletion of DO and elevation of nutrient concentrations are predicted to be low and confined to within the MBAs.

3.8.3 *Results of Transitional Season Disposal Scenarios*

During the transitional period the dominant oceanic currents can switch between conditions typical of the dry and wet season. Disposal events for both seasonal conditions were simulated in scenarios 5 and 6 in which trailer dredged material was introduced at a rate of 25,000 m^3 in the centre areas of the MBAs. To ensure that the modelling produced conservative results, the Area at the shortest distance upstream from sensitive receivers was selected for each of the seasons (see *Figure 2.5*). Scenario 5 simulated disposal into Area 6, which is the most southerly of the disposal areas, under dry season conditions when currents flow to the southwest. Scenario 6 simulated disposal into the mid-point between areas 4 and 5, which is the most northerly of the disposal areas, under wet season conditions when currents flow to the northeast. Modelling results for both scenarios are presented in *Figures F1* to *F5* and *Figures F6* to *F10* in *Annex F*.

Scenario 5: Disposal into Area 6 under Dry Season Conditions

Suspended sediment concentrations are predicted to be elevated to the southwest of the disposal site in a similar pattern to other disposals simulated under dry season conditions (Scenarios 1, 2, 8 and 9). The results predict the largest spread of the plume towards sensitive receivers is to the southwest. This is because Area 6 is the most southerly of the disposal sites simulated under dry season conditions and therefore closest to these sensitive receivers, and because this site is shallower than sites in the northeastern (deep) MBA and experiences stronger currents. Elevations above the assessment criterion are predicted to occur over the area presented in *Figure F1*. Approximately half of this area falls within the MBAs. In the bottom layer of the model the maximum concentration plot shows three spurs which correspond to plumes from disposal events at different times in the tidal cycle; the direction the plumes are transported varies at different times in the cycle.

At sensitive receivers to the southwest of the disposal site (Sung Kong North, Sung Kong West and Sung Kong South) suspended sediment concentrations are predicted at very low levels of less than 1 mg l^{-1}. However despite these being small elevations, this disposal scenario probably has the greatest potential of all the scenarios considered for causing adverse impacts at sensitive receivers to the southwest of the MBAs. This is because the scenario represents disposal at the closest point to the sensitive receivers at a time when the prevailing current will carry suspended sediment towards them (ie to the southwest). Elevations at sensitive receivers would have been considerably higher had the currents carried sediment plumes directly toward sensitive receivers at Sung Kong rather than to the north of it.

Sediment deposition is predicted to be largely confined to a small area within the MBAs. Small areas of low deposition are also predicted around in a number of locations on the coastline of Sung Kong and Poi Toi Islands. This deposition probably results from low current speeds and relatively shallow water around the islands.

Tidally-averaged DO depletion and nutrient elevation simulations predict that only the area immediately surrounding the disposal site will be affected and the respective DO depletions and nutrient elevations are very low.

Absolute DO depletion predictions, within individual plumes as they are transported away from the disposal site, are small as detailed in *Annex G*. Because they are small and because the surrounding waters are well oxygenated (see *Tables 3.3a, 3.3b* and *3.3c*) exceedances of the WQO for DO (see *Section* 3.2) are not expected.

Scenario 6: Disposal into Area 4/5 under Wet Season Conditions

Suspended sediment concentrations are predicted to be elevated to the northeast and west of the disposal site in a similar pattern to disposals simulated under wet season conditions. Elevations above the assessment criterion are predicted to occur only within the gazetted boundaries of the MBAs.

At sensitive receivers elevations in suspended sediment concentrations are not predicted with the exception of Pak Kwo Chau West at which an elevation of less than 1 mg l^{-1} is predicted.

Sediment deposition is predicted to be largely confined to a small area within the MBAs. A very small area of deposition is predicted to the north of the gazetted boundary to the north of the northeastern (deep) MBA.

Tidally-averaged DO depletion and nutrient elevation simulations predict that only the area immediately surrounding the disposal site points will be effected and the respective DO depletions and nutrient elevations are very low in both cases.

Absolute DO depletion predictions, within individual plumes as they are transported away from the disposal site, are small as detailed in *Annex G*. Because they are small and because the surrounding waters are well oxygenated (see *Tables 3.3a, 3.3b* and *3.3c*) exceedances of the WQO for DO (see *Section* 3.2) are not expected.

3.8.4 Disposal Intervals

The interval between consecutive disposal events used in the modelling predictions detailed in *Section 3.7* was calculated by evenly distributing the dumps over 24 hours. In practice dumps are not likely to be spread evenly over time. For reasons that follow it is important that trailer disposal events are separated by a minimal interval period.

Modelling results of trailer disposal in the dry season predict that the plumes from consecutive dumps will be independent. This is as can be seen in *Figure D6* which shows plumes that have been carried to the southwest of the dump site.

Decreasing the time interval between trailer dumps would lead, at some point, to the plumes from consecutive dumps combining. As the interval was further decreased the plumes would increasingly interact and at some point the peak concentration within the combined plumes would exceed the peak concentration for the plume resulting from a single dump. Provided a short enough disposal interval, a higher suspended sediment concentrations would be observed at the dump site than was predicted in the results presented in *Annex D*. Higher predicted concentrations at the dump site would be expected to lead to higher predicted concentrations at sensitive receivers. To ensure that this does not occur a minimum disposal interval has been calculated.

The required disposal interval depends on the speed of currents carrying the plumes away from the dump site. The slower the currents, the longer the disposal interval that is required. Comparison of the spread of the plumes resulting from trailer dumps on the neap tide in *Figure D27*, with those on the spring tide in *Figure D6*, shows that currents are slower on the neap. Disposal intervals have therefore been defined on the basis of neap tide predictions. Examination of the plots shows that an interval of 2 hours would be ample to prevent the plumes from consecutive trailer dredger disposal events interacting. However initially an interval of 3.84 hours, which is consistent with the minimum disposal interval modelled, is recommended. The interval may be reduced from 3.84 hours provided environmental monitoring results show impacts to be acceptable at this interval.

Since it would require 10 barges dumping simultaneously to be equivalent to a single trailer dump, the frequency of barge dumping needs not be specified. However, the interaction between barge disposals and trailer disposals warrants further discussion. Maximum predicted sediment elevations at sensitive receivers are approximately 60% of the 10 mg l^{-1} assessment criterion. Therefore it would be expected that at least a 67% increase in the quantity of material disposed would be required for predicted levels at SRs to exceed the assessment criterion. On this basis, one trailer and six or seven barges could dump simultaneously before the assessment criterion would be predicted to be exceeded at the SRs. In practice, for the reasons given above this is highly unlikely. However, to prevent substantial overlap of plumes, it is recommended that no more than 5 barge disposals be undertaken in the two hour period following a trailer disposal and that trailer disposals be restricted so that they only occur after an interval of half an hour after the preceding barge disposal.

3.8.5 *Summary of Modelling Results Conducted for the EIA*

Dry season scenarios of disposal into the northeastern (deep) MBA predict sediment transport to the southwest of the disposal areas in accordance with prevailing oceanic currents. Small elevations in suspended sediment concentrations are predicted at sensitive receivers to the southwest as presented in *Table 3.8a*. Elevation of suspended sediment concentrations above the assessment criterion are predicted to be restricted to an area within, or in close proximity to, the gazetted boundary of the MBAs. DO depletions and nutrient elevations are predicted to be small with respect to background concentrations and the WQOs which are presented in *Section* 3.2. Therefore disposal operations under the Operations Plan in the dry season are not expected to result in unacceptable impacts.

The wet season scenario of disposal into the southwestern (shallow) MBA predict sediment transport to be predominantly driven by oceanic currents to the northeast. Tidal effects were also apparent and resulted in some transport to the northwest. Elevations of suspended sediment concentration above the assessment criterion are predicted to be restricted to within the MBAs and no elevations in suspended sediment concentration are predicted at any of the sensitive receivers to the northeast of the MBAs. As for the dry season scenarios, DO depletions and nutrient elevations were predicted to be small with respect to background concentrations and WQOs. Therefore disposal operations under the Operations Plan in the wet season are also not expected to result in unacceptable impacts.

Transitional scenarios simulated disposal into the central area of the pits in the period during which oceanic current directions are unstable and can switch rapidly between currents that predominate in the dry and wet seasons. Therefore, sediment introduced into the water column at the point of disposal in the centre of the MBAs can either be transported to the southwest, or, be transported to the northeast.

For the transitional wet season scenario, a small elevation (<1 mg l^{-1}) of suspended sediment concentration is predicted at Pak Kwo Chau which is the only sensitive receiver to the northeast at which elevations in suspended sediment concentrations are predicted in any of the scenarios. Sediment transport is predicted to the northeast and the northwest reflecting the influence of the tide on oceanic currents. Predicted elevations of suspended sediment above the assessment criterion are restricted to an area within the gazetted boundary of the MBAs. DO depletions and nutrient elevations are predicted to be small with respect to background concentrations and WQOs.

For the transitional dry season scenario, small elevations (<1 mg l^{-1}) in suspended sediment concentrations are predicted at sensitive receivers to the southwest at Sung Kong. DO depletions and nutrient elevations are predicted to be small with respect to background concentrations and WQOs.

As disposal operations during the transitions between wet and dry season are not predicted to result in unacceptable impacts under either wet or dry season conditions, disposal operations under the Operations Plan in the transitional season are not expected to result in unacceptable impacts.

A summary of predicted elevations of suspended sediment concentration at sensitive receivers is presented in *Table 3.8a*. It should be noted that to avoid interaction of consecutive plumes resulting from trailer dumps, a minimum disposal interval for trailers of 3.84 hours is recommended. In addition, no more than 5 barge dumps should be undertaken in the two hour period following a trailer dump, and trailer dumps may follow barge disposal events only after an interval of 30 minutes.

Table 3.8a *Summary of Predicted Elevations of Suspended Sediment at Sensitive Receivers*

Sensitive Receiver	Season	Scenarios in which an Elevation is Predicted	Approximate Maximum Predicted Elevation in SS
Sensitive Receivers to the Southwest			
Sung Kong N	Dry	1, 2, 3, 4, 8, 9	3 mg l^{-1}
	Transitional	5	< 1 mg l^{-1}
Sung Kong S	Dry	1, 2, 3, 4, 8, 9	7 mg l^{-1}
	Transitional	5	< 1 mg l^{-1}
Sung Kong W	Dry	1, 2, 3, 4, 8, 9	2 mg l^{-1}
	Transitional	5	<1 mg l^{-1}
Swire Marine Lab	Dry	1, 2, 3, 4, 8	0.5 mg l^{-1}
Sensitive Receivers to the Northeast			
	Transitional	6	<1 mg l^{-1}

3.9 *STABILITY OF BACKFILL MATERIAL*

Further modelling was conducted to evaluate the stability of recently disposed material under various storm conditions and the results are presented in this section. After a disposal event the vast majority of material does not become suspended in the water column but sinks to the bottom of the pit. Under certain storm conditions the surface layers of the recently deposited backfill material may be remobilised and then, under certain tidal conditions, be transported from the pits. The results of the modelling allow evaluation of the degree to which recently deposited backfill material is expected to erode from the pits at different backfill levels under tidal and wave (storm) action. Conclusions regarding backfill level are presented at the end of the section and further details of the analyses are presented in *Annex H*.

When considering the results presented it must be recognised that under typical conditions remobilisation and transport of deposited backfill material from the pits would not occur. However if a storm followed soon after backfilling, before material at the pit surface had consolidated, then material could be remobilised if the forces exerted by the storm were of sufficient strength. Remobilised material would then either be constrained within the pit by the sides of the pit, in which case it would subsequently settle back in the pit, or it would be transported from the pit by seasonal and tidal currents. The scenarios that have been considered in this report reflect rare occurrences (ie storms that happen infrequently) and assume that the storms occur immediately following backfilling. In actual operations, provided there is a sufficient interval between the last disposal event and the storm, backfill material would consolidate ultimately to densities similar to those of the surrounding un-dredged seabed. In order to prevent the presence of unconsolidated material coinciding with strong storms, mitigative measures are recommended which will halt backfilling, and allow sufficient consolidation before storms arrive (see *Section 2.5* and *Section 3.10*).

3.9.1 *Factors Affecting the Stability of the Backfilled Pits*

Bed stability is dependent on the critical shear stress of the bed material (the stress at which material begins to erode) and the shear stress exerted by currents flowing over the bed. The critical bed shear stress depends on:

- the nature of the material (eg mud or sand); and
- the degree to which the material has consolidated following disposal.

The current speed over the bed, which determines the shear stress exerted by the current, depends on:

- the speed of tidal and seasonal currents which vary with the depth of the water column and hence vary with the level to which the pit is backfilled;
- the speed of wave-induced currents which are dependent on the size of the waves over the pit and the depth of the water column.

Note that tidal and seasonal currents in isolation would not be sufficient to cause remobilisation of backfilled material as discussed below.

To evaluate the stability of the backfilled pits at varying backfill levels, shear stresses generated by currents under different seasonal, tidal and wave climates were calculated and compared to known critical shear stresses for materials of different densities.

3.9.2 *Potential Backfill Levels*

The following backfill levels were examined:

- for the northeastern (deep) MBA, bed levels of -45 m, -42 m, -39 m, -36 m, -33 m, -30 m and -27 m PD;
- for the southwestern (shallow) MBA, bed levels of -33 m, -30 m and -27 m PD.

3.9.3 *Shear Stress Required to Erode Backfill Material*

The critical bed shear stress, and hence the current speed at which backfill material is eroded is dependent on material density. A range of densities was considered in this Study based on the assumption that typical backfill material (both grab and trailer dredged material) has bulk densities in the range 1,230 - 1,350 kg m^{-3} and that low density fluid mud that may be generated during disposal activities has a density of approximately 1,080 kg m^{-3} [8][9][10].

The densities evaluated and their respective critical bed shear stresses are presented in *Table 3.9a*.

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(8) HWR Asia(1993) Disposal of Contaminated Spoil at East Sha Chau; An Assessment of the Stability of Dumped Soil and Capping Layers HWR Report 059

(9) HWR Asia (1993) Disposal of Spoil at South Tsing Yi: An Assessment of the Stability and losses of Dumped Spoil HWR Report 064

(10) HWR Asia (1993) Disposal of Spoil at West Po Toi: An Assessment of the Stability and losses of Dumped Spoil HWR Report 067

Table 3.9a *Critical Bed Shear Stresses for Backfill Material*

Material Density	Density ($kg\ m^{-3}$)	Critical Bed Shear Stresses ($N\ m^{-2}$)
Low	1,080	0.3
Intermediate	1,150	0.8
Intermediate	1,230	1.5
Normal	1,350	2.5

3.9.4 *Consolidation of Backfill Material*

When backfill material reaches the seabed it will begin to consolidate and as it does so its density, and hence its critical shear stress, will increase. The density of any low density material and intermediate density material is expected to reach that of normal density material in a relatively short period of time. The material will then continue to consolidate to densities similar to that of the surrounding un-dredged seabed, which at about to 5 cm below the seabed has a density in the range of 1,300 - 1,500 kg m^{-3} [11].

Results of field studies carried out in Japan[12], as part of a feasibility assessment of Kumamoto Port, suggest that the period required for material of low density to consolidate to intermediate / normal densities would be around 2 days. Prior to construction of the port, trial pits were dredged in a bay with a soft muddy bottom. Fluidisation of the bed and subsequent movement of the fluid layers during a storm led to infill of the trial pits. One of the three pits was surrounded by a submerged wall, approximately 1 m in height, and this pit received much less siltation than the others, indicating that fluid mud was the main mechanism of infill. Samples of bed material taken from within the pit 2 days after the storm had bulk densities in the range of 1260-1305 kg m^{-3} (equivalent to material of density in between normal density backfill material and the higher of the intermediate density backfill materials), indicating that the fresh deposits had consolidated rapidly. Laboratory experiments[13] using muds from Hong Kong also suggest that material will consolidate rapidly. In 1987 the vertical density profile of a sample of Hong Kong mud was tested over time in the HR Wallingford laboratory. The results showed that the majority of consolidation occurred within 48 hours.

3.9.5 *Predicted Current Induced Shear Stresses*

Current-induced shear stresses were predicted from tidal and seasonal current predictions from the WAHMO tidal model and from wave-induced current predictions derived from wave height predictions generated by the OUTRAY wave refraction model. Details of the conversions used between current speeds and shear stresses are provided in *Annex H*. Simulations were conducted for three locations which are presented in *Figure 3.9a*. The northern position (RP1) has been used to represent flows in the northeastern (deep) MBA, and two locations (RP2 and RP3) have been used to represent the flows over the relatively shallow southwestern MBA.

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(11) Civil Engineering Department Hong Kong Government (1997) Investigation of CMPIIa and CMPIIb Caps, East Sha Chau Contaminated Mud Disposal Area GEO technical Note TN6/97

(12) Harbour Institute of Japan (1990) Mathematical Modelling of Mud Transport In Ports with Multi layered Model - Application to Kumamoto Port Report of the Port and Harbour Research Institute, Vol 29, No 1 March 1990

(13) HR Wallingford (1987) Hydraulic and Water Quality Studies in Victoria harbour. Properties of Marine Muds HR Wallingford Report EX1617

WAHMO produces two layer predictions of current velocity. Maximum speeds for different seasonal and tidal conditions were extracted for simulations using the pre-dredged bed bathymetry as this results in the highest currents and represents the most conservative conditions. The strongest currents predicted in the lower layer of the model occurred in the dry season at location RP3.

OUTRAY produces predictions of wave activity at coastal sites based on offshore wave data. For this Study, wave heights and directions were generated for storm return periods of 0.1 year, 1 year, 10 years and 100 years. Note that a storm with a return period of 1 year is similar to a Typhoon Signal 8[14]. Wave conditions across the Study Area vary considerably. Over the northeastern (deep) MBA, substantial shelter is provided by Ninepins group of Islands. In the middle of the MBAs some shelter is still afforded by these islands. Over the southwestern (shallow) MBA wave conditions are largely unaffected by the island group and of the three sites considered, location RP3 was predicted to be the most exposed and hence subject to the highest waves and wave-induced currents. Further details of the maximum current predictions from the WAHMO model are presented in *Annex H*.

The bed shear stresses generated for different combinations of seasonal conditions and backfill levels at the northern (RP1) and southern (RP2 and RP3) areas are presented in *Table 3.9b* and *Table 3.9c*. The predicted shear stresses resulting from seasonal currents alone are low in comparison to the predicted currents resulting from waves under different storm events. To predict the shear stresses resulting from a combination of seasonal currents and wave-induced currents two methods were used: the Temperville[15] method and the Fredsoe[16] method. Both methods generally produce very similar results. However, where differences in predicted shear stresses were identified, the higher of the two values was adopted before making comparisons to critical bed shear stresses. This is a conservative approach as the higher the value of the combined wave and current-induced shear stress the more likely erosion of bed material is to occur. Two other factors serve to make the modelling conservative. Firstly, wave height predictions assume that the depth of the MBAs are consistent with the depth of the surrounding un-dredged seabed. This is not the case since at all but the final stages of backfilling, the level of the pits will be below that of the surrounding un-dredged seabed. As a result waves passing over the pits will have a smaller amplitude and hence induce weaker currents at a given depth than waves passing over the surrounding un-dredged seabed. Secondly and more importantly, no allowance has been made in the model for any reduction in current velocity that occurs because of the increased depth of pits. In the field the depression will reduce the tidal currents and restrict the export from the pits of any remobilised sediment.

(14) Hong Kong Observatory (1997) Pers Comm - Miss Ho In the period 1956-1996 typhoon signal 8 was hoisted on average 1.4 times per year

(15) Temperville J (1991) A numerical model of the rough turbulent boundary layer in combined wave and current interaction. Sand Transport in Rivers, Estuaries and the Sea. Balkema.

(16) Fredsoe J (1984) Turbulent boundary layer in wave-current motion. J Hydraulic Eng ASCE.

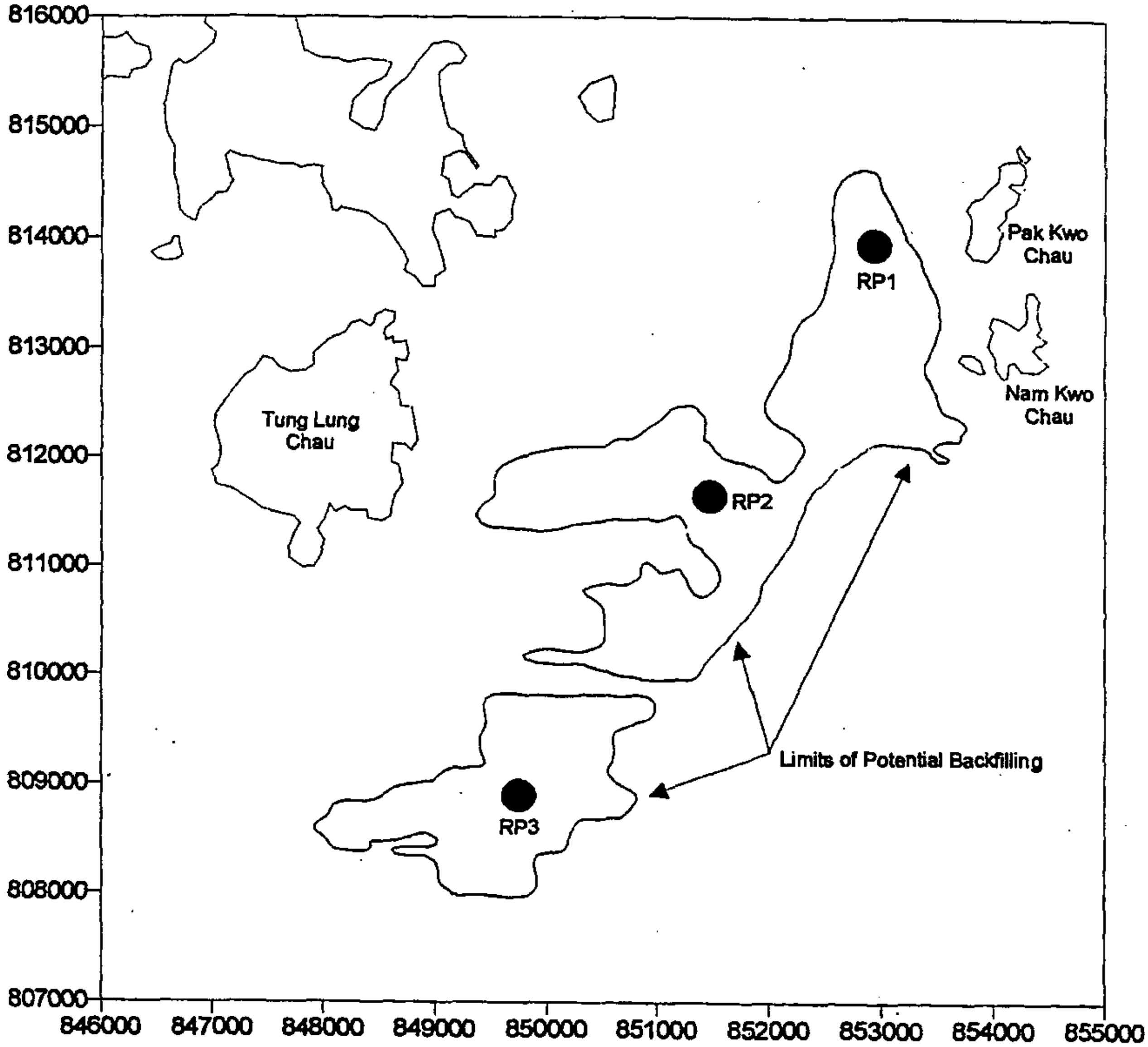

FIGURE 3.9a - LOCATION OF POINTS FOR WAVE AND TIDAL CURRENT SIMULATIONS FOR BED STABILITY ANALYSES

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

Table 3.9b *Bed Shear Stresses (in N m^{-2}) Predicted for Different Seasons and Wave Events for the Northeastern (deep) MBA (RP1)*

Bed Level in mPD Season	Wave Return Period (Years)	-45	-42	-39	-36	-33	-30	-27
Wet season	Waves not included	0.01	0.01	0.01	0.01	0.01	0.02	0.03
Dry season	Waves not included	0.02	0.02	0.03	0.04	0.05	0.06	0.08
Typhoon	Waves not included	0.03	0.03	0.03	0.03	0.03	0.04	0.07
No tidal/ oceanic currents	0.1	0.01	0.01	0.01	0.02	0.03	0.04	0.05
No tidal/ oceanic currents	1	0.12	0.15	0.18	0.22	0.28	0.35	0.44
No tidal/ oceanic currents	10	0.68	0.78	0.90	1.05	1.23	1.44	1.70
No tidal/ oceanic currents	100	1.94	2.17	2.44	2.76	3.13	3.58	4.13
Dry (Fredsoe method)	0.1	0.04	0.05	0.06	0.08	0.10	0.14	0.19
Dry (Fredsoe method)	1	0.17	0.20	0.25	0.31	0.39	0.49	0.63
Dry (Fredsoe method)	10	0.73	0.85	0.98	1.15	1.35	1.61	1.93
Dry (Fredsoe method)	100	2.00	2.25	2.54	2.88	3.29	3.78	4.40
Dry (Temperville method)	0.1	0.04	0.04	0.06	0.07	0.10	0.12	0.17
Dry (Temperville method)	1	0.16	0.20	0.24	0.30	0.39	0.48	0.61
Dry (Temperville method)	10	0.73	0.85	0.99	1.15	1.35	1.60	1.92
Dry (Temperville method)	100	2.01	2.25	2.54	2.88	3.29	3.79	4.41
Wet (Temperville method)	0.1	0.02	0.02	0.03	0.04	0.05	0.07	0.10
Wet (Temperville method)	1	0.14	0.17	0.20	0.25	0.32	0.40	0.50
Wet (Temperville method)	10	0.70	0.81	0.93	1.09	1.27	1.50	1.79
Wet (Temperville method)	100	2.03	2.28	2.57	2.92	3.34	3.85	4.50

Table 3.9c *Bed Shear Stresses (in N m^{-2}) Predicted for Different Seasons and Wave Events for the Southwestern (shallow) MBA (RP2 and RP3)*

Bed Level (m PD) Season	Wave Return Period (Years)	RP2			RP3		
		-33	-30	-27	-33	-30	-27
Wet	Waves not included	0.02	0.02	0.03	0.02	0.03	0.04
Dry	Waves not included	0.07	0.09	0.12	0.10	0.13	0.17
Typhoon	Waves not included	0.05	0.05	0.07	0.05	0.07	0.09
No tidal/ oceanic currents	0.1	0.16	0.21	0.28	0.46	0.56	0.69
No tidal/ oceanic currents	1	0.90	1.08	1.32	1.50	1.74	2.04
No tidal/ oceanic currents	10	2.20	2.58	3.04	2.93	3.35	3.87
No tidal/ oceanic currents	100	4.59	5.29	6.14	4.84	5.56	6.43
Dry (Fredsoe method)	0.1	0.24	0.31	0.41	0.65	0.80	1.01
Dry (Fredsoe method)	1	0.96	1.17	1.44	1.71	2.02	2.41
Dry (Fredsoe method)	10	2.25	2.64	3.13	3.16	3.65	4.27
Dry (Fredsoe method)	100	4.74	5.47	6.39	5.05	5.83	6.79
Dry (Temperville method)	0.1	0.22	0.30	0.39	0.63	0.77	0.97
Dry (Temperville method)	1	0.95	1.16	1.42	1.68	1.99	2.37
Dry (Temperville method)	10	2.24	2.63	3.11	3.13	3.62	4.23
Dry (Temperville method)	100	4.71	5.44	6.39	5.02	5.79	6.74
Wet (Temperville method)	0.1	0.17	0.23	0.30	0.51	0.62	0.77
Wet (Temperville method)	1	0.90	1.09	1.33	1.55	1.81	2.14
Wet (Temperville method)	10	2.21	2.58	3.05	2.99	3.43	3.97
Wet (Temperville method)	100	4.76	5.50	6.43	5.02	5.79	6.72

3.9.6 *Stability Analyses*

The environmental acceptability of erosion of backfill material at a particular level depends on the degree to which it occurs compared with the degree to which the surrounding un-dredged seabed is eroded. Predictions of backfill stability must therefore be considered in the context of erosion of the surrounding seabed which will occur if the current-induced shear stress exceeds the critical bed shear stress of the surface material. Field data[17] suggest that this surface material on the natural seabed will have relatively low shear stress and hence be fairly readily eroded. The low shear stress is inferred from the presence of a thin veneer of loosely consolidated mud overlying surface mud deposits which is apparent in REMOTS data from the un-dredged area adjacent to the ETLC MBAs. Erosion and deposition of the natural seabed can also be inferred from comparison[18] of the results of bathymetry surveys conducted in 1994 and 1997 which show that the pits have progressively infilled since their excavation.

Comparisons of critical bed shear stresses (associated with different backfill material densities) with predicted current-induced shear stresses at RP1, RP2 and RP3 are presented below. When considering these comparisons it should be recognised that the predictions are for backfill material immediately following disposal. During and following backfilling, the backfill material will settle and its density is expected to increase rapidly as detailed in *Section 3.9.4*. In addition eroded material may be constrained to within the pit by the sides of the pit.

Stability Analyses for Backfilling at RP1

The stability of backfill material following backfilling is dependent on the density of the material in the pit, the level to which backfilling has been conducted and the current-induced shear stress at that depth. *Figure 3.9b* presents the relationship between the predicted shear stress (Y axis) at varying backfill levels (X axis) under different seasons and different storm severities (represented by different lines on the graph) at RP1. Four different storm events are shown for the two seasons. The 1 in 0.1 year storm event under wet and dry seasons is shown at the bottom of the graph and the 1 in 100 year storm event is shown at the top of the graph. The critical shear stresses required to remobilise material of different densities are represented by horizontal lines across the graph.

The graph shows that changes in shear stress resulting from the different seasons are small when compared to changes in the shear stress that result from different storm events. The slope of the lines shows the sensitivity of the predicted shear stress generated under particular season and storm events to backfill level: a shallow slope shows that the shear stress generated is relatively insensitive to backfill level while steeper slopes show greater sensitivity of the generated shear stress to the level of backfilling. The slopes are shallower for the lines representing the shorter storm return periods than for the longer storm return periods. Therefore varying the backfill level is predicted to have a smaller effect on the rate of erosion under short return period storm events than under longer return period storm events.

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(17) Binnie & SAIC (1993) REMOTS Survey of Soft Bottom Environments in Coastal Waters of Hong Kong

(18) Civil Engineering Department Hong Kong Government (1997) Comparison of Survey 6/94 and 4/97

As the storm return period increases (ie rarer storm events which are associated with bigger waves) so does the predicted shear stress that is exerted at a particular backfill level. The point at which the critical shear stress for a given density of material intersects with the predicted shear stress exerted under a season and storm return period is the backfill level at which remobilisation will begin to occur. A summary of the intersections between critical shear stresses for different density materials and predicted shear stresses generated under varying storm return periods at RP1 is presented in *Table 3.9d*. Although low density material which represents fluid mud is included in the table no fluid mud was observed during the disposal trials described in *Annex B*.

Table 3.9d *Summary of Stability Analyses for Recently Deposited Material at RP1*

Wave Return Period (Years)	100	10	1	0.1
Low density soft material (Critical shear stress = 0.3 N m^{-2})	Eroded at all backfill levels	Eroded at all backfill levels	**Eroded above -37 mPD**	Not eroded at any backfill level
Intermediate density material (Critical shear stress = 0.8 N m^{-2})	Eroded at all backfill levels	**Eroded above -43 mPD**	Not eroded at any backfill level	Not eroded at any backfill level
Intermediate density material (Critical shear stress = 1.5 N m^{-2})	Eroded at all backfill levels	**Eroded above -32 mPD**	Not eroded at any backfill level	Not eroded at any backfill level
Normal density material (Critical shear stress = 2.5 N m^{-2})	**Eroded above -39 mPD**	Not eroded at any backfill level	Not eroded at any backfill level	Not eroded at any backfill level

Note: After approximately 2 days following deposition all backfill material is expected to have consolidated to Intermediate (Critical shear stress = 1.5 N m^{-2}) or Normal (Critical shear stress = 2.5 N m^{-2}) densities as detailed in *Section 3.9.4*.
The depth of the MBA at RP1 is approximately -47 mPD and the depth of the surrounding seabed is approximately -27 to -30 mPD.
The part of the table surrounded by double lines is referred to in *Section 3.9.7*

Stability Analyses for Backfilling at RP2

A similar analysis to that conducted for RP1 was conducted for RP2. *Figure 3.9c* presents the relationship between the predicted shear stress at varying backfill levels under different seasons and storm return periods. Comparison of *Figure 3.9b* (RP1) with *Figure 3.9c* (RP2) shows that the lines representing the shear stresses for respective storm return periods are shifted higher on the Y axis for RP2 than for RP1. This is due to higher predicted shear stresses at RP2 than RP1 for a storm of a given return period. Higher shear stresses are a result of stronger predicted tidal/seasonal currents and larger predicted waves, (with associated faster wave-induced currents), at RP2 than at RP1. Larger waves are predicted at RP2 than at RP1 because the former is more exposed than latter. Consequently for a given material density under given storm and seasonal conditions, erosion is predicted at lower backfilling levels at RP2 than at RP1.

Table 3.9e presents a summary of the intersections between critical shear stresses for different density materials and predicted shear stresses generated under varying storm return periods for RP2.

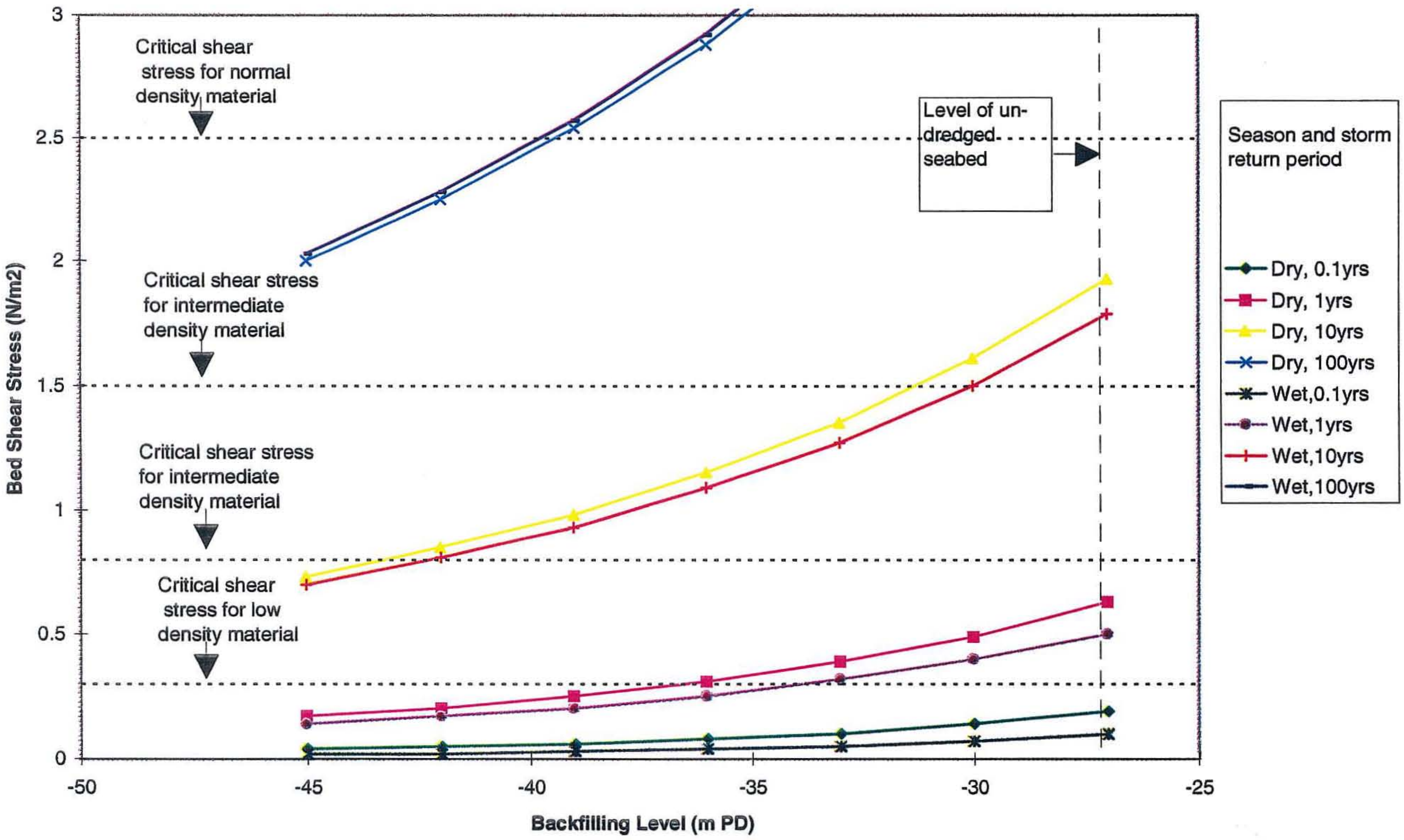

FIGURE 3.9b COMPARISON OF PREDICTED BED SHEAR STRESSES WITH CRITICAL BED SHEAR STRESSES FOR RP1 AT VARYING BACKFILL LEVELS

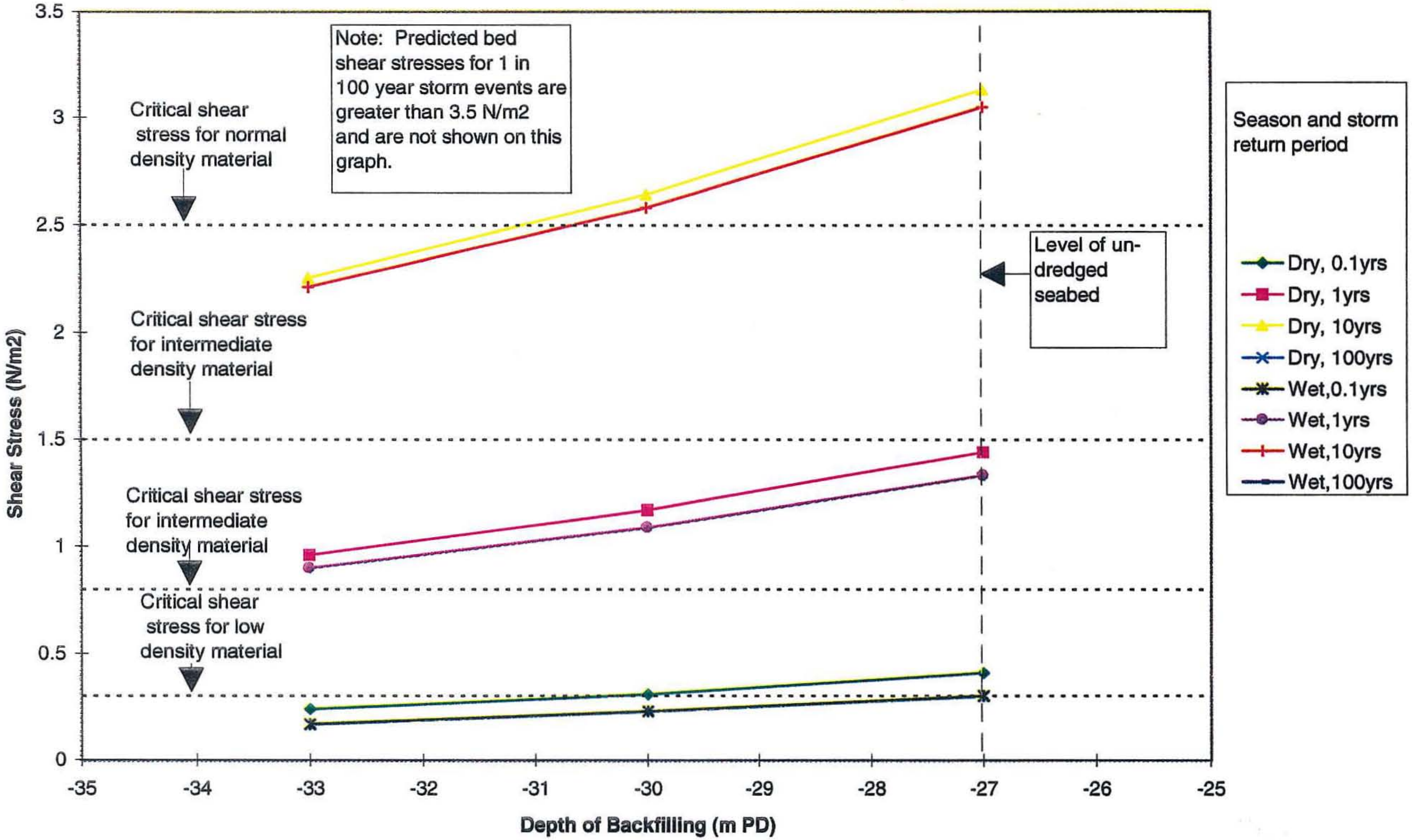

FIGURE 3.9c COMPARISON OF PREDICTED BED SHEAR STRESSES WITH CRITICAL BED SHEAR STRESSES FOR RP2 AT VARYING BACKFILL LEVELS

Table 3.9e *Summary of Stability Analyses for Recently Deposited Material at RP2*

Wave Return Period (Years)	100	10	1	0.1
Low density soft material (Critical shear stress = 0.3 N m^{-2})	Eroded at all backfill levels	Eroded at all backfill levels	Eroded at all backfill levels	**Eroded above -30 mPD in the dry season Eroded above -27 mPD in the wet season**
Intermediate density material (Critical shear stress = 0.8 N m^{-2})	Eroded at all backfill levels	Eroded at all backfill levels	Eroded at all backfill levels	Not eroded at any backfill level
Intermediate density material (Critical shear stress = 1.5 N m^{-2})	Eroded at all backfill levels	Eroded at all backfill level	Not eroded at any backfill level	Not eroded at any backfill level
Normal density material (Critical shear stress = 2.5 N m^{-2})	Eroded at all backfill levels	**Eroded above -31 mPD**	Not eroded at any backfill level	Not eroded at any backfill level

Note: After approximately 2 days following deposition all backfill material is expected to have consolidated to Intermediate (Critical shear stress = 1.5 N m^{-2}) or Normal (Critical shear stress = 2.5 N m^{-2}) densities as detailed in *Section 3.9.4*.
The depth of the MBA at RP2 is approximately -32 to -34 mPD and the depth of the surrounding seabed is approximately -27 to -30 mPD.
The part of the table surrounded by double lines is referred to in *Section 3.9.7*

Stability Analyses for Backfilling at RP3

A similar analysis to that conducted for RP1 and RP2 was conducted for RP3. *Figure 3.9d* presents the relationship between the predicted shear stress at varying backfill levels under different seasons and storm return periods.

Comparison of *Figure 3.9d* (RP3) with *Figure 3.9b* (RP1) and *Figure 3.9c* (RP2) shows that the lines representing the shear stresses for different storm return periods are shifted higher on the Y axis for RP3 than for RP1 and RP2. This is due to higher predicted shear stresses for a given storm at RP3 than RP2. RP2 in turn has higher predicted shear stresses than RP1. Higher predicted shear stresses are a result of seasonally stronger currents being predicted at RP3 and, more importantly, stronger predicted wave-induced currents. Consequently for a given material, erosion is predicted at lower backfilling levels at RP3 than at RP2 and RP1.

Table 3.9f presents a summary of the intersections between critical shear stresses for different density materials and predicted shear stresses generated under varying storm return periods at RP3.

Table 3.9f *Summary of Stability Analyses for Recently Deposited Material at RP3*

Wave Return Period (Years)	100	10	1	0.1
Low density soft material (Critical shear stress = 0.3 N m^{-2})	Eroded at all backfill levels	Eroded at all backfill levels	Eroded at all backfill levels	Eroded at all backfill levels
Intermediate density material (Critical shear stress = 0.8 N m^{-2})	Eroded at all backfill levels	Eroded at all backfill levels	Eroded at all backfill levels	**Eroded above -30 mPD in the dry season Not eroded at any backfill level during the wet season**
Intermediate density material (Critical shear stress = 1.5 N m^{-2})	Eroded at all backfill levels	Eroded at all backfill level	Eroded at all backfill levels	Not eroded at any backfill level
Normal density material (Critical shear stress = 2.5 N m^{-2})	Eroded at all backfill levels	Eroded at all backfill levels	Not eroded at any backfill level	Not eroded at any backfill level

Note: After approximately 2 days following deposition all backfill material is expected to have consolidated to Intermediate (Critical shear stress = 1.5 N m^{-2}) or Normal (Critical shear stress = 2.5 N m^{-2}) densities as detailed in *Section 3.9.4*.
The depth of the MBA at RP3 is approximately -34 mPD and the depth of the surrounding seabed is approximately -27 to -30 mPD.
The part of the table surrounded by double lines is referred to in *Section 3.9.7*

3.9.7 *Conclusions: Selection of Acceptable Backfill Levels*

Stability analyses have been conducted to predict the stability of backfilled material immediately following backfilling before significant consolidation of the material has occurred. Tidal currents alone are predicted to be insufficient to cause remobilisation of material at all the depths considered including the depth of the surrounding seabed. Waves generated by storms are, in certain cases, predicted to induce currents of sufficient magnitude to remobilise recently deposited material. However, it must be recognised that most of the storm events considered are rare, that the remobilisation will only occur when unconsolidated backfill material is present at the surface of the pit, that backfilled material is expected to consolidate relatively quickly (see *Section 3.9.4*) and that remobilised material may be contained within the pit by the sides of the pit. Provided backfilling management practices (specified in *Section 3.10*) are implemented, the coincidence of storms with the presence of unconsolidated material can be avoided.

Recommended backfill levels for the northeastern (deep) MBA, the northern part of the southwestern (shallow) MBA and the southern part of the southwestern (shallow) MBA have been based on stability analyses at RP1, RP2 and RP3 respectively. The levels selected were based on the following premises:

- Predictions of erosion for low density material in the top row of *Tables 3.9d, 3.9e* and *3.9f* have not been used in selecting acceptable backfill levels. This is because low density material corresponds to fluid mud. Fluid mud was not observed during the trial disposal and consequently fluid mud is not expected to be generated during backfilling operations. (The top row of *Tables 3.9d, 3.9e* and *3.9f* can therefore be ignored).

- Recently deposited backfill material will be subject to storms with return periods of 0.1 years relatively frequently. Backfilling must not, therefore, be

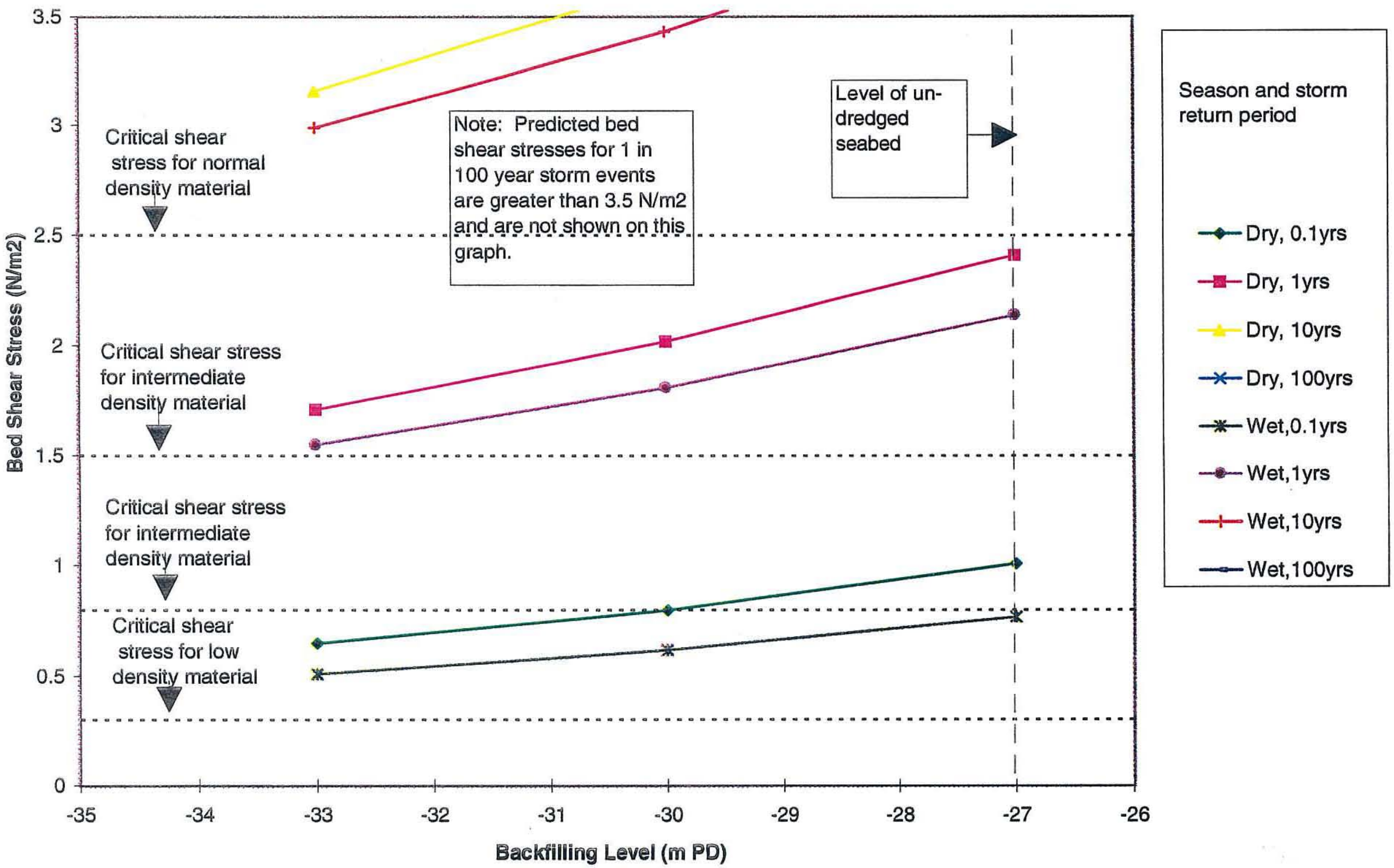

FIGURE 3.9d COMPARISON OF PREDICTED BED SHEAR STRESSES WITH CRITICAL BED SHEAR STRESSES FOR RP3 AT VARYING BACKFILL LEVELS

{4-17}

conducted to above a level at which material is predicted to be eroded under these conditions. Erosion predictions for each of the material densities are presented in the 4th column of *Tables 3.9d, 3.9e* and *3.9f*. (The 4th column of *Tables 3.9d, 3.9e* and *3.9f* is therefore important with the exception of the top row).

- Storms with return periods of 10 years and above, for which erosion predictions are given in the 1st and 2nd columns of *Tables 3.9d, 3.9e* and *3.9f*, are very rare occurrences and would probably result in considerable erosion of the surrounding natural seabed. Therefore, as both backfill material and the un-dredged seabed will be eroded it would be inappropriately conservative to base acceptable backfill levels on these storm events. (The 1st and 2nd columns of *Tables 3.9d, 3.9e* and *3.9f* can therefore be ignored).

- The implementation of mitigation measures which prevent disposal in the southwestern (shallow) MBA when the Typhoon Signal No 3 is hoisted will allow consolidation of backfill material to between normal and the higher of the two intermediate densities considered. (Note that a storm with a return period of 1 year is similar to conditions experienced under a Typhoon signal 8.) As a result, for storms with return periods of 1 year, backfill levels are acceptable as long as they would not result in erosion of the high-intermediate density to normal density material. (The 3rd row of the 3rd column *Tables 3.9d* and *3.9e* can therefore be ignored and the prediction in the 3rd row of the same column in *Table 3.9f* should be treated with some reservation).

On the bases of the premises given in the preceding bullet points acceptable backfill levels are derived from:

- erosion predictions for both the intermediate density materials and the normal density material under a storm with a return period of 0.1 years; and

- erosion predictions for the higher density intermediate material and normal density material under a storm with a return period of 1 year.

The cells containing these predictions in *Tables 3.9d, 3.9e* and *3.9f* are surrounded by a double line.

RP1 is the most sheltered of the three areas considered. The 4th column of *Table 3.9d* shows that during a storm with a return period of 0.1 year, recently deposited backfill material is not predicted to be eroded at any backfill level including that of the surrounding un-dredged seabed. The 3rd column shows that during a 1 in 1 year storm, which is similar to a Typhoon Signal 8, intermediate density materials and normal density material are predicted to be stable at all levels considered including that of the surrounding un-dredged seabed. Backfilling to the level of the surrounding un-dredged seabed is therefore predicted to be acceptable at the northeastern (deep) MBA. In the event that enhancement works are required, backfilling should be conducted to a level below that of the surrounding seabed. This will allow enhancement material to be placed over the backfill material without raising the backfilled areas above the surrounding seabed.

RP2 is less sheltered than RP1. The 4th column of *Table 3.9e* shows that during a storm with a return period of 0.1 year both intermediate density materials and normal density material are predicted to be stable at all backfill levels considered including that of the surrounding seabed. The third column shows that during a storm with a return period of 1 year, the higher of the two intermediate densities materials and normal density material are predicted to be stable at all levels considered including the level of the surrounding un-dredged seabed. Backfilling to the level of the surrounding un-dredged seabed is therefore predicted to be acceptable in the northern part of the southwestern (shallow) MBA. In the event that enhancement works are required, backfilling should be conducted to a level below that of the surrounding seabed. This will allow enhancement material to be placed over the backfill material without raising the backfilled areas above the surrounding seabed.

RP3 is the most exposed of the three locations. The 4th column of *Table 3.9f* shows that for a storm with a return period of 0.1 year, erosion of the lower intermediate density material is predicted in the dry season for backfill levels above -30 mPD. As a result, backfilling above -30 mPD level is not recommended. For the same storm, the lower of the intermediate densities in the wet season and higher density materials are predicted to be stable. The 3rd column shows that during a storm with a return period of 1 year, the higher of the intermediate density materials is predicted to be eroded at all levels considered and normal density material is predicted to be stable at all levels considered including the level of the surrounding un-dredged seabed. There may, therefore, be some erosion at this location of recently deposited backfill material under storms with a return period of 1 year. However, given the presence of low density material on the surface of the surrounding un-dredged seabed (see *Section 3.9.6*) this erosion is not deemed to be unacceptable and backfilling to a level of -30 mPD is thus acceptable.

3.10 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 dumped material, can be kept to a minimum and 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.

Mitigation measures for backfilling will take two main forms: the Operations Plan and the general plant maintenance and working methods.

The Operations Plan, which is detailed in *Section 2.5*, specifies backfilling operations in terms of rates and volumes of disposal, and spatial-temporal restrictions on disposal activities. These measures have been evaluated using water quality modelling predictions detailed in *Section 3.8*. Further verification of predictions will be undertaken as part of the Environmental Monitoring and Audit (EM&A) programme which will be implemented during disposal operations.

Three further restrictions on disposal operations are recommended for inclusion in the Operations Plan as follows

- A minimum interval for trailer disposals of 3.84 hours is recommended on the basis that plumes resulting from disposals this far apart in time are predicted to be independent, as shown in the top part of *Figure D27*. Extrapolation of modelling results suggests that a 2 hour interval will be ample to prevent plumes from consecutive disposals from interacting (see *Section 3.8.4*). There is therefore the potential to reduce the dumping interval following commencement of backfilling provided that environmental monitoring conducted as part of the EM&A programme shows that impacts are acceptable. Although no minimum interval for barge dumping is necessary, no more than 5 barge dumps should be undertaken in the hour following a trailer dump, and trailer dumps may follow barge disposal events only after an interval of 30 minutes.

- Cessation of backfilling operations in the southwestern MBA is recommended (see *Section 3.9*) prior to the arrival of storms. This should allow material to consolidate before the arrival of the storms and hence prevent erosion of recently deposited material. Accordingly backfilling operations should cease upon the hoisting of the Typhoon Signal 3[19].

- Backfilling should only be conducted up to levels deemed acceptable in *Section 3.9*.

General plant maintenance and working methods measures will be applied to supplement the Operations Plan and minimise further losses. The contractor must implement these measures to:

- minimise disturbance to the seabed while backfilling;

- prevent the avoidable reduction, due to backfilling, of the dissolved oxygen content of the water in the immediate vicinity of the MBAs;

- prevent avoidable deterioration in water quality which may cause adverse effects on marine ecology and bathing beaches; and

- ensure that backfilling will cause no visible foam, oil, grease, litter or other objectionable matter to be present in the water within and adjacent to the MBAs.

Pollution avoidance measures should include but not be limited to the following:

- all barges and hopper dredgers should be fitted with tight seals to their bottom openings to prevent leakage of fill material during transportation. Barge and hopper seals will be verified through annual inspection by Marine Department;

- the contractor will have to monitor, any or all, of the vessels transporting fill material and to ensure that no dumping outside the approved location takes place;

- after dumping, excess material should be cleaned from the decks and exposed fittings of barges and hopper dredgers before the vessel is moved; and

- adequate freeboard should be maintained on barges to ensure that decks are not washed by wave action. Freeboard maintenance is regulated through specification of a barge loading line which is enforced under Marine Department's vessel safety regulations.

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(19) Hong Kong Observatory (1997) Pers Comm - Miss Ho Data on the time interval between hoisting of the various typhoon signals is not published by the Hong Kong Observatory.

3.11 *EM&A REQUIREMENTS FOR WATER QUALITY*

A water quality monitoring and audit 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 Operations Plan, will be introduced.

The details of the EM&A programme are presented in the EM&A Manual, which is released as a separate document. Bathymetric, water quality and ecological monitoring is specified. Bathymetric monitoring will be carried out within and around the MBAs to ensure that mounding and excessive loss of fluid mud from the MBAs is not occurring. Water quality monitoring will be carried out around the MBAs to assess whether impacts are in accordance with the predictions made in this EIA. Ecological monitoring will be performed to verify predictions regarding the lack of impacts at ecologically sensitive receivers. The manual includes site-specific monitoring and auditing protocols for all phases of the backfilling operations including prior to the start of backfilling. Such protocols include but are not limited to the location of monitoring stations, parameters and frequencies for monitoring, monitoring equipment, data management procedures, and reporting of monitoring results.

Environmental audit specifications have been 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.

3.12 *CUMULATIVE IMPACTS*

Cumulative impacts have not been evaluated in this EIA in accordance with the Operations Plan (presented in *Section* 2.5.4) which imposes the following conditions on backfilling operations:

- backfilling at ETLC MBAs is prohibited during dredging and / or backfilling in the Eastern Waters MBAs;
- backfilling at ETLC MBAs is prohibited during dredging in the Tathong Channel and the West / East Po Toi MBA; and
- backfilling at the ETLC MBAs is prohibited during reclamation work at Tseung Kwan O;
- backfilling of the ETLC MBAs and concurrent disposal a the East of Ninepins Disposal Site will not be authorised since the former is intended to replace the latter.

3.13 *CONCLUSIONS*

Water quality impacts associated the proposed disposal of material at the ETLC MBAs were evaluated using sediment transport mathematical models. Predicted concentrations of SS and resulting depletions, elevations and deposition rates for

DO, nutrients and sediment respectively, were derived. These predictions were used to assess the impact of backfilling operations on the water quality of the study area and on specific sensitive receivers. Modelling scenarios were designed to evaluate variations in disposal rate and disposal location with season in order to specify mitigation measures to minimise adverse impacts. These mitigation measures were developed as operational constraints and presented as an Operations Plan for further assessment.

Results of all modelled scenarios predicted a maximum elevation of suspended sediment at sensitive receivers of 7 mg l^{-1} at Sung Kong South. Where elevations are predicted at other sensitive receivers, lower elevations of 1 -2 mg l^{-1} are typical. Predicted suspended sediment concentrations above the assessment criterion of 10 mg l^{-1} are largely restricted to within the gazetted boundaries of the MBAs. Dissolved oxygen depletions and nutrient elevations in all cases are predicted to be low with respect to background levels and WQOs. Therefore backfilling in accordance with the Operations Plan is not predicted to result in unacceptable impacts to water quality.

The stability of recently deposited material in the MBAs was predicted at various backfill levels. The northeastern (deep) MBA is fairly sheltered and analyses predict that the pit can be filled to the level of the surrounding seabed without causing unacceptable erosion. The northern part of the southwest (shallow) MBA is less exposed than the southern part. Analyses predict that the northern part can be filled to seabed level without causing unacceptable erosion. In the southern part of the southwestern (shallow) MBA backfilling may result in the erosion of some recently deposited backfill material under a storm with a return period of 1 year. However, this erosion is deemed acceptable in the context of natural erosion of the un-dredged seabed. Due to slightly greater exposure of disposed materials in the southwestern (shallow) pit to storm-induced erosion, backfilling above -30 mPD is not recommended in this MBA. In order to allow consolidation of recently disposed material to densities which will better resist the erosive forces of storms, a mitigation measure requiring cessation of backfilling once the Typhoon Signal No 3 is hoisted has been recommended.

4 MARINE ECOLOGY

4.1 INTRODUCTION

This section presents an assessment of the impacts to marine fauna and flora which may arise as a result of the proposed backfilling of the ETLC MBAs. Potential impacts to fisheries resources and fishing operations which may occur as a result of the works are also discussed.

A review of existing ecological data for the study site in Hong Kong's eastern waters has been conducted to collate information on the baseline ecological conditions in the study site. Particular focus has been placed on benthic invertebrates, demersal and pelagic communities and marine mammals. Ecological sensitive receivers have been identified, potential impacts discussed and, where appropriate, mitigation measures suggested.

The objectives of this impact assessment are as follows:

- to identify ecological sensitive receivers;
- to assess the scale of possible ecological impacts from backfilling;
- to highlight unacceptable environmental impacts and propose practical and cost-effective mitigation measures to reduce impacts to acceptable levels.

This assessment of impacts has been performed in order to determine the environmental acceptability of backfilling the ETLC MBAs given the policy principle of the Hong Kong SAR Government's Fill Management Committee to utilize uncontaminated dredged materials as fill for MBAs in preference to open seafloor disposal.

4.2 STATUTORY REQUIREMENTS AND EVALUATION CRITERIA

Legislation which applies to marine species includes the Wild Animals Protection Ordinance (Cap.170) 1980 which protects all cetaceans, and 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. In addition, legislation specific to marine ecology includes the Fisheries Protection Ordinance (Cap.171) 1987 which provides for the conservation of fish and other aquatic life and regulates fishing practices.

There are nine Fish Culture Zones (FCZs) located to the west and north of the ETLC MBA, of which Tung Lung Chau FCZ is the closest. Presently mariculturists will be eligible for ex gratia allowances when the level of suspended solids at the fish culture zone, as a result of public dredging or dumping works, is detected to reach 50 mgl^{-1} or 100% more than the highest level recorded at the zone during the 5 years before commencement of the works in the vicinity. When such criteria are exceeded, appropriate mitigatory measures, possibly including cessation of works, should be considered to keep the impact within acceptable levels.

There are no regulatory criteria for the evaluation of impacts upon ecological resources from developments. Therefore, for the purposes of this report, two means of evaluating such impacts have been defined. The first considers the rarity of individual species and communities, which is often used as an indication of ecological significance or importance. Rarity may be officially recognized through regulatory protection, such as for cetaceans like the Chinese White Dolphin (*Sousa chinensis),* as described above, or may result from an informal acknowledgment of threatened species or habitats. In such cases, habitat conservation is often as important as individual species preservation.

The second type of ecological criterion is the commercial value of capture fisheries, which in the eastern waters of Hong Kong has been estimated to be high (discussed below in *Section* 4.3). Impacts to fisheries, and the supporting ecological resources, may be assessed either in terms of the loss of revenue or the loss of fish production from the area.

4.3 *EXISTING ECOLOGICAL ENVIRONMENT*

4.3.1 *Introduction*

The ETLC MBAs are situated to the east of Hong Kong Island in the eastern waters of Hong Kong. As described in *Section* 3, the hydrography of this area is determined by the predominantly oceanic influence of the Hainan, Chinese Taipei and the Kuroshio currents with high salinities and variable temperatures. The fauna and flora of these waters reflect the oceanic influence and many species occur here which are absent in the estuarine conditions found to the west of Hong Kong[(3)]. In recent years, there have been many studies which investigate the ecology of MBAs in Hong Kong. Several of these provide baseline ecological information of direct relevance to this Study. The findings from these ecological studies are summarized below, with particular reference to the identification of any species or habitats of key ecological, conservation or economic importance which may be affected by the proposed backfilling works.

4.3.2 *Physical Characteristics of ETLC MBA*

As described in *Section* 2, the ETLC MBAs comprise two physically connected sites. The northeastern MBA (Area A) is a deep and distinct borrow pit which has been excavated to a depth of -47mPD and has a potential backfilling capacity of 17.9 Mm^3. The second site (Areas B & C), situated to the southwest of area A, is a less well defined site where up to 5 m of sand has been extracted. Dredging at the MBAs ceased in June 1994. This site has a potential backfilling capacity of 13.6 Mm^3. In accordance with the policy of the Fill Management Committee, it is proposed that the borrow areas be backfilled with uncontaminated marine mud to restore the seabed to approximately its original level and substrate type, ie soft marine muds with some sand and gravel.

Information on the pre-dredged condition indicates that for the southwest (shallow) MBA, the surface lithology over 43% of the area was composed of silty, sandy and occasionally gravelly clay, whereas the other 57% comprised clayey and silty sand. The northeast (deep) MBA was composed of 33% silty clay and 67% clayey and silty sand (*Figure 4.3a*).

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(3) Morton B and Morton J (1983) The Seashore Ecology of Hong Kong. Hong Kong University Press.

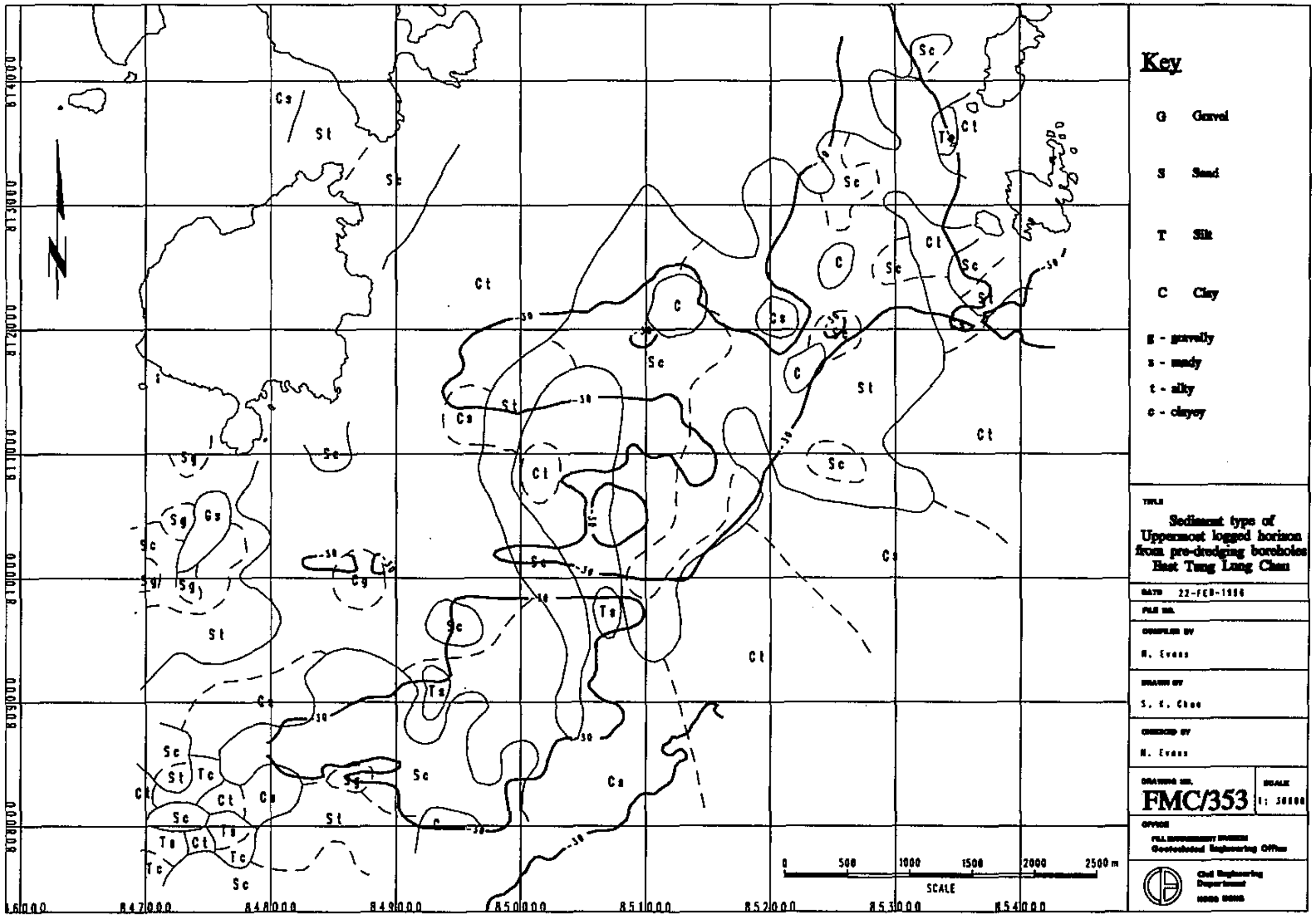


FIGURE 4.3a - SEDIMENT TYPE OF THE EAST TUNG LUNG CHAU AREA (PRE-DREDGING)

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

REMOTS surveys carried out in the ETLC MBAs revealed that areas disturbed by dredging showed the presence of feeding voids[4]. This infers that colonisation of the dredged sediments is occurring. Typical REMOTS images are presented in *Figure 4.3b* illustrating sediment profiles for an area in the gazetted borrow area that was never dredged, an area during dredging, and an area that had been dredged 14 months prior the sampling.

4.3.3 *Benthic Communities*

Benthic infauna and communities in Hong Kong are generally characterised by high diversity, low numbers of individuals and low biomass. The composition of such communities may be determined by sediment characteristics[5] since a high percentage of silt restricts the number of species able to colonise the substrate. Previous studies from other parts of the world have determined that the distribution and abundance of benthic organisms are commonly related to salinity, organic content and silt-clay fraction of the sediment [6][7][8][9].

Comparatively little work has been conducted on the marine benthic communities of Hong Kong particularly those occurring in eastern waters. The spatial distribution of the infaunal benthos in Hong Kong waters was the subject of a study in which grab samples were collected from 200 different sites, including 81 in eastern waters[10]. The results are summarised in *Table 4.3a* and indicate that the structure of the benthic assemblage in eastern waters is broadly similar to that found throughout Hong Kong, reflecting the identified homogeneity in sediment composition. However, Wu and Richards (1981)[11] found that abundance and biomass of benthic infauna decreased, and diversity increased, from west to east in Hong Kong.

Table 4.3a ***Summary of Principal Environmental and Biological Parameters recorded in Eastern Waters.***

Parameter	Eastern Waters	Mean for Hong Kong
Depth (m)	23.0	19.5
Bottom Salinity (%)	32.6	31.9
% Gravel (>2 mm)	0	1.5
% Sand (0.062-2 mm)	6.2	15.4

(4) Binnie & SAIC (1994) REMOTS Surveys of Tathong Channel Borrow Pits and Surrounding Borrow Pits.

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

(6) Sanders H.L. (1958) Benthic Studies in Buzzards Bay Animal-Sediment Relationships. Journal of Oceanography. 3: 245 - 282

(7) Nicholls H. (1970) Benthic Polychaete Assemblages and their Relationship to the Sediment in Port Madison, Washington. Marine Biology. 6:48-57.

(8) Bloom S.A., Simon J.L. and Hunter V.D.(1972) Animal-Sediment Relations and Community Analysis of a Florida Estuary. Marine Biology. 6:48-57

(9) Knight G.S. (1974) Benthic Community Structure in Lyttelton Harbour. N.Z.L. Marine Freshwater Research. 8: 291 - 306.

(10) Paul K.S.Shin and G.B.Thompson (1982) *op cit*

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

Parameter	Eastern Waters	Mean for Hong Kong
% Silt (2-62 μm)	88.7	78.5
% Clay (<2μm)	5.1	4.7
Organic Content (%)	1.90	1.91
No. individuals m^{-2}	88.2	101.4
No. species 0.5 m^{-2}	19.2	18.5
% Polychaetes	72.5	71.2
% Molluscs	5.2	12.4
% Crustaceans	9.5	7.6
% Echinoderms	5.9	3.7
% Other Groups	6.9	5.2
Wet weight (g m^{-2})	22.5	35.2

Invertebrate communities around the Ninepin Islands were the subject of another study undertaken during December 1993 and January 1994[(12)], in which grab sampling was carried out at eleven sites, including 2 within the ETLC MBA. A total of 89 taxa were recorded and polychaetes were the most abundant species at every location. The two areas sampled within the MBAs showed a higher than average number of benthic Molluscs, mainly bivalves and gastropods. Crustaceans and Echinoderms were virtually absent despite being abundant outside of this area. Mean density of individuals varied considerably from 400 m^{-2} north and west of the Ninepins group down to less than 154 individuals m^{-2} within the dredged MBA. Species diversity was also variable with the lowest diversity (1.95 species m^{-2}) recorded from within the ETLC MBAs, and the highest (2.95 species m^{-2}) directly north of the MBAs, to the east of Ching Chau. The benthic fauna within the dredged area was unlike that found at the control stations.

A recently released report has characterised the soft bottom community around Basalt Island (north of the ETLC MBAs)[(13)]. The study site has never been disturbed by permitted dredging activities and in general, is thought to represent a community typical of pristine areas of the eastern waters of Hong Kong (see *Figure 3.3c*). Abundance of infaunal organisms was low and the community was dominated by polychaetes (mainly Pilargiidae, Maldanidae and Spionidae).

The Study used the ABC technique to assess the extent of disturbance. In this technique, taxa are ranked in order of abundance or biomass on the x axis with percentage dominance on the y axis. 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. The Study found that the majority of the sampling stations were undisturbed. Some stations, however, were classified

(12) Binnie Consultants Ltd (1994a) Marine Ecology of the Ninepins Islands.

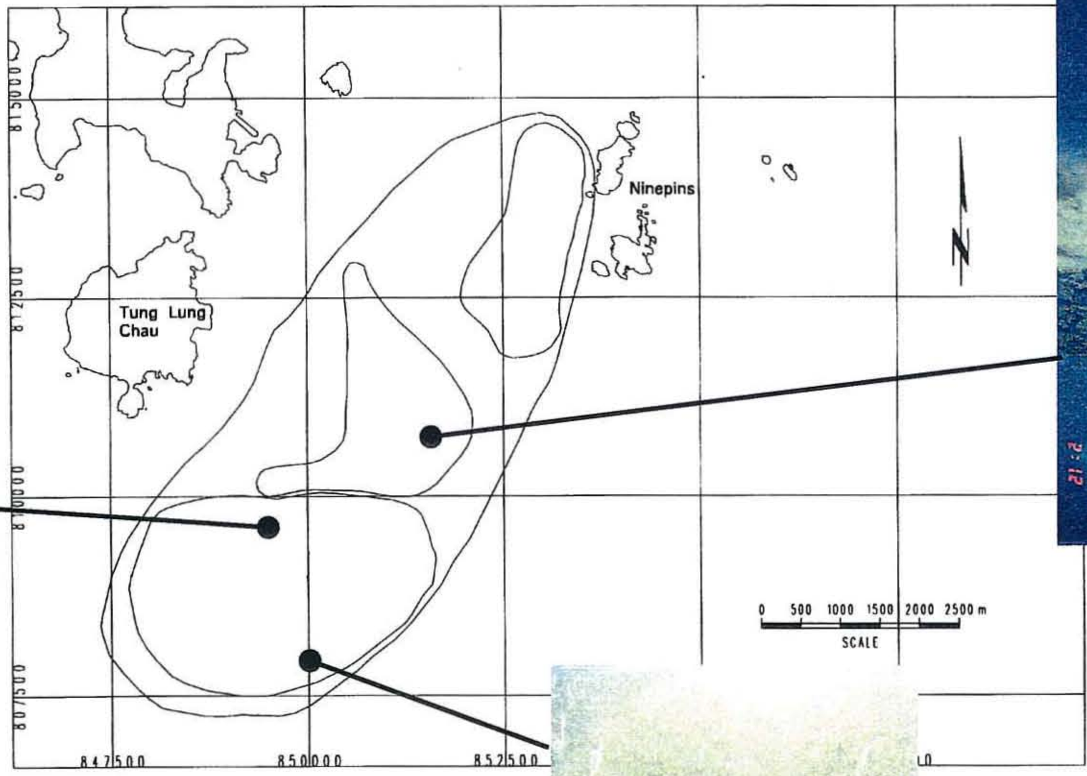
(13) ERM-Hong Kong Ltd (1997) Seabed Ecology Studies: Basalt Island Final Report, March 1997.

EIA- ~~130.1~~

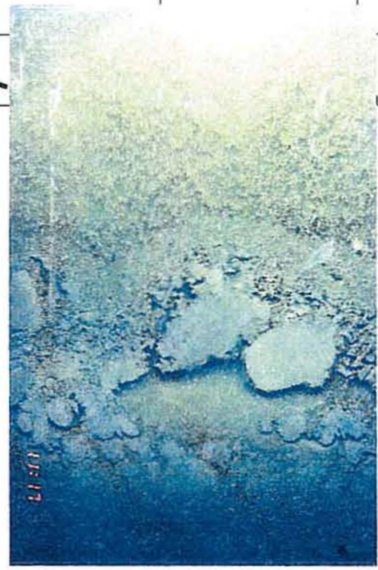
~~131.1~~

136.1

UNDREDGED



POST DREDGING



DURING DREDGING

UNDREDGED SEDIMENT PROFILE
TYPICAL REMOTS IMAGE OF AN UNDREDGED AREA OF THE ETLC MBA. THE SEDIMENTS ARE UNDISTURBED WITH A DISTINCT REDOX POTENTIAL DISCONTINUITY AND A LACK OF MUD CLASTS. SOME FEEDING VOIDS ARE ALSO PRESENT.

DURING DREDGING SEDIMENT PROFILE
TYPICAL REMOTS IMAGE OF CONDITIONS DURING DREDGING OF THE ETLC MBA. THE SEDIMENTS ARE HIGHLY DISTURBED. THERE IS A DISTINCT LAYER OF SURFACE MUD CLASTS.

POST DREDGING SEDIMENT PROFILE
TYPICAL REMOTS IMAGE OF CONDITIONS 14 MONTHS AFTER DREDGING OF THE ETLC MBA. THE DISTURBED MATERIAL HAS CONSOLIDATED, WITH A LAYER OF MUD CLASTS. THE PRESENCE OF FEEDING VOIDS INDICATES THAT COLONISATION OF THE MATERIAL HAS OCCURRED.

FIGURE 4.3b - TYPICAL REMOTS IMAGES TAKEN FROM THE ETLC MBA DURING 1994 (BCL & SAIC 1994) REPRESENTING UNDREDGED, DURING DREDGING AND POST DREDGING CONDITIONS

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Tsimshatsui, Kowloon
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as moderately disturbed and were identified as locations where unpermitted disposal of construction waste has occurred.

Under the same Seabed Ecology Studies, the findings of grab sampling at sites east of the Ninepins indicate that disposal mound stations were distinct from the surrounding reference stations[14]. The mound stations were physically more heterogeneous than reference stations and were dominated by opportunistic spionid polychaetes. Though abundances of benthic organisms were similar to the reference stations, taxonomic richness was low. The mound stations were classified as moderately disturbed.

In addition to disturbance due to dredging and disposal the seabed of eastern waters is also subject to the effects of continuous trawl fishing. This fishing method scours the surface layer of the seabed, causing disturbance to the benthic community. The impact of trawling upon the abundance and diversity of benthic fauna has not been assessed and the rate at which the seabed community recolonises is also unknown.

The findings of a beam trawl survey of SE waters in Hong Kong have recently been published in two papers by researchers from the Swire Institute of Marine Science[15][16]. As part of the study, carried out in April 1995, sampling stations were split into two groups, dredged and not dredged. Of the dredged group, four sites were located within the MBA (T33, T34, T41, T46) and four sites in areas that may have been affected by sediment plumes arising from dredging in the MBA (T45, T29, T30, T43). The undredged group stations were located away from the MBA area (T31, T32, T40 see *Figure 3.3c*).

The epifaunal gastropod community was characterised by lower abundances in the dredged areas (mean = 2618) as compared to the undredged areas (mean = 3579). The community in both dredged and undredged areas was dominated by the scavenging gastropod *Nassarius siquijorensis*. This species is the dominant gastropod throughout Hong Kong and is said to be one of the few gastropods that has been unaffected by the perturbated conditions prevalent in Hong Kong's marine benthos[17]. Other abundant species included *Bursa rana* and *Armina* sp in dredged areas and *Philine* sp in undredged areas. Diversity of the gastropod community in the pit was low but similar to that outside the pits in undredged areas. Despite the low diversity value for stations in the ETLC area, they had a more diverse gastropod community than other stations in the SE waters of Hong Kong. A complete list of gastropod species (and abundances) collected from the beam trawl survey in the ETLC MBAs is provided in *Annex J*.

(14) ERM Hong Kong Ltd (1997) Seabed Ecology Studies: East of Ninepins Final Report, May 1997.

(15) Leung KF & Morton B (1997) The Impacts of Dredging on the Epibenthic Molluscan Community of the Southeastern Waters of Hong Kong: A Comparison of the 1992 and 1995 Trawl Programmes. p. 401-436. In Marine Flora & Fauna of Hong Kong & southern China IV (ed. B Morton). Proceedings of the 8th International Marine Biological Workshop: the Marine Flora & Fauna of Hong Kong & Southern China, Hong Kong: Hong Kong University Press.

(16) Leung AWY (1997) The Impact of Dredging and Fishing on the Benthic Fish Fauna of the Southeastern Waters of Hong Kong. p. 437-462. In Marine Flora & Fauna of Hong Kong & southern China IV (ed. B Morton). Proceedings of the 8th International Marine Biological Workshop: the Marine Flora & Fauna of Hong Kong & Southern China, Hong Kong: Hong Kong University Press.

(17) Morton B (1995) Perturbated Soft Intertidal and Subtidal Marine Communities in Hong Kong: the Significance of Scavenging Gastropods. In The Marine Biology of the South China Sea II (ed. B Morton eta l), 1-15. Proceedings of the 2nd International Conference on the Marine Biology of the South China Sea, Guangzhou, China. Beijing World Publishing Corporation.

The infaunal bivalve community also did not differ between the dredged and undredged areas. The most abundant species in both areas were *Placamen calophylla, Corbula crassa* and *Anadara ferruginea*. There was little difference in bivalve diversity between the pit ($H' = 1.09$) and undredged areas ($H' = 1.02$). In comparison with stations in southeast Hong Kong, bivalve diversity at ETLC was low (eg Po Toi $H' = 1.39$). A complete list of bivalve species (and abundances) collected from the surveys of the ETLC MBAs is provided in *Annex J*.

The fisheries community present in the MBAs was also sampled during this beam trawl study. The results indicated that with a few station-specific exceptions, the fish fauna of the dredged areas was similar to that recorded from surrounding areas, and comparable to undredged areas in Mirs Bay. The conclusion of the study was that sand borrowing activities in southeast waters has not adversely affected the benthic fauna and fisheries resources of the study area. Colonisation of the post dredging MBA by demersal fish had, as is expected with a mobile population, occurred rapidly. This area of Hong Kong however does not support the richest demersal fisheries in Hong Kong[18]. More detailed information, from literature reviews and from the AFD Fisheries Survey, on the fisheries resources of the area is presented below in *Section 4.3.6*.

4.3.4 *Phytoplankton and Zooplankton*

The phytoplankton of the coastal waters of Hong Kong are dominated by the genera *Thalassiosira, Chaetoceros, Rhizosolenia, Skeletonema* and *Coscinodiscus*. In 1989, Lam and Ho identified 83 species of phytoplankton of which 70% were diatoms and 26% were dinoflagellates[19]. Phytoplankton (measured as chlorophyll-a) are indicators of pollution levels within a water body. In unpolluted tropical oceanic water the chlorophyll-a level is normally below $2\mu g\ l^{-1}$ and levels of over $10\mu g\ l^{-1}$ are indicative of nutrient enrichment. Monitoring by EPD recorded mean chlorophyll-a concentrations at stations around ETLC as being below $1\mu g\ l^{-1}$[20].

Zooplankton are generally recognised as being important food sources for the larvae and juveniles of commercially valuable fish. There is very little existing information on the zooplankton of Hong Kong particularly in the eastern waters. It is reported, however, that these waters are more diverse than the estuarine western waters. Around the Ninepins, the most abundant species was *Echinopluteus* larvae which occurred at a density of 800 individuals m^{-3}. Other common species were *Penilia avirostris, Oncaea venusta, Canthocalanus pauper* and *Corycaeus affinis* and the larvae of crab and shrimp[21].

4.3.5 *Commercially Important Invertebrates*

There are twelve species of shrimp, seven species of squid and six species of cuttlefish which occur in eastern waters, many of which are economically important and the basis of commercial fisheries. Trawls were conducted in the

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(18) ERM -Hong Kong Ltd(1997) Fisheries Resources and Fishing Operations in Hong Kong Waters. Draft Final Report.

(19) Lam W.Y.L and Ho K.C (1989) Phytoplankton characteristics of Tolo harbour. Asian Marine Biology Vol.6 5-18.

(20) EPD (1993) Marine Water Quality In Hong Kong for 1993.

(21) Binnie Consultants Ltd. (1994a) *op cit*

Ninepins area as part of the Fill Management Study[22], and obtained a total of 67 species of invertebrates from 28 tows. The majority of the samples were dominated by Crustacea, such as crabs and shrimps (70% of the total catch), and Mollusca, such as clams and snails. Trawls were conducted in two areas: the South Ninepins MBA and a reference area to the east of this. Catch size and weight were higher in the reference area than the MBA. Species captured are listed in *Annex I*. Additional studies of Fury Rocks, Sung Kong and Waglan Island revealed a high diversity adjacent to the Fury Rocks and Sung Kong and lower species numbers at Waglan Island. The community at Fury Rocks was dominated by sea anemones, sea cucumbers, starfish and molluscs[23][24].

4.3.6 *Fisheries Resources*

Historical Information

In 1995, Hong Kong's fishing fleet yielded approximately 195,000 tonnes of fish, with a total value estimated at $2,150 million. The Agriculture and Fisheries Department (AFD) 1991 Port Survey showed that areas with the highest yields for fisheries in Hong Kong were mainly concentrated along the eastern and northeastern coasts. *Table 4.3b* illustrates the types of fisheries resources in the region of the proposed MBAs.

Table 4.3b ***Composition of Fisheries Resources in the Ninepins Region during surveys in 1994***[25]

Type	Percentage (%) Total Catch
Fish	76.4
Molluscs	9.4
Shrimps and Crabs	14.2

According to the 1997 AFD Vessel Count there are a total of 4,857 fishing vessels based in Hong Kong waters, approximately 70% of which are classified as small vessels (<15 m) which spend a large percentage of their time operating in inshore waters[26]. The percentage production derived from the various fishing methods conducted near Ninepins (area not defined in the report) are summarised in *Table 4.3c*. Gill netting (27.6 %), purse seining (26.0%) and cage trapping (23.3%), operated from outboard powered sampans comprise the largest percentage of fishing methods. Gill netting (32.8%) yields the greatest catch from inboard powered craft (<10 m), whereas purse seining (49.4%) accounts for the largest percentage of catch from the slightly larger craft (10-15 m). For the large vessels (>15 m), the greatest proportion of fish caught are by gill netting (28.3%) and purse seining (25.5%) [27].

(22) Binnie Consultants Ltd. (1994a) *op cit*

(23) Binnie Consultants Limited. Marine Ecology of Hong Kong (1995a) Report on Underwater Dive Surveys October 1991 - November 1994 Volume II

(24) Binnie Consultants Ltd(1995b) Underwater Ecological Survey of Fury Rocks, Sung Kong and Waglan October 1995

(25) *Ibid*

(26) ERM-Hong Kong Ltd (1997) Fisheries Resources & Fishing Operations in Hong Kong Waters, Draft Final Report.

(27) Binnie Consultants Ltd. (1994a) *op cit*

Table 4.3c *Percentage (%) Catch Derived from Different Fishing Methods in the Ninepins Region*[28].

Fishing Method	Outboard Powered Sampans	Inboard Powered Craft <10m	Inboard Powered Craft 10-15m	All Craft >15m
Gill Netting	27.6	32.8	22.3	28.3
Hand Lining	10.8	16.2	1.6	10.6
Purse Seining	26.0	9.5	49.4	25.5
Cage Trapping	23.3	17.2	2.1	15.1
Long Lining	2.6	18.3	10.6	11.2
Clam Collection	4.5	1.9	2.2	2.8
Stern Trawling	0.0	0.0	1.6	0.4
Shrimp Trawling	0.1	2.2	10.2	3.7
Miscellaneous	5.1	1.9	0.0	2.4
Total	100.0	100.0	100.0	100.0

A non quantitative dive survey of local fish populations (October 1991 and November 1994), has been conducted in the vicinity of the proposed MBAs [29]. This survey suggested that the rocky sea bed at Tung Lung Chau Island, restricts the type of fishing gear used, accounting for the large abundance and diversity observed there. This survey was proceeded by a quantitative survey utilising trawl and gill netting fishing methods (December 1994 and January 1995). The location of the fishing sites are illustrated in *Figure 4.3c*, and the abundance and distribution of fish species caught are summarised in *Annex I*. The abundance of invertebrate species collected during the same quantitative survey are summarised in *Annex I*. Commercial species made up 74 % of the catch. No specific figures are available for squid, cuttlefish and other molluscs harvested from these islands. Approximately 4 tonnes of Sea Urchins (*Anthocidaris crassispina*) are collected annually from along the Ninepins Islands coastline, generating a revenue of HK$260,000 [30].

Fisheries Resources and Fishing Operations in Hong Kong Waters - ERM for AFD

As part of the ongoing AFD study on Fisheries Resources and Fishing Operations in Hong Kong Waters, trawl, gillnet and purse seine samples have been collected at stations in the area surrounding the ETLC MBAs[31] (*Figure 4.3c*). Data gathered indicated average, or below average, catch yields as compared to other areas sampled in Hong Kong (*Table 4.3d*).

The most abundant organisms collected during trawling in this area were mantis shrimps (*Oratosquilla* spp), velvet shrimps (*Metapenaeopsis* spp) and the cardinal fish *Apogon quadrifasciatus*. In the gill net programme the catches were highly variable between months, though yields were low compared with other stations in Hong Kong. The most abundantly caught organisms were the cardinal sea bream (*Evynnis cardinalis*) and the chicken grunt (*Parapristipoma trilineatum*). The squid, *Loligo edulis* and the silver shrimp (*Acetes japonicus*) were the most

(28) Binnie Consultants Ltd. (1994a) *op cit*

(29) Binnie Consultants Ltd. (1994a) *op cit*

(30) Binnie Consultants Ltd. (1994a) *op cit*

(31) ERM- Hong Kong Ltd (1997). Fisheries Resources and Fishing Operations in Hong Kong Waters. Draft Final Report

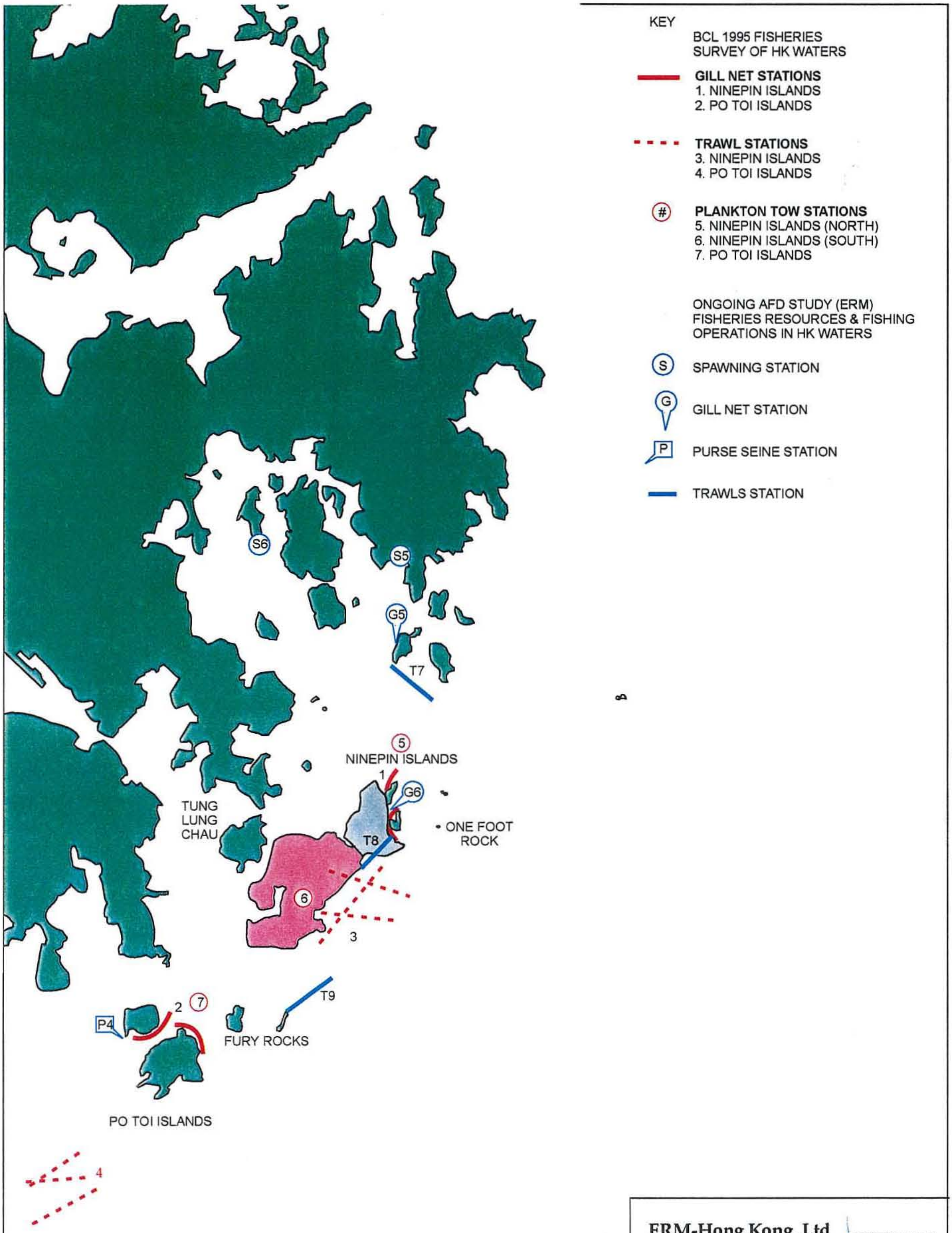

FIGURE 4.3c - LOCATION OF SAMPLING STATIONS FOR ASSESSMENT OF FISHERIES RESOURCES

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abundant organisms in the purse seine catches. Another aspect of the AFD Study involves the identification of potential nursery and spawning grounds. Two areas near the MBAs, Leung Shuen Wan and Sharp Island, were sampled. Data have indicated that catches from these areas are dominated by the flathead (*Platycephalus indicus*), the lizardfish (*Saurida tumbil*) and various species of penaeid prawns.

Table 4.3d *Information on the Fisheries Resources of the Area Surrounding the ETLC MBAs (Data from March 1996 - March 1997).*

Station	Code	Most Abundant Organisms (by biomass)	Ranking in relation to other stations in Hong Kong in terms of total catch biomass (g)
Trawl Catches			
Basalt Island	T7	*Metapenaeopsis palmensis* *Oratosquilla oratoria* *Oratosquilla anomala* *Portunus sanguinolentus* *Apogon quadrifasciatus*	10th of 19 (57,115 g)
Ninepins	T8	*Apogon quadrifasciatus* *Metapenaeopsis palmensis* *Oratosquilla oratoria* *Oratosquilla anomala* *Metapanaeipsis barbata*	17th of 19 (42,156 g)
Waglan Island	T9	*Trachypenaeus curvirpstris* *Saurida elongata* *Oratosquilla anomala* *Johnius belengeri* *Argyrosomus macrocephalus*	16th of 19 (44,043 g)
Gill Net			
Shelter Island	G5	*Evynnis cardinalis* *Lagocephalus lunaris* *Portunus sanguinolentus* *Charybdis cruciata* *Argyrosomus macrocephalus*	11th of 11 (2,799 g)
Ninepins	G6	*Parapristipoma trilineatum* *Octopus* spp *Upeneus tragula* *Duymaeria flagellifera* *Caranx kalla*	4th of 11 (6,749 g)
Purse Seine			
Po Toi	P4	*Loligo edulis* *Acetes japonicus* *Lagocephalus lunaris* *Trachurus japonicus* *Trichiurus haumela*	4th of 6 (13,755 g)

Station	Code	Most Abundant Organisms (by biomass)	Ranking in relation to other stations in Hong Kong in terms of total catch biomass (g)
Spawning & Nursery			
Leung Shuen Wan	S5	*Platycephalus indicus* *Metapenaeopsis palmensis* *Saurida tumbil* *Apogon quadrifasciatus* *Leiognathus brevirostris*	6th of 12 (8,800 g)
Sharp Island	S6	*Metapenaeopsis palmensis* *Saurida tumbil* *Siganus oramin* *Portunus sanguinolentus* *Apogon quadrifasciatus*	10th of 12 (6,589 g)

The Study combined reviews of existing information and the results of field sampling to recommend areas for protection as spawning grounds. The ETLC area falls within an area recommended for protection. Sampling stations at the Ninepins, Waglan, Basalt Island and Sharp Island appear to be important spawning areas for target fish species. Temporal variation in spawning patterns indicated that this area was important during June - August.

During the above Study, information on fishing effort was also gathered using helicopter surveys of fishing operations in the area. Data for June 1996 through to May 1997 indicated that the most common actively fishing vessels in the study area are P4s (mainly gill netters) although stern and shrimp trawlers were also noted in the area (*Table 4.3e*).

Table 4.3e *Fishing Operations in the vicinity of the ETLC MBAs (AFD Zones 95, 103, 106, 108).*

Activity	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
Stern Trawler		1	5	4	1	1	1	3		1	5		20
Shrimp Trawler	2	2	2		3		1	3		1			14
Traditional Vessel								3		2	1		6
P4 Vessels	8	2	1	1	11	9	10	11	2	4	5	1	64

A comparison of catches reported by fishermen from the area surrounding the MBAs indicates that catches have increased in size and value relative to other areas of Hong Kong since the 1989-91 Port Survey (*Table 4.3f*). This information may reflect greater effort by fishermen in the ETLC area in 1996-1997 as compared to 1989-1991. However, whether or not effort levels have increased, the higher post-dredging production values indicate that the dredging of the area has not caused a long-term adverse impact to the fisheries resources of the area.

Table 4.3f *Fisheries production in terms of Adult Weight, Fry Abundance & Value, for vessel <15m in length surrounding the ETLC MBAs. Ranking relative to other stations in Hong Kong before (89-91) and after (96-97) dredging are listed in brackets.*

	AFD Zone	89-91 (out of 194)	96-97 (out of 179)
Adult Weight (kg)	Tung Lung Island E 103	20,219 (144th)	114,119 (24th)
	Pak Kwo Chau 106	62,843 (98th)	93,747 (36th)
	Nan Kwo Chau 108	64,492 (94th)	227,156 (10th)
	Waglan 95	224,605 (28th)	133,008 (22nd)
Fry Abundance (tails)	Tung Lung Island E	21,367 (101st)*	60,891 (30th)**
	Pak Kwo Chau	26,698 (96th)*	91,329 (21st)**
	Nan Kwo Chau	32,147 (92nd)*	93,204 (20th)**
	Waglan	9,963 (116th)*	1,875 (86th)**
Value (HK$)	Tung Lung Island E	538,665 (122nd)	4,276,071 (16th)
	Pak Kwo Chau	747,254 (99th)	4,036,939 (20th)
	Nan Kwo Chau	822,144 (95th)	4,581,540 (11th)
	Waglan	1,281,660 (70th)	4,829,160 (8th)

* 166 areas recorded fry collection in 1989-91
** 89 areas recorded fry collection in 1997

4.3.7 *Mariculture Fisheries*

Nine Fish Culture Zones (FCZ) are located in the region of the proposed MBAs. Tung Lung Chau FCZ and Po Toi O FCZ (*Figure 3.4a*) are located nearest to the MBAs. Figures are not available for individual FCZs, however, total production in Hong Kong during 1995 was 2,950 tonnes, valued at HK$181 million[32].

4.3.8 *Fish Fry Collection*

Fish fry collection occurs in the vicinity of Ninepins, as illustrated in *Table 4.3g*. The main family collected are the Sparidae, especially the red pargo (*Pagrus major*).

Table 4.3g *Fish Fry Collection from within the Ninepins Study Area according to AFD Zones 95, 103, 106 & 108 (1996 - 1997)[33].*

Family	Catches (tails yr^{-1})	Catches (tails yr^{-1} ha^{-1})
Sparidae	159,375	19.22
Carangidae	9,542	1.15

(32) AFD (1996) Annual Report

(33) ERM-Hong Kong Ltd (1997) Fisheries Resources & Fishing Operation in Hong Kong Waters, Draft Final Report.

4.3.9 *Intertidal Habitats*

The ecology of intertidal habitats is largely dictated by coastal geomorphology. As much of the eastern part of the Territory is composed of igneous rock, a steep rocky coastline predominates, which are characterised by a diverse community of macroalgae, coralline algae, gastropods, limpets, bivalves, crabs, sea anenomes and coral. Ephemeral use by some bird and fish species is also supported[34]. Much of Hong Kong's coastline has been modified for development and undisturbed intertidal habitat such as that found on the isolated islands and coastline near ETLC is becoming increasingly rare[35].

The oceanic conditions prevalent in eastern waters create strong wave action on the islands and coastlines adjacent to ETLC. One Foot Rock, Tung Lung Chau and the Eastern Ninepin Island support predominantly wave-adapted species such as barnacles, the mussel *Septifer virgatus* and the crabs *Grapsus albolineatus* and *Plagusia tuberculata*. Ching Chau, however, has more sheltered shores and in the lower intertidal zone supports corals. Underwater dive surveys of the sublittoral zone at over seventy sites in eastern waters identified a high diversity and abundance of organisms at almost all sites[36](*Annex I*). There are several gazetted beaches in eastern Hong Kong which comprise some of the least polluted in Hong Kong. While sampling of water quality parameters at these beaches is routinely undertaken, detailed ecological studies have not been performed.

4.3.10 *Coral Communities*

Over 50 species of coral occur in Hong Kong, predominantly in eastern waters. Coral reefs support a range of species providing sheltering, feeding, spawning and nursery areas, resulting in the large and diverse community for which they are renowned. The coral reef system has been shown to be sensitive to pollution and impacts from development can cause the ecosystem to collapse, resulting in widespread mortality of coral and the numerous associated organisms. Natural fluctuations in water quality can also regulate coral communities. For example, during the summer of 1994 the intrusion of hypoxic water into Mirs Bay, resulted in widespread mortality of both hard and soft corals [37]. Hard or hermatypic corals are dependent upon symbiotic photosynthesising zooxanthellae for their survival and are therefore highly sensitive to increases in suspended sediment and the corresponding reduction in light penetration. Elevated levels of suspended sediments can also clog the corals' respiratory and feeding apparatus. Several surveys of Hong Kong's corals have been conducted as a component of the Territory-Wide Study of the Ecological Effects of Dredging, between July 1993 and April 1994. Five sites were surveyed (Tung Lung Chau, Ching Chau, One Foot Rock, East Ninepin and South Ninepin) and although bare rock and coralline algae dominated at most stations, the diversity of invertebrates and fish was considered high. Corals were recorded at all sites, with Ching Chau identified as having the highest diversity and percentage cover of species. Hard and soft corals were present at all stations although their distribution was patchy. South Ninepin Island was studied in greater detail due to its close

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(34) Morton B and Morton J (1983) *op cit*

(35) *Ibid*

(36) Binnie Consultants Ltd. (1994a) *op cit*

(37) Binnie Consultants Ltd. (1995c) 1994 Hypoxia and Mass Mortality Event at Mirs Bay. Final Report

proximity to dredging operations and it was observed that approximately 10% of the hard corals on the south and west coast of the island had been damaged. It was stated that this was due to sedimentation arising from dredging of the ETLC MBAs. Eleven dead and almost dead colonies of *Porites* were identified and some damage to soft coral communities was reported.[38]

Additional dive surveys were conducted from October 1991 to November 1994 covering sites throughout the eastern waters, the southern coast of Hong Kong Island and Lamma Island[39]. The results for eastern waters are summarised below in *Table 4.3h* with the dive surveys location indicated in *Figure 4.3d*, and the species found are listed in *Annex I*.

Table 4.3h *Coral communities observed during dive surveys in eastern waters.*

Location	Summary of Dive Survey
Victor Rock	Abundant and diverse soft corals, ahermatypic hard corals, sponges and oysters observed. High cover, 80-100%, observed. *Tubastrea* populations some of richest in Hong Kong in both diversity and abundance[40].
Basalt Island	A rich marine environment relatively unspoiled. High diversity of hard, soft and non-reef building corals. Numerous fish, gorgonians and anenomes.
Bluff Island	Marine life diverse but less abundant than observed elsewhere. Nudibranchs common with presence of many eggs.
Ching Chau	Abundant marine life, particularly hard corals, which occur in large colonies. Over 80% cover in some areas.
Clear Water Bay Peninsula	Large amount of refuse in water. Many invertebrates, hard coral and fish present.
Trio Island	High abundance of hard corals, up to 80% cover on the western side. High diversity of fish species recorded.
Tung Lung Chau	Fish particularly abundant, presence of hard and soft corals. Some siltation observed.
North Ninepin	Some of the largest table corals in Hong Kong, with colonies >2 m in diameter (approximately 50 years old). Large colonies of dead *Porites* and partial mortality, with sediment build up, on *Cyphastrea* colonies.. Many gorgonians buried in 25 cm of sediment.
South Ninepin	Large table corals, sea anenomes, large numbers of urchins, barracuda, cornet fish and fan worms. Minimal sediment action observed.
East Ninepin	Abundant encrusting flaviid hard corals. No siltation evident.
One Foot Rock	Few hard corals, abundant gorgonians, soft corals and non-reef building corals. Wave scoured.
Cape d'Aguilar	Heavily scoured by wave action. Within the protected bay high diversity of algae, molluscs, crustaceans, echinoderms, juvenile fish and fish fry.
Po Toi Island	Many seafans, sea whips and gorgonians. Hard and soft coral uncommon. Apparently affected by sediment plumes.

(38) Binnie Consultants Ltd. (1994a) *op cit*

(39) Binnie Consultants Ltd (1995d) The Marine Ecology of Hong Kong, Report on Underwater Dive Surveys October 1991 -November 1994 Volume I.

(40) Binnie Consultants Ltd (1995e) Two-Day Ecological Survey of Victor Rock

Location	Summary of Dive Survey
Beaufort Island	Hard corals uncommon, increasing abundance of gorgonians and seafans. Abundant large fish. Apparently affected by sediment plumes.
Fury Rocks	Soft coral and gorgonians abundant. Some of the largest schools of fish in Hong Kong were recorded here. Diverse habitats result in a rich marine community.
Sung Kong Island	Soft coral lawn, sea fans, urchins, gorgonians, crinoids, abundant holothurians and large loggerhead sponges. Some silt accumulation.

A detailed underwater survey of the Fury Rocks was conducted by Binnie Consultants Ltd in August 1994. Hard and soft corals were present at all depths although some of the soft corals appeared to have necrotic body parts or were in an unhealthy state. Sediment plumes were observed passing by the Fury Rocks but it was concluded that the strong currents which exist in this area prevent the sediment from settling on the corals[(41)]. A thin veneer of sediment was observed along with evidence of local hypoxia on corals in the Sung Kong area[(42)]. Damage has also been observed to coral on Po Toi and Beaufort Islands[(43)].

A recent underwater survey focusing specifically on coral recruitment in dredging-damaged areas of the North Ninepins, has been completed by Binnie Consultants Ltd[(44)]. Initial assessment of impacts at the study sites, in 1992, claimed that sediment deposition arising from dredging of the ETLC MBA had caused the greatest damage to corals along the west side of the North Ninepins. Corals located on the south side were comparatively less impacted. 10-20 % of the *Porites* and *Cyphastrea* colonies were affected and large colonies of the table coral *Acropora* suffered either partial mortality or were killed entirely.

A follow up assessment in 1995[(45)] indicated that there had been little change to the damaged *Acropora* colonies. The affected areas showed no signs of recruitment or regrowth by corals, instead, colonization by erect green algae, encrusting coralline algae and bryozoans had occurred. In other parts of the study area, recruits of six species of corals were observed, however, there was no indication as to whether this was above or below normal levels of recruitment. Though not quantitatively assessed, the gorgonian colony in the study area was said to be larger than in 1992. The overall conclusion of the report was that recruitment was perceived to be higher at a site less damaged by sedimentation.

A recently released report[(46)] has indicated that since dredging operations ceased in the area around Pak Kwo Chau (1994) the coral communities, both hard and soft corals, are continuing to recover from the effects of sediment deposition. Soft corals and gorgonians were recorded recolonizing the area of seabed that had been buried by up to 25 cm of sediment during the dredging operations.

(41) Demas Consulting Engineers (1994) Dredge monitoring near Fury Rocks, East Po Toi Marine Borrow Area. Draft Final Report.

(42) Binnie Consultants Ltd (1995b) *op cit*

(43) Binnie Consultant Ltd. (1995d) *op cit*

(44) Binnie Consultants Ltd (1995f) Underwater Ecological Survey of North Ninepins with a Focus on Coral Recruitment December 1995

(45) Binnie Consultants Ltd. (1995f) *op cit*

(46) Binnie Consultants Limited (1996) Coastal Ecology Studies. North Ninepin Island Quantitative Survey, Draft Report November 1996.

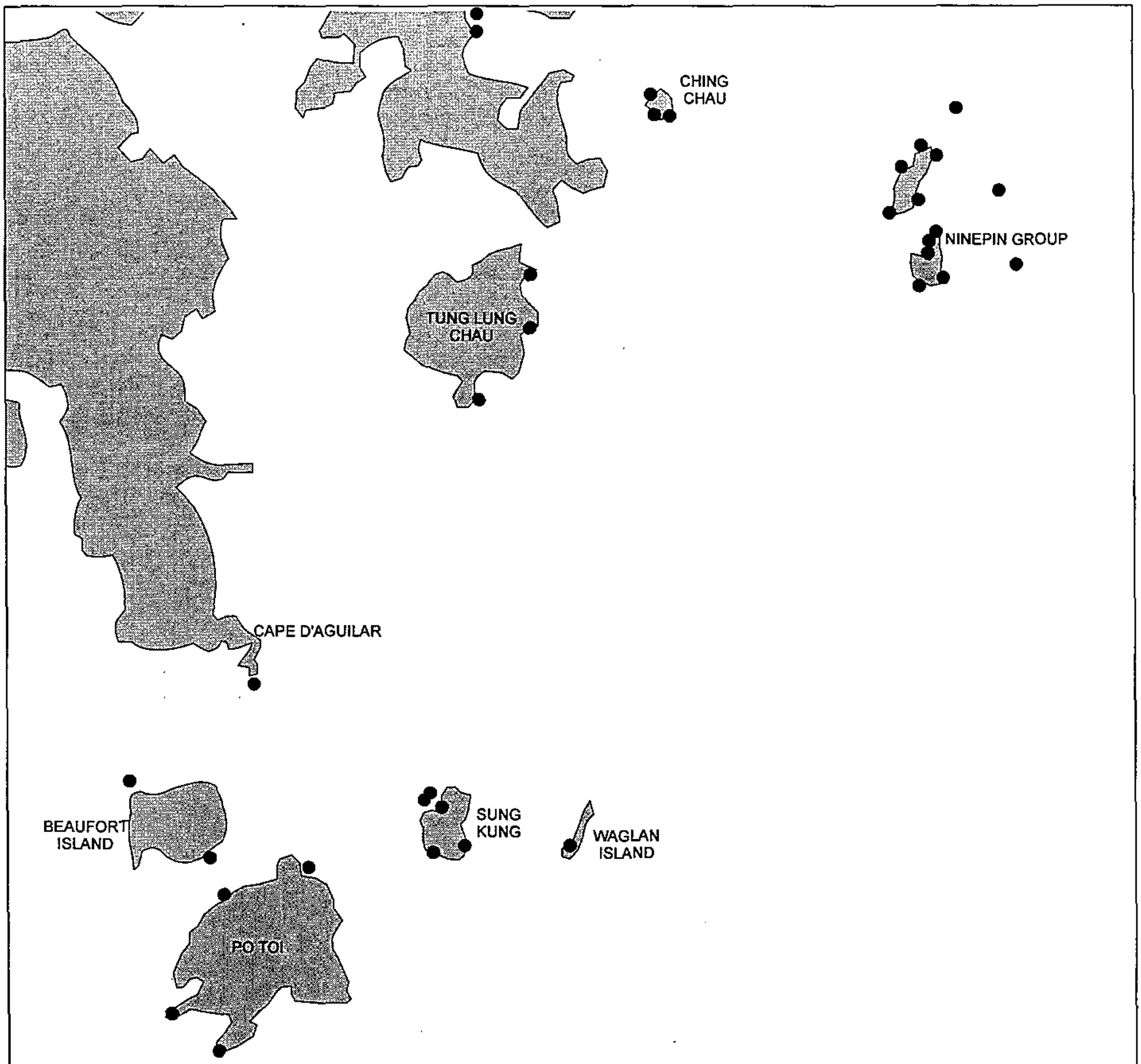

FIGURE 4.3d - DIVING SURVEYS CONDUCTED IN THE VICINITY OF THE ETLC MBAs

SOURCE: BINNIE CONSULTANTS LTD (1996) FINAL INCEPTION REPORT COASTAL ECOLOGY STUDIES

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4.3.11 *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. Over the last 5 years research has been conducted on *Sousa* but information regarding other cetaceans is sparse. Population size and ecology of the Hong Kong Finless Porpoise is unknown. Research on the Finless Porpoise in other parts of Asia suggests that this species prefers shallow waters. For example, in Japan this species is recorded as favouring inshore areas with a water depth of less than 30 m[(47)], and in the Yangtze River, China the porpoise was frequently observed actively fishing in shallow water near sandbanks[(48)]. Recently published information[(49)] on strandings of marine mammals in Eastern Hong Kong waters has revealed that 24 individuals of the Finless Porpoise have stranded since 1980 (see *Figure 4.6b*).

4.4 SENSITIVE RECEIVERS

Based upon the above review of baseline ecological conditions in the Study Area, ecological sensitive receivers which may be affected by the proposed backfilling operations have been identified. These are shown in *Figure 3.4a* and are as follows:

- Fish Culture Zones at Ma Nam Wat, Kai Lung Wan, Tai Tau Chau, Tiu Cham Wan, Kau Sai, Leung Shuen Wan, Po Toi O, Tung Lung Chau and Po Toi Island;
- Fish Nursery Areas and Fry Collection Areas ;
- Commercial Fisheries Resources;
- Hard and soft coral habitats at Tung Lung Chau (Nam Tong Mei, Fat Tong Mun), the Ninepin Island Group (Nam Kwo Chau W and E, Pak Kwo Chau W and E, Tung Kwo Chau N and S) Bluff Island, Basalt Island, the Po Toi Island Group (Sung Kong N, S and W), Victor Rock and the Clearwater Bay Peninsula (Steep Island (Ching Chau), Po Toi O S, Tai Wan Tau);
- SSSIs at Tai Long Bay, Bluff Island, Basalt Island and Ninepin Islands;
- The proposed marine park at Outer Port Shelter; and,
- The Cape d'Aguilar Marine Reserve.

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(47) Shirakihara K *et al* (1992) A Questionnaire Survey on the Distribution of the Finless Porpoise, *Neophocaena phocaenoides*, in Japanese Waters. Marine Mammal Science 8: 160-164

(48) Liu R, *et al*. The Behaviour of *Lipotes vexillifer* and *Neophocaena phocaenoides* in the Changjiang River and in captivity in China.

(49) Parsons ECM *et al*. (1995) An annotated checklist of Cetaceans Recorded from Hong Kong's Territorial Waters. Asian Marine Biology 12: 79-100

4.5 *POTENTIAL SOURCES OF IMPACTS*

Impacts to ecological resources arising from backfilling may be divided into those arising from direct disturbance to the habitat and those arising from associated changes in water quality. Disposed material will be uncontaminated, therefore, impacts due to the release of sediment-associated contaminants are not expected. Potential water quality impacts are described in detail in *Section 3*, and are as follows:

- increased SS concentrations;
- a resulting decrease in DO concentrations; and
- an increase in nutrient concentrations in the water column.

The relationships between SS and DO are complex, with increased SS in the water column combining with a number of other effects to reduce DO concentrations in the water column. Such effects are as follows:

- Elevated SS (and turbidity) reduces sunlight penetration, lowers the rate of photosynthesis of phytoplankton (primary productivity) and thus lowers the rate of oxygen production in the water column; and
- Elevated SS causes increased energy retention from sunlight, resulting in higher temperatures, and thus possibly lower oxygen levels as oxygen is more soluble in colder water.

A description of the effects these changes may have on the identified ecological sensitive receivers within the study site is given in *Section 4.6*.

In addition to the effects of suspended sediments, underwater noise and increases in marine traffic associated with disposal operations may disturb cetaceans through potential collision with vessels, increased turbidity generated by propellers and submerged equipment, and disturbance of normal movement patterns. For example it has been reported that Spinner dolphins reduced their use of a Hawaiian bay after the start of a noisy construction project for a water pipeline[50].

4.6 *EVALUATION OF IMPACTS*

This section discusses potential impacts to benthic communities, fisheries, intertidal habitats, coral communities and marine mammals with reference to the modelled predictions for suspended sediment levels. Dissolved oxygen and nutrients are not discussed due to the lack of any substantial predicted elevations. Potential noise impacts to marine mammals are considered in light of the findings that marine traffic will not increase (see *Section 2.6*). A discussion cumulative impacts, in the context of operational restrictions on concurrent projects, is also provided.

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(50) 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 US Minerals Service. Atlantic OCS Reg. Herndon VA 462 p.NTIS PB91-168914

4.6.1 *Benthic Communities*

Impacts to benthic organisms are dependent upon the location of the community in relation to the MBAs. Within the MBAs, primary impacts will be the smothering and burial of organisms which have colonized the MBAs following the cessation of dredging, and habitat modification. These impacts will necessarily occur during backfilling operations, therefore, it is important to determine whether the MBAs contain unique or otherwise noteworthy benthic assemblages which will be lost. As stated above in *Section 4.3.3*, a study comparing the ETLC MBAs with surrounding areas suggested that the benthic fauna within the MBAs comprised a different species composition, a lower species diversity, and a lower density of individuals than adjacent areas. Community structure also differed with a higher proportion of molluscs and an absence of crustaceans and echinoderms. The study did not identify any unique, rare or environmentally sensitive species in or around the MBA.

Impacts to benthic assemblages outside of the pits are unlikely to occur as only small areas were predicted to be affected by sediment deposition. During the wet season deposition is predicted to occur only inside the pits, in the dry season deposition occurs in a small area to the southeast of the pits, and during the transition season deposition occurs to the southwest of the pits (see *Section 3.8.1, 3.8.2, 3.8.3* and *Annexes D - F*). Predicted deposition levels are not likely to impact the natural benthic assemblages as this area is regularly disturbed by trawling and the organisms present are thus assumed to be adapted to seabed disturbance[51][52][53]. In addition, the study area is regularly disturbed by wave (storm) induced erosional forces and subsquent deposition (see *Section 3.9.6*).

The modelling scenarios indicate that impacts outside the pit are predicted to be minimal and confined to small areas. Based on the assumption that eventually the backfilled pits will be recolonised by fauna typical of the area, then the temporary loss of this low ecological value assemblage within the pits is deemed acceptable.

4.6.2 *Fisheries*

Suspended sediment (SS) fluxes occur naturally in the marine environment, consequently fish have evolved behavioural adaptations to tolerate increased SS loads (eg, clearing their gills by flushing water over them). Where SS levels become excessive, fish will move to clearer waters. This level is defined as the tolerance threshold, which varies for each species and at different stages of the life cycle. If SS levels exceed tolerance thresholds, fish are likely to become stressed, injured and may ultimately die. Previous studies have indicated that sediment can harm organisms either directly or indirectly[54], however specific effects of SS elevations upon fish species found in Hong Kong waters have not been studied. Elsewhere studies have identified that juvenile Coho Salmon (*Oncorhynchus kisutch*) survive sediment concentrations as high as 50 g l^{-1}, although sublethal effects were not monitored. Juvenile Sockeye Salmon (*Oncorhynchus nerka*) became stressed when exposed to sediment of 1 g l^{-1}.

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(51) Leung KF & Morton B (1997) *op cit.*

(52) Leung AWY (1997) *opcit.*

(53) Morton B (1995) *op cit.*

(54) Binnie Consultants Limited. (1994a) *op cit*

Susceptibility generally decreases with age, with eggs the most vulnerable and adults the least sensitive to effects from sediments[55]. The rate, season and duration of SS elevations will influence the type and extent of impact upon fish.

Results of the modelling exercises undertaken for this assessment indicate that in the dry season elevated concentrations of SS (ie 10 mg l^{-1}) are predicted outside of the gazetted works area. This will occur only in the area immediately south of the northeastern (deep) MBA (*Annex D*). In the wet season all plumes with concentrations greater than 10 mg l^{-1} are contained within the MBAs (*Annex E*). In transitional season modelling scenarios, plumes with concentrations greater than 10 mg l^{-1} occur outside the MBAs only when the disposal point is in the southwestern (shallow) MBA (*Annex F*). As these areas are limited, concentrations transient and sensitive receivers are distant, fisheries resources are unlikely to experience a long-term adverse impact.

AFD has set a threshold limit for SS in the Tung Lung Chau FCZ of 10 mg l^{-1} above background levels, beyond which damage to fish stocks may occur. In addition to this no backfilling will be permitted during periods when suspended solids rise to levels exceeding 50mg l^{-1}. As noted in *Section* 3, however, no exceedances of this criterion are expected, therefore no impacts to mariculture fisheries are predicted.

The findings of the ERM/AFD fisheries study have indicated that the area from Port Shelter to Po Toi is an important spawning ground for a variety of high value target species. However, the ETLC MBA itself represents less than 5% of this area. Furthermore, the spawning activities for high value target species occur only during a short period in the summer (June-August) and the modelling predictions for this period (ie the wet season as modelled in Scenario 7) reveal that all increases above the assessment criterion are confined within a small area of the MBAs (approximately 7.8% of the MBA). Therefore, although suspended sediment concentrations resulting from backfilling may affect spawning fish, the maximum area of spawning grounds predicted to be disturbed would be less than 0.4% and this area would only be affected on a temporary basis immediately following disposal events.

In light of the recently published findings of work carried out within the MBAs[53][56], backfilling is not predicted to have a detectable long-term impact on fisheries resources in the area. This work indicated that dredging activities had no discernable effect on the demersal fisheries resources of the area[57]. Loss rates for trailer dredgers during backfilling are approximately 222.4 tonnes per disposal event (3.8 hours) (*Table 3.7b*). In contrast, DRL has estimated that trailers engaging in overflow dredging at ETLC for periods of 120 minutes released up to 3 tonnes of sediment per second or approximately 21,600 tonnes in total. Thus, over a period of several hours, the loss rates associated with dredging are up to 2 orders of magnitude greater than those associated with backfilling. Since these higher loss rates, and an approximately equal level of seabed disturbance, associated with dredging had no discernable effect on fisheries resources, it is expected that backfilling activities' effect will be equally undetectable.

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(55) Legore & Desvoigne (1973), J. Fish. Res. Board of Canada. 30:1240-1242.

(56) Leung KF & Morton B (1997) *op cit*

(57) Leung AWY (1997) *op cit.*

Backfilling will smother the benthic communities within the MBAs which could potentially affect fishing operations in the area. *Table 4.6a* details the dependence of the Hong Kong fleet on the area within the MBAs. It should be noted that the area assumed to represent the ETLC MBAs also includes areas outside the pits due to the delineation of AFD zones. Therefore, dependence is interpolated across an entire fishery zone when in reality fishermen, due to their fishing behaviour, may use only one small part of the zone (*Figure 4.6a*).

Table 4.6a *Dependence (%) of the Hong Kong Fleet on the ETLC MBAs and Main Operation in the Area*

			Percent Dependence By		
Home Port	**Fleet Size**	**Main Operation**	**Adult Weight***	**Time Fishing**	**Value**
Tin Ha Wan	22	Hand Line	19	16	20
Hang Hau	42	Hand Line	14	28	13
Po Toi O	61	Gill Net	13	13	15
Shau Kei Wan	380	Gill Net & Purse Seine	12	<5	11
Chai Wan	148	Shrimp Trawler	8	8	9
Leung Shuen Wan	98	Gill Net	6	5	6
Aberdeen	701	Purse Seine	6	<5	<5
Po Toi	8	Gill Net	5	<5	<5

* Only home ports with a catch weight dependence value of 5% or over are included. Adult catch weight and Value of catch data are for Hong Kong waters only. Time spent fishing includes time spent outside Hong Kong waters, and for the larger vessels is a more realistic assessment of dependence on the area as they may spend the majority of their fishing time outside Hong Kong waters[58].

Considering the fishing dependency and production value of each homeport, it is estimated that up to approximately 650 fishing vessels from various homeports could be affected by the backfilling operation but the effect is expected to be temporary. The main fishing operations in the study area are gillnetting, handlining, purse seining and shrimp trawling. Disruption of fishing operations will be minimised through implementation of operational conditions discussed in *Section 2.5.4*.

Although the table indicates that shrimp trawlers from Chai Wan use the area, the bathymetry of the pits, particularly in the northeastern deep pit, prevents the trawlers from trawling the MBAs at present. Backfilling activities are, therefore, unlikely to have a detectable, long-term impact on the activities of these vessels. Demersal trawlers may benefit from the backfilling in that once disposal operations have ceased, and the fish fauna recolonised, the area will again be trawlable. This is in contrast to other non-borrow area disposal grounds such as at South Cheung Chau which due to its irregular topography is difficult, if not impossible to trawl.

The area itself is, according to interview records from fishermen, responsible for 2.5% of the total catch from Hong Kong waters (*Table 4.6b*). When calculated on a per hectare basis, these data reconfirm the finding in *Section 4.3.6* that the ETLC area is an important fisheries production area.

(58) Data taken from the Fisheries Information Management System prepared for the Agriculture & Fisheries Department as part of the Fisheries Resources & Fishing Operations in Hong Kong Waters Study.

Table 4.6b *Fisheries Production from the ETLC MBAs**

Catch Statistic	MBA (Total)	MBA (per ha)	Hong Kong Waters (Total)	Hong Kong Waters (per ha)	Contribution to the HK Fishery (Total)
Catch Weight (kg)	413,992	249	17,681,241	70	2.3%
Value of Catch ($)	8,746,612	5253	343,969,859	1362	2.5%
Fry Catch (Tails)	112,722	68	6,383,436	25	1.8%

* - area defined as the actual area of the north and south pits.
Data source: Fisheries Information Management System developed under the Study of Fisheries Resources and Fishing Operations in Hong Kong Waters by ERM for AFD.

If backfilling operations were to disrupt all fishing operations over the entire area of the MBAs, up to 414 tonnes per year of fisheries resources at a value of 8.7 million HKD per year would be lost to the fishery. However, physical disturbance caused by suspended sediment plumes above the assessment criterion (10 mg l^{-1}) and sediment deposition over 100 g m^{-2} day^{-1} are predicted to affect less than 10% of the MBA at any one time under all scenarios modelled. As these impacts are minor, localised, and temporary, they are not expected to cause long-term reductions in fisheries resources. Furthermore, with the implementation of operational conditions discussed in *Section* 2.5.4, disruption of fishing activities will be minimised.

Present disposal of mud at the East of Ninepins site occurs on an open seafloor mound which restricts fishing activities in the area (especially trawling). Backfilling of the ETLC MBAs will restore the natural seabed bathymetry and reinstate the area as a fishing ground. This is particularly relevant for the northeastern (deep) pit where dredged material would be used to fill a 19 m deep depression that presumably restricts trawl activities over a 3.75 km^2 area of the seabed. The benefits of this to the fishery are not likely to be seen until some time after backfilling has been completed. Based on the information presented in this assessment a reinstatement of a fish assemblage typical to the area is likely to occur post-backfilling.

4.6.3 *Intertidal Habitats*

Intertidal habitats within the study area which may be affected by backfilling activities include sixteen gazetted beaches located along the Clear Water Bay Peninsula and the east side of Hong Kong Island and rocky shores at the Cape d'Aguilar Marine Reserve, Ninepins, Po Toi, Tung Lung Chau, and Bluff and Basalt Islands.

Sediment transport modelling results predict that SS concentrations will not be elevated above ambient levels at any of the 16 beaches in the study area. Therefore backfilling operations will not adversely impact the biota at these beaches.

4.6.4 *Coral Communities*

The isolated islands and submerged rocks in the vicinity of the ETLC MBAs support some of the most diverse and locally important coral habitats in Hong Kong. Of particular interest are Fury Rocks in the Po Toi Island group, Ching Chau, the Ninepin Island group and Victor Rock. These areas host a diverse

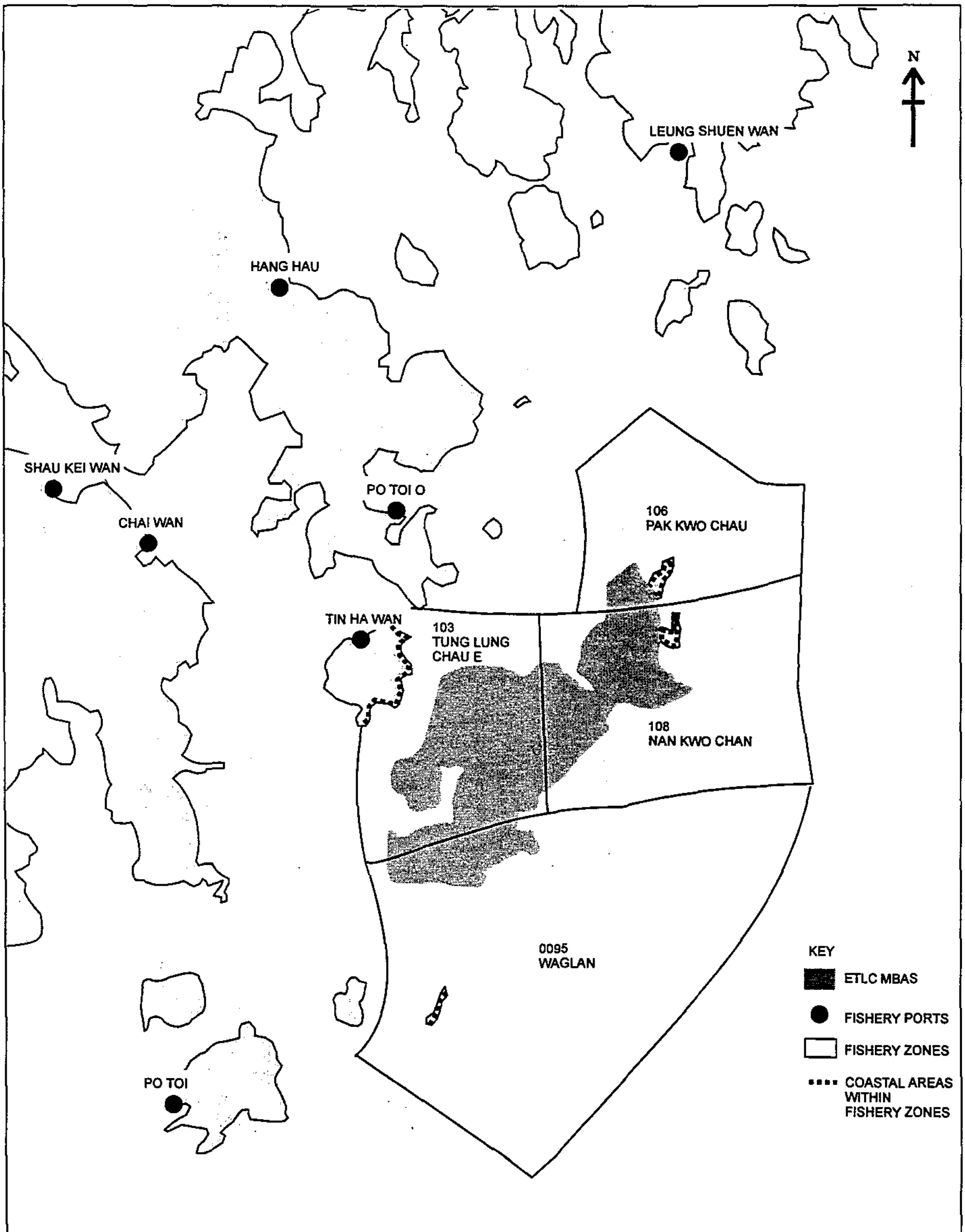

FIGURE 4.6a - AFD FISHERY AND ZONES PORTS DEPENDENT ON THE ETLC MBAS

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community of hard and soft coral, gorgonians, sponges, holothurians, sea urchins, seafans and fish. Previous studies have indicated that some coral damage has already occurred at Po Toi and Ninepins, apparently due to previous dredging activities in the eastern waters. Despite this, these islands' coral communities remain of high conservation value.

Corals may be injured by both high suspended sediment concentration and high deposition rates. Damage or mortality occurs as a reduction in light penetration kills the photosynthesising symbiotic algae associated with the hard corals, and also as the deposition of sediment onto the corals surface physically blocks the respiratory and feeding apparatus. An assessment of the effects of backfilling in Mirs Bay assumed that prolonged turbidity and a sustained sedimentation rate of 20 mg cm^{-2} day^{-1} (= 0.2 kg m^{-2} day^{-1}) was damaging to corals[59].

The results of the modelling exercises undertaken for this assessment were compared with this defined threshold. A summary of predicted sedimentation rates at coral and SSSI sensitive receivers is given below in *Table 4.6c* (and in *Annexes D to F*). As shown, the predicted deposition rates for the proposed operations do not exceed the defined tolerance thresholds at any of the coral sensitive receivers and reach a maximum of only 25% of this value. These values were derived from dry season model scenarios. No sediment deposition was predicted at any of the coral sensitive receivers during the wet season.

Negative impacts to corals may also arise from increased SS in the water column. An equivalent threshold value to account for this, however, is not available due to the lack of species tolerance data specific to corals in Hong Kong waters. Nevertheless, sensitive receiver locations specified to represent coral habitat show that SS concentrations greater than 10 mg l^{-1} are not predicted. It is thus expected that unacceptable impacts to corals from SS concentrations will not occur.

Table 4.6c *Summary of Sedimentation Rates at Coral and SSSI Sensitive Receivers.*

Scenario/ Season	Sensitive Receiver	Max Predicted Sedimentation Rate (kg m^{-2})	% Tolerance Threshold (0.2 kg m^{-2})
1 / Dry	Sung Kong N	0.01 - 0.05	5 - 25
	Sung Kong W	0.01 - 0.05	5 - 25
2, 3, 4, 5, 8, 9 / Dry	Sung Kong N	0.01 - 0.05	5 - 25
	Sung Kong S	0.01 - 0.05	5 - 25
	Sung Kong W	0.01 - 0.05	5 - 25

No sediment deposition was predicted to occur at the coral sensitive receivers during any of the wet season scenarios.

Note: Max predicted sedimentation rates are taken from 24 hr model predictions and represent worse case rates.

4.6.5 *Marine Mammals*

Underwater noise and disturbance from backfilling activities and marine traffic can have a disruptive effect upon behaviour of marine mammals. However, at this stage it is not possible to assess impacts to marine mammals as data

(59) Binnie Consultant Ltd (1992) South Mirs Bay Borrow Area. IAR

regarding specific species, numbers and behaviour in this area is limited to stranding records (*Figure 4.6b*). Marine traffic impacts are not expected as the vessels currently operating at the East of Ninepins disposal site will be diverted to the ETLC MBAs. Therefore, no increases in the number of vessels in the area are expected due to the backfilling operations.

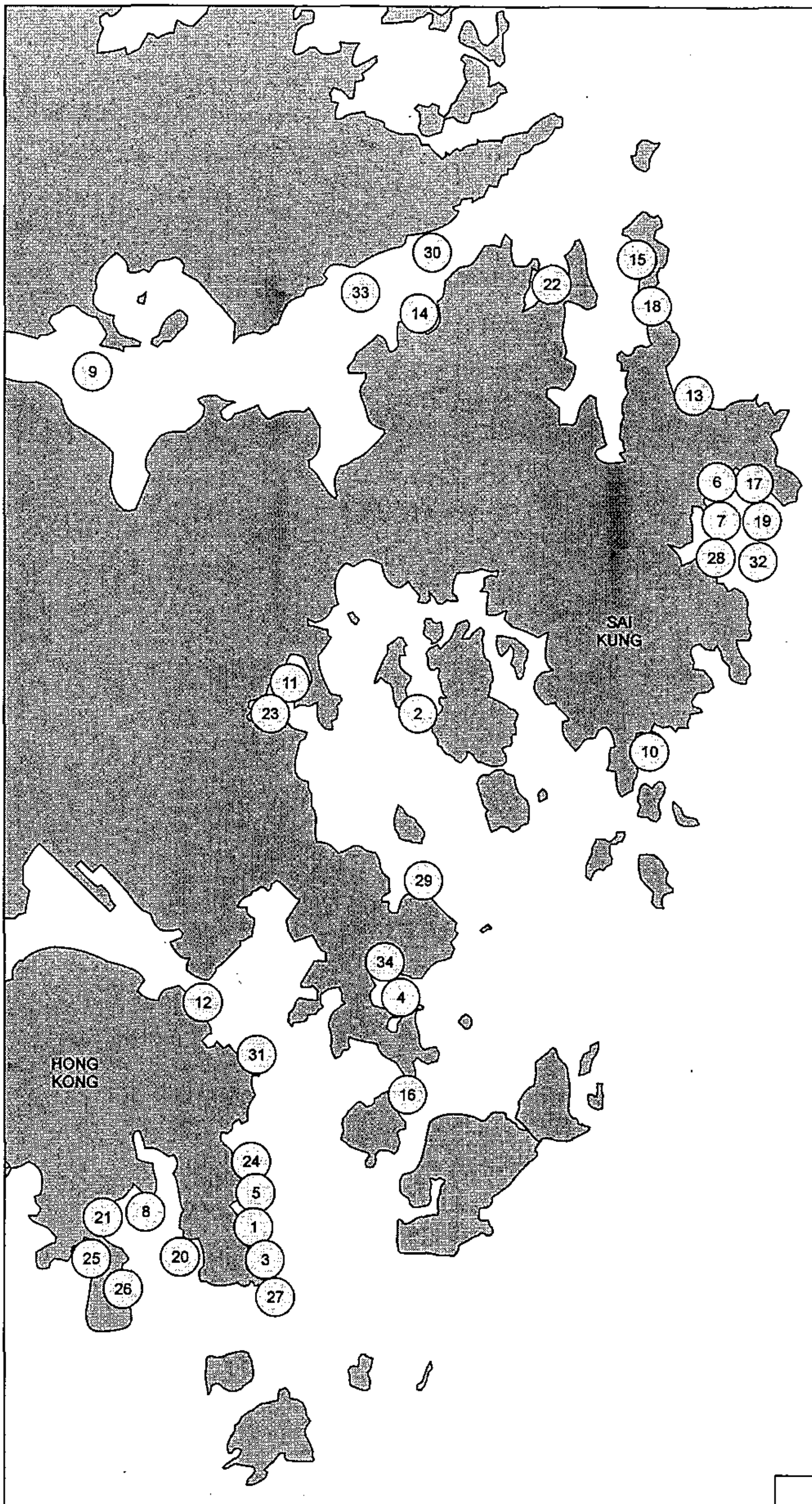
4.6.6 *Cumulative Impacts*

Cumulative impacts to marine ecological resources may arise from concurrent operations at the Po Toi, Tathong Channel and Eastern Waters MBAs, the East Ninepins open seafloor disposal area, reclamation at Tseung Kwan O and/or dredging of the remaining sand in the East Tung Lung Chau MBAs. Types of impacts may include physical effects (eg increased suspended sediment concentrations), water quality effects (eg changes in dissolved oxygen or nutrients), 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 ETLC MBA are expected to be directly related to the levels of suspended sediment, dissolved oxygen, nutrients and the degree of habitat disturbance. Water quality modelling results presented in *Section* 3 indicate that no sensitive receivers are predicted to be impacted at concentrations above the assessment criterion for suspended sediments or above the WQO for dissolved oxygen and nutrients. In addition, as discussed in *Section 3.12*, no disposal will be allowed at the ETLC MBAs during dredging or backfilling of the Eastern Waters MBA, during dredging in the Tathong Channel, West/East Po Toi and ETLC MBAs, during reclamation at Tseung Kwan O, and during disposal at the East of Ninepins Disposal Site. These operational controls will prevent the occurrence of cumulative effects due to dredging and disposal activities. Thus, 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 4.7*, habitat disturbance is expected to be low-level and temporary in the water column but more prolonged with regard to benthic habitat disturbance within the MBAs themselves. This assessment has thus concluded that the proposed operations are not predicted to result in unacceptable impacts to marine habitat. 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. 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 backfilled pits has been suggested as a means of enhancing the



1 *Tursiops truncatus* 1980
2 *Steno bredanensis* 1982
3 *Neophocaena phocaenoides* 1982
4 *Neophocaena phocaenoides* 1983
5 *Stenella sp* 1985
6 *Stenella sp* 1985
7 *Neophocaena phocaenoides* 1985
8 *Kogia breviceps* 1986
9 *Grampus griseus* 1986 x 4
10 *Tursiops truncatus* 1986
11 *Grampus griseus* 1988
12 *Neophocaena phocaenoides* 1989
13 *Neophocaena phocaenoides* 1989
14 *Neophocaena phocaenoides* 1989
15 *Neophocaena phocaenoides* 1990 x 2
16 *Neophocaena phocaenoides* 1990 x 2
17 *Neophocaena phocaenoides* 1990
18 *Neophocaena phocaenoides* 1991
19 *Neophocaena phocaenoides* 1991
20 *Kogia breviceps* 1991
21 *Neophocaena phocaenoides* 1992
22 *Stenella coeruleoalba* 1992
23 *Kogia breviceps* 1992
24 *Neophocaena phocaenoides* 1992 x 2
25 *Neophocaena phocaenoides* 1993 x 2
26 *Neophocaena phocaenoides* 1994
27 *Tursiops truncatus* 1994
28 *Stenella coeruleoalba* 1994
29 *Neophocaena phocaenoides* 1994
30 *Baleanoptera edenii* 1994
31 *Tursiops truncatus* 1994
32 *Tursiops truncatus* 1994
33 *Tursiops truncatus* 1994
34 *Neophoceena phocaenoides* 1994

FIGURE 4.6b - RECORDS OF MARINE MAMMAL STRANDINGS IN THE EAST OF HK TERRITORIAL WATERS 1980 - 1994

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Tsimshatsui, Kowloon
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ecological value of the area[60]. This could, therefore, result in an increase in abundance of benthic fauna.

Given the findings above, any project-specific ecology impacts associated with backfilling the ETLC MBAs, 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 ETLC MBAs. Thus, based on this assessment, cumulative impacts are predicted to be acceptable.

4.6.7 *Mitigation Measures*

This assessment has highlighted the ecological importance of the Study Area for marine biota, especially corals and fisheries resources. It is vital that appropriate measures are applied to the disposal procedures to ensure that ecological impacts from backfilling are minimised. Impacts to ecological resources, either through changes in water quality or changes in habitat, are not predicted based on the operational scenarios modelled. Mitigation measures designed to control impacts to water quality, which are summarised in *Section 2.5* and *3.10* 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.

4.7 CONCLUSIONS

A review of existing information on the ecological resources located within and around the ETLC MBAs has identified the area as supporting soft bottom benthic assemblages, corals, rocky intertidal species, fish and pelagic invertebrates (eg squid) many of which are commercially valuable. SSSIs occur within the study area, notably the Ninepin Islands and also the newly formed Marine Reserve at Cape d'Aguilar, the location of the Swire Institute of Marine Science.

Impacts arising from changes in water quality were assessed using the sediment transport and water quality modelling results described in *Section 3*. Sediment plumes are predicted to occur outside of the MBA during the dry season and during the transitional season when disposal occurs in the southwestern MBA. Although predicted concentrations of SS are low, impacts to fish, particularly coral reef fish, intertidal rocky shore assemblages and corals were investigated through evaluation of tolerance thresholds. As few data are available on the tolerance thresholds of these organisms and habitats to SS concentrations, the magnitude of the impacts to these resources cannot be precisely assessed. However, using predicted sediment deposition data, and a sedimentation rate tolerance threshold for corals defined in a previous study, it was noted that no exceedances of this threshold occur. Furthermore, as elevations of SS above the assessment criterion are not predicted at any of the identified ecological sensitive receivers, impacts due to elevated SS in the water column are also not predicted to occur.

Impacts to fisheries resources and fishing activities were discussed in the context of an increase in fisheries production values in recent, post-dredging years. This

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

may reflect either an increased level of fishing effort in the area after the post-dredging years, or that the dredging of the area has not caused a long-term adverse impact to the fisheries resources. Through assessment of catch and value statistics it was determined that the ETLC area is an important fisheries area. It is reported that the study area has a fisheries production value of $8.7 million annually and represents 2.5% of the value of the total annual fisheries production in Hong Kong waters. The ETLC MBA also comprises approximately 5% of a large zone of southeastern waters recommended for protection as a spawning habitat in the recent AFD Study of Fisheries Resources and Fishing Operations in Hong Kong Waters. However, since impacts to fisheries resources were predicted to be localised (affecting no more than 10% of the MBA at any one time) and temporary (occurring only during and shortly after sporadic disposal events), they are not expected to cause a long-term adverse impact to fisheries resources. Up to approximately 650 fishing vessels from various homeports could be affected by the backfilling operations which is expected to last for several years. Disruption of fishing operations will be minimised through implementation of operational conditions discussed in *Section 2.5.4*. These include the requirement of disposal vessels to delay disposal when fishing operation are being undertaken within the gazetted MBAs.

Impacts to marine mammals could not be assessed as data regarding specific species, numbers and behaviour in this area is limited to stranding records. Nevertheless, as no substantial changes in vessel operations in the area are expected as a result of the proposed operations, impacts to marine mammals resulting from vessel disturbance are not predicted.

It was observed that impacts to ecological resources may be mitigated through limiting the impacts to water quality, as discussed in *Sections* 2 and 3. All identified impacts to ecological resources are expected to be mitigated to environmentally acceptable levels through implementation of the Operations Plan and the supplemental mitigation measures given in *Section 3.10*.

In conclusion, based on this assessment, backfilling of the ETLC MBAs is not predicted to result in any unacceptable ecological impacts as the only community predicted to be adversely impacted is the infaunal community within the MBAs. Mud disposal at the ETLC MBAs would replace the existing operations at the East of Ninepins site and would allow implementation of a more rigorous site management and monitoring programme. Disposal at the ETLC MBAs are also environmentally preferable to the East of Ninepins Disposal Site because they consist of a seafloor depression which is more likely to contain disposed material than the open seafloor mound at the East of Ninepins site.

5 AIR QUALITY

5.1 INTRODUCTION

This section presents a detailed assessment of the potential air quality impacts from the proposed backfilling of ETLC MBAs. The assessment focused on likely scenarios to determine if unacceptable air quality impacts associated with the MBAs backfilling activities are expected to occur and whether mitigation measures are warranted. Worst-case assumptions have been used to assess the potential air quality environment during backfilling operations.

5.2 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 on 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 5.2a*.

Table 5.2a ***Relevant Hong Kong Air Quality Objectives***

Pollutant	Concentration in micrograms per cubic metre[a]			
	Averaging Time			
	1 Hour[b]	8 Hours[c]	24 Hours[c]	1 Year[d]
Sulphur Dioxide (SO_2)	800		350	80
Total Suspended Particulates (TSP)			260	80
Respirable Suspended Particulates [e] (RSP)			180	55
Nitrogen Dioxide (NO_2)	300		150	80
Carbon Monoxide (CO)	30,000	10,000		

Note:
(a) Measured at 298K (25°C) and 101.325 kPa (one atmosphere).
(b) Not to be exceeded more than three times per year.
(c) Not to be exceeded more than once per year.
(d) Arithmetic means.
(e) Respirable suspended particulates means 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 Total Suspended Particulates (TSP) concentration of 500 μgm^{-3} should not be exceeded at the site boundary. Such a control limit has been imposed on a number of construction projects in Hong Kong in the form of contract clauses. An odour level at Air Sensitive Receivers equal to or greater than 5 odour units based on a prediction averaging time of 5 seconds shall be considered as an odour nuisance.

5.3 *BASELINE AND FUTURE CONDITIONS*

5.3.1 *Existing Conditions*

The East Tung Lung Chau MBAs are located between the Ninepin Islands and Tung Lung Chau. Clearwater Bay Peninsula is located to the northwest of the site. Light traffic flow on Clearwater Bay Road is a primary source of pollutants in the area.

Frequent users of the area are fishing boats, which transit to distant fishing grounds, and small coastal freighters en route to and from Hong Kong. Large vessels do not frequently use the region. As a result, emissions from small vessels are the largest sources of pollutants in the immediate area and air quality of the area is expected to be good and well within the AQOs.

5.3.2 *Future Conditions*

There are no current plans for future developments on Tung Lung Chau, Clearwater Bay Peninsula and the Ninepins Islands. Therefore the existing ambient air quality at the study area is not expected to change dramatically in the future.

5.4 *AIR SENSITIVE RECEIVERS*

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

At Tung Lung Chau, a few scattered houses along the northern coast near Tung Lung Fort have been identified as ASRs. Clearwater Bay Golf and Country Club and Clearwater Bay Yacht Club located at the southern tip of Clearwater Bay Peninsula are also sensitive to air impacts. The Ninepin Islands are uninhabited areas and are not considered to be air sensitive areas. The local ASRs and their respective worst-case distances to the boundary of the MBAs sites are given in *Table 5.4a*. The locations of these receivers are shown in *Figure 5.4a*.

Table 5.4a *ASRs of East Tung Lung Chau MBAs*

ASR		Location	Distance (m)
A1:	Rural Village	Northern Coast of Tung Lung Chau	1230
A2:	Clearwater Bay Golf and Country Club	Southern Tip of Clearwater Bay peninsula	1600
A3:	Clearwater Bay Yacht Club	Southern Tip of Clearwater Bay peninsula	2300

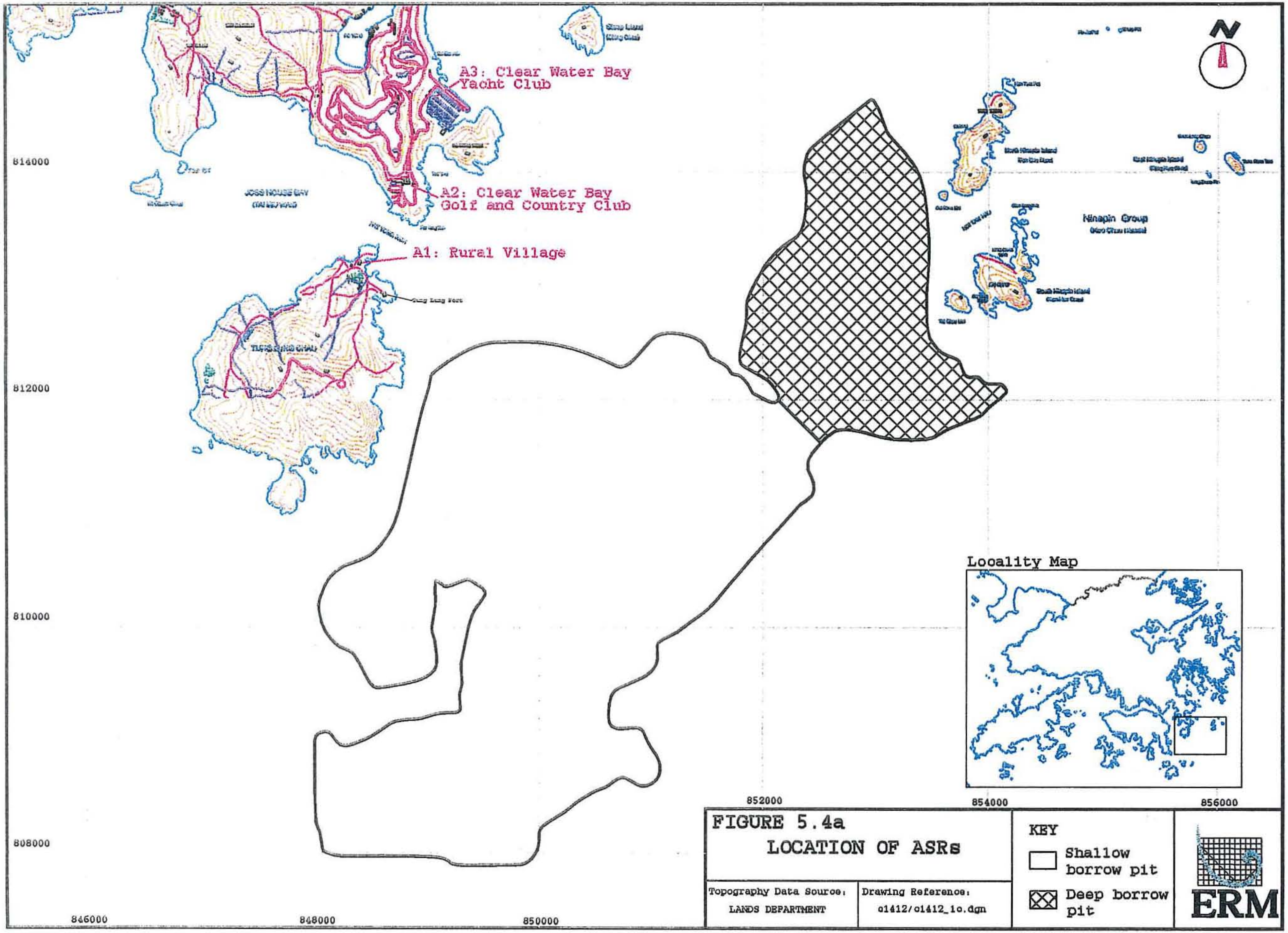

FIGURE 5.4a
LOCATION OF ASRs

Topography Data Source: LANDS DEPARTMENT

Drawing Reference: c1412/c1412_1c.dgn

5.5 POTENTIAL SOURCES OF IMPACT

There will be two primary potential sources of air quality impact from the backfilling operations, these are:

- disposal operations carried out by trailer suction dredges; and
- disposal operations carried out by barges.

Emissions from marine vessels used in the backfilling operations will be a source of gaseous pollutants. During marine transit to and from the site, the time spent in the Study Area will be short and hence emissions from vessels will be low during a 1-hour period. As all materials for the backfilling operation will be disposed directly into the water and will have a high moisture content, dust emission is expected to be low.

Assumptions concerning the number of active plant and the working hours for each type of disposal activity have been derived from the Operations Plan (Section 2) and are used to predict impacts as described below.

5.5.1 *Trailer Disposal*

For trailer suction dredge disposal operations, it has been assumed, as a worst case, that two trailer suction dredgers will be allowed to dispose simultaneously at the MBAs during a 1-hour period. There are no legal restrictions limiting the hours of such disposal. As a worst-case, 24-hour disposal has been assumed.

In Hong Kong, 8,000 m^3 trailer suction dredgers are known to have an engine size of approximately 10,000 kilowatts. However, for this assessment it has been assumed that these dredgers, during disposal, would be moving slowly (2-3 knots) and so 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. Estimations of emission factors for nitrous oxide (NO_2), respirable suspended particulates (RSP), and carbon monoxide (CO) have been made in accordance with *US EPA - Compilation of Air Pollution Emission Factors (AP-42), 4th Edition, 1985* and are shown below:

- NO_2: $0.3\ g\ s^{-1}$
- RSP: $0.092\ g\ s^{-1}$
- CO: $0.64\ g\ s^{-1}$

5.5.2 *Barge Disposal*

For barge disposal, it has been assumed that the barges will be towed by tug boats. A worst-case scenario of two barges and two tug boats working simultaneously in a 1-hour period has been assumed.

In Hong Kong, adequately-sized tug boats used for barge towing (800 m^3) are known to have an engine size of approximately 500-600 kilowatts. Similarly to the case of trailer dredgers above, the tug boats would be moving slowly (2-3 knots) and under minimal load. Again output is assumed to be a few hundred kilowatts or roughly equivalent to a single bulldozer or truck under load. Thus, the emission factors will be similar to that of a trailer dredger.

5.6 EVALUATION OF IMPACTS

5.6.1 *Air Emissions Impact*

The analysis above has indicated that the trailer dredgers and barge / tug combination will be the main sources of pollutants for the backfilling operations. Dredged materials will be disposed directly into water and low fugitive dust impact is expected. In addition, the disposal vessel (either trailer dredger or barge / tug combination) will be operated at minimal load. Each marine vessel's engine should be operating at a comparable output to a piece of typical heavy construction plant (eg, bulldozer or truck). As the distances to the ASRs are in excess of 1,200 m and only two trailer dredgers or two tug boats will be operating at the MBAs, it is considered that air quality impacts on ASRs, arising from backfilling operations, should be negligible and the AQOs will not be exceeded.

5.6.2 *Odour Impact*

Odorous gas may be emitted during the transit or disposal of the dredged materials. As the distances to the ASRs are in excess of 1,200 m and the amount of dredged materials are small, odour impacts from the dredged materials will be limited and the odour criteria should be satisfied.

5.7 MITIGATION MEASURES

Considering that no exceedances of AQOs have been predicted for the local air quality from backfilling operations, no air quality mitigation measures are recommended for these activities.

5.8 OUTLINE OF EM&A REQUIREMENTS

As no exceedances of the relevant AQOs have been predicted for the worst-case analysis, no air quality monitoring is recommended for disposal operations at the MBA.

5.9 *CONCLUSIONS*

This assessment has indicated that no exceedances of the AQOs are predicted and thus no major impacts to air quality are anticipated from backfilling operations at the East Tung Lung Chau MBAs. Mitigation measures and an air quality monitoring programme are not necessary for the backfilling operations.

6 NOISE

6.1 INTRODUCTION

This section presents an assessment of potential noise impacts associated with the proposed backfilling operations at the ETLC MBA. The objective is to predict the extent, magnitude and acceptability of the potential impacts. Worst-case assumptions have been used with respect to the hours of operation and equipment employed, to assess the potential noise climate during backfilling operations.

As the backfilling of the MBAs will be a short-lived activity, it has been classified as a *construction* activity rather than an *operational* activity. No post-backfilling activities have been assessed as none are considered capable of producing significant noise impacts at the nearest Noise Sensitive Receivers (NSRs).

The methodology for assessing noise from the backfilling of the ETLC MBAs was developed based on the *Technical Memorandum on Noise From Construction Work Other Than Percussive Piling (TM)*. In general, the methodology is as follows:

- locate NSRs that may be affected by the worksite;
- calculate distance attenuation and any barrier corrections to NSRs from worksite notional noise source point;
- predict construction noise levels at NSRs in the absence of any mitigation measures; and
- calculate maximum total site sound power level (SWL) for construction activities such that noise levels at NSRs comply with appropriate noise criteria.

The practicability of achieving the aforementioned maximum total site sound power level is then considered since this might offer a preferred form of mitigation. Other mitigation measures are then considered and recommended as appropriate.

6.2 STATUTORY REQUIREMENTS AND EVALUATION CRITERIA

In Hong Kong the control of construction noise outside of weekday daytime working hours (0700-1900, Monday through to Saturday) is governed by the Noise Control Ordinance (NCO) and the subsidiary *TM*. This *TM* establishes the permitted noise levels for construction work depending upon working hours and the existing noise climate.

The NCO criteria for the control of noise from powered mechanical equipment (PME) are dependent upon the type of area containing the NSR rather than the measured background noise level. As the NSRs surrounding the proposed MBAs fall into mainly rural areas, the Area Sensitivity Rating (ASR) for these NSRs, according to the *TM*, is specified as 'A' as there are no influencing factors such as major roads and industrial areas affecting the NSRs. The NCO requires that noise levels from construction at affected NSRs be less than a specified Acceptable Noise Level (ANL) which depends on the ASR.

It is intended that the construction activities of the proposed works should be planned and controlled in accordance with the NCO. Works requiring the use of PME during restricted hours (ie outside of 0700-1900 Monday to Saturday 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) by applying corrections for the duration of the works and the effect of any other nearby sites operating under a CNP. For this assessment these corrections are negligible and so have been set to zero. As a result, the ANLs are equal to the BNLs. These are shown in *Table 6.2a* below.

It should be noted that a 5 minute interval is used during restricted hours to monitor noise levels relative to the NCO ANL criteria.

Table 6.2a *Acceptable Noise Levels (ANL, $L_{Aeq, 5 min}$ dB(A))*

Time Period	ASR - A
All days during the evening (1900-2300) and general holidays (including Sundays) during the day and evening (0700-2300)	60
All days during the night-time (2300-0700)	45

Although the NCO does not provide for the control of construction activities during normal working hours, a limit of $L_{Aeq, 30 min}$ 75 dB(A) is proposed in the 'Practice Note For Professional Persons, PN2/93' issued by the Professional Persons Environmental Consultative Committee (ProPECC) in June 1993. This limit has been applied on major construction projects, and is now generally accepted in Hong Kong, and will therefore be adopted in this study in order to protect NSRs to an appropriate extent during normal daytime periods (0700 - 1900 hours).

6.3 BASELINE AND FUTURE CONDITIONS

6.3.1 *Existing Conditions*

The nearest NSRs to the ETLC MBAs are the scattered huts on the northern coast of Tung Lung Chau and the scattered houses on the southeastern tip of the Clearwater Bay peninsula. The Ninepin Group to the east of the MBA are uninhabited and are not considered to be noise sensitive areas.

Tung Lung Chau is designated a countryside conservation area with limited infrastructure development. It lies to the east of the Kai Tak flight path, and as a result, the noise environment in the vicinity of the NSRs on Tung Lung Chau is dominated by the natural environment and intermittent aeroplane engine noise.

A large proportion of the south-eastern tip of the Clearwater Bay peninsula comprises the Clearwater Bay Golf Country Club with some scattered houses to the northwest in Po Toi O. The main road in the vicinity of the NSRs is Clearwater Bay Road which connects the Clearwater Bay Country Park to the Country Club. Clearwater Bay Road has limited traffic flows. The existing noise environment in the vicinity of the NSRs is dominated by intermittent aeroplane noise, the Country Club's activities, the light traffic flows on Clearwater Bay Road and the natural environment.

It should be noted that Tung Lung Chau and the Clearwater Bay Peninsula lie outside of the zone of impact from the Kai Tak flight path (NEF 30; Final Report Kai Tak Consultancy, October 1988).

6.3.2 *Future Conditions*

There are no current plans for future developments on Tung Lung Chau, the Clearwater Bay peninsula and the Ninepins Group. It is assumed that the opening of Chek Lap Kok airport in April 1998 and closure of Kai Tak airport, will reduce aeroplane noise in the area, but no other changes to the existing noise environment at these locations are expected.

6.4 *NOISE SENSITIVE RECEIVERS*

NSRs, as defined by the HKPSG and the NCO, have been identified with reference to Geographical Information System (GIS) maps of the Study Area.

The local NSRs and their respective distances to the notional centre of the site are given in *Table 6.4a*. NSR locations are shown in *Figure 6.4a*.

Table 6.4a ***Noise Sensitive Receivers near the ETLC MBA***

NSR	Location	Area Sensitivity Rating	Distance (m)
Scattered Huts	Northern Coast of Tung Lung Chau	A	1230
Scattered Houses	Southeastern Tip of Clearwater Bay Peninsula	A	3000

The ETLC MBAs have jointly linear dimensions in the range of 3.5 km from northwest to southeast and 7.8 km from northeast to southwest. The distances shown in the above table are the closest separation distances between the worksite and the sensitive receiver locations. Therefore these distances are strictly for a worst-case assessment.

6.5 *POTENTIAL SOURCES OF IMPACT*

There will be two primary plant options affecting the noise impact from the backfilling operations. These are:

- disposal operations carried out by trailer suction dredgers; and
- disposal operations carried out by barges in combination with tug boats.

Assumptions based on the Operations Plan described in Section 2, have been made concerning the number of active plant and the working hours for each of these types of disposal activities.

6.5.1 *Trailer Dredger Disposal*

For trailer suction dredger disposal operations, it has been assumed for the purposes of this detailed assessment that a worst-case scenario would consist of two trailer suction dredgers disposal during the same 5 minute time period at similar locations at the MBA. As a trailer suction dredger has a sound power level of 111 dB(A), two acting together would generate a total site sound power level of 114 dB(A).

There are no legal restrictions limiting the hours of such disposal operations. Therefore, as a worst-case, 24-hour disposal has been assumed.

6.5.2 *Barge / Tug Disposal*

For barge / tug disposal, it has been assumed that barges will be moved to the MBA by tug boats, as described in *Section* 2.3. The worst-case plant inventory for barge disposal is shown in *Table 6.5a* below. For the purposes of this worst-case assessment, it has been assumed that plant will operate concurrently in a similar location.

Table 6.5a ***Barge Disposal Plant Inventory***

Plant	Number	TM Reference Number	Sound Power Level (dB(A))
Derrick Barge	2	CNP 061	104+3
Tug Boat	2	CNP 221	110+3

The total sound power level calculated for all plant operating at one notional point is 114 dB(A).

6.6 *EVALUATION OF IMPACTS*

For both trailer dredger and barge / tug disposal operations it has been assumed that disposal activities will take place at a speed of 2-3 knots. As backfilling activities will be quite rapid (less than 10 minutes) it has been assumed that the worst-case notional point would not change dramatically, during backfilling, from that previously noted in *Table 6.4a*. As a result, the worst-case (closest noise source) values listed in these tables have been used for the assessment of noise impacts.

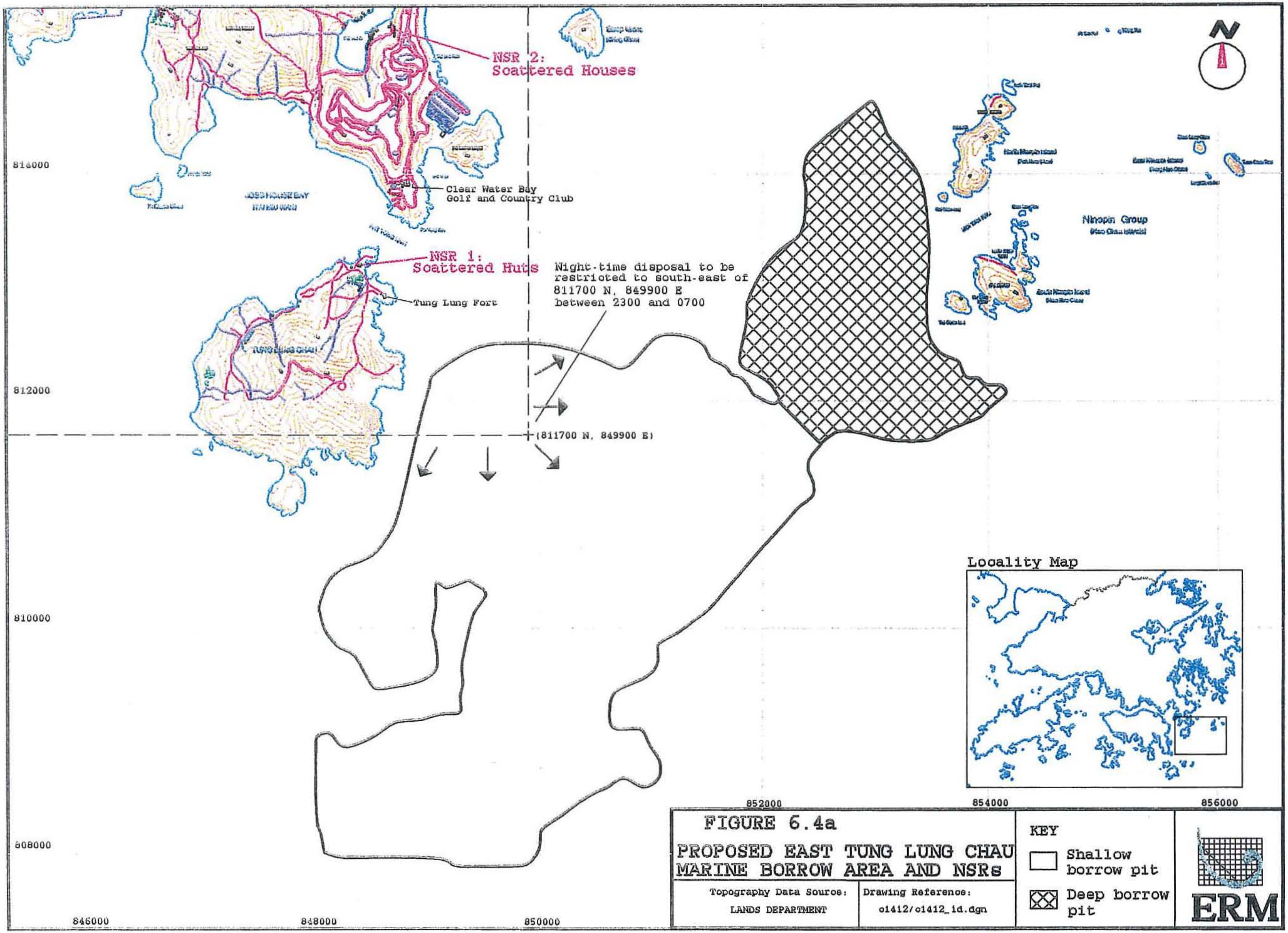

FIGURE 6.4a

PROPOSED EAST TUNG LUNG CHAU MARINE BORROW AREA AND NSRs

Predictions of worst-case noise levels from trailer dredger and barge disposal operations at nearby Noise Sensitive Receivers are shown in *Table 6.6a* below.

Table 6.6a *Predicted Impacts at Noise Sensitive Receivers ($L_{Aeq, 5min}$ dB(A))*

NSR	Trailer Disposal	Barge / Tug Disposal
Scattered Huts - Tung Lung Chau	47	47
Scattered Houses - Clearwater Bay Peninsula	40	40

The above predictions indicate that similar levels of noise emission are expected from the two methods of disposal operations. There are no exceedances of the daytime (0700-1900) or evening (1900-2300) noise criteria are anticipated at nearby NSRs. However, exceedances are predicted at the huts on Tung Lung Chau for night-time (2300-0700) backfilling operations. As a result, noise mitigation measures for the night-time period should be employed at the ETLC MBA to ensure full compliance with the NCO.

6.7 *Mitigation Measures*

The foregoing analysis has indicated that no exceedances of the daytime or evening noise criteria are anticipated at nearby NSRs. In addition, no exceedance of the night-time noise criterion has been predicted for the scattered houses on the Clearwater Bay peninsula.

However, a 2 dB(A) exceedance of the night-time noise criterion has been predicted for the rural village on Tung Lung Chau. Therefore, noise mitigation measures should be employed for night-time disposal operations at the MBA.

To comply with the night-time noise criterion at Tung Lung Chau, two alternative types of noise mitigation could be adopted. One option would be to restrict all night-time disposal operations to a maximum of one dredger or one barge/tug boat combination in operation during any 5 minute time period. This would reduce impacts at nearby NSRs at Tung Lung Chau by 3 dB(A) and so would bring them into full compliance with the night-time NCO noise criterion. A second option would be to restrict all disposal operations during night-time hours to locations outside a 1585 m radius from the NSR or to locations south of the 811700 N and east of the 849900 E Hong Kong grid reference lines, as shown on *Figure 6.4a*. This latter mitigation measure is in place in the present operations design, since all current proposed disposal areas within the MBA lie outside this region. Any future modifications of the operations plan should ensure compliance with this measure is maintained.

These mitigation measures would be capable of controlling the night-time noise exceedances at the NSRs on Tung Lung Chau to levels in compliance with those specified under the NCO.

6.8 *Outline of EM & A Requirements*

As no residual (ie after mitigation) exceedances of the NCO night-time criteria have been predicted for the analysed scenarios, no noise monitoring is recommended for disposal operations at the ETLC MBA.

6.9 CONCLUSIONS

The foregoing noise assessment predicted that disposal operations at the ETLC MBA will not lead to exceedances of the recommended daytime limit, or the NCO evening criteria, at any nearby sensitive receivers. However, noise modelling of the backfilling activities has shown that operations during night-time (2300-0700) hours could lead to a 2 dB(A) exceedance of the NCO night-time criteria at NSRs on Tung Lung Chau.

To ensure full compliance with the night-time noise criterion at Tung Lung Chau, the following mitigation measures are suggested:

- restrict night-time disposal options to at most one dredger or barge/tug boat combination during any 5-minute period ; and/or

- restrict night-time disposal operations to locations outside a 1585 m radius from the Tung Lung Chau NSR or south of the 811700 N and east of the 849900 E Hong Kong grid reference lines, as shown on *Figure 6.4a*. This has been incorporated in the present operations plan.

With the adoption of such measures no unacceptable noise impacts have been predicted for the proposed ETLC MBA backfilling activities. As no residual exceedances of the NCO night-time criteria, in the worst-case, have been predicted at nearby NSRs, no noise monitoring programme has been recommended for disposal operations at the ETLC MBA.

7 *CONCLUSIONS*

Sand excavated from marine borrow areas (MBAs) at East Tung Lung Chau has been used primarily for the West Kowloon reclamation, with main excavation operations completed by July 1996. In accordance with the policy of the Fill Management Committee, it is proposed to backfill the MBAs both to provide disposal capacity for uncontaminated dredged materials and to reinstate the natural seabed. Mud disposal at the ETLC MBAs would replace the existing operations at the East of Ninepins site and would include implementation of a more rigorous site management and monitoring programme. Disposal at the ETLC MBAs is likely to be environmentally preferable to the East of Ninepins Disposal Site because the ETLC MBAs consist of a seafloor pit which is better able to contain disposed material than the open seafloor mound at the East of Ninepins site. This report presents the finding of an Environmental Impact Assessment (EIA) associated with backfilling operations including evaluation of potential impacts to water quality, marine ecology, air quality and noise.

7.1 *WATER QUALITY*

Water quality impacts associated the proposed disposal of material at the ETLC MBAs were evaluated using sediment transport mathematical models. Predicted concentrations of SS and resulting depletions, elevations and deposition rates for DO, nutrients and sediment respectively, were derived. These predictions were used to assess the impact of backfilling operations on the water quality of the study area and on specific sensitive receivers. Modelling scenarios were designed to evaluate variations in disposal rate and disposal location with season in order to specify mitigation measures to minimise adverse impacts. These mitigation measures were developed as operational constraints and presented as an Operations Plan for further assessment.

Results of all modelled scenarios predicted a maximum elevation of suspended sediment at sensitive receivers of 7 mg l^{-1} at Sung Kong South. Where elevations are predicted at other sensitive receivers, lower elevations of 1 -2 mg l^{-1} are typical. Predicted suspended sediment concentrations above an agreed assessment criterion of 10 mg l^{-1} are largely restricted to within the gazetted boundaries of the MBAs. Dissolved oxygen depletions and nutrient elevations in all cases are predicted to be low with respect to background levels and Water Quality Objectives. Therefore backfilling in accordance with the Operations Plan is not predicted to result in unacceptable impacts to water quality.

The stability of recently deposited material in the MBAs was assessed at various backfill levels. The deep MBA is fairly sheltered and analyses predict that the pit can be filled to the level of the surrounding seabed without causing unacceptable erosion. The northern part of the shallow MBA is less exposed than the southern part. Analyses predict that the northern part can be filled to seabed level without causing unacceptable erosion. In the southern part of the shallow MBA there may be erosion of some recently deposited backfill material under a storm with a return period of 1 year. However, this erosion is deemed acceptable in the context of natural erosion of the natural seabed. Due to slightly greater exposure to storm-induced erosion of disposed materials in the shallow pit, backfilling above -30 mPD is not recommended in this part of the MBA.

7.2 *Marine Ecology*

A review of existing information on the ecological resources located within and around the ETLC MBAs has identified that the area supports soft bottom benthic assemblages, corals, rocky intertidal species, fish and pelagic invertebrates (eg squid) many of which are commercially valuable. SSSIs occur within the study area, notably the Ninepin Islands and also the newly formed Marine Reserve at Cape d'Aguilar, the location of the Swire Institute of Marine Science.

Impacts arising from changes in water quality were assessed using the sediment transport and water quality modelling results described above. Sediment plumes are predicted to occur outside of the MBA during the dry season and during the transitional season when disposal occurs in the shallow MBA. Although predicted concentrations of SS are low, impacts to fish, particularly coral reef fish, intertidal rocky shore assemblages and corals were investigated through evaluation of tolerance thresholds. As few data are available on the tolerance thresholds of these organisms and habitats to SS concentrations, the magnitude of the impacts to these resources cannot be precisely assessed. However, using predicted sediment deposition data, and a sedimentation rate tolerance threshold for corals defined in a previous study, it was noted that no exceedances of this threshold occur. Furthermore, as elevations of SS above the assessment criterion are not predicted at any of the identified ecological sensitive receivers, impacts due to elevated SS in the water column are also not predicted to occur.

Impacts to fisheries resources and fishing activities were examined in the context of an increase in fisheries production values in recent, post-dredging years. This may reflect either an increased level of fishing effort in the area after the post-dredging years, or that the dredging of the area has not caused a long-term adverse impact to the fisheries resources. Through assessment of catch and value statistics, it was determined that the ETLC area is an important fisheries area. It is reported that the study area has a fisheries production value of $8.7 million annually and represents 2.5% of the value of the total annual fisheries production in Hong Kong waters. The ETLC MBA also comprises approximately 5% of a large zone of southeastern waters recommended for protection as a spawning habitat in the recent AFD Study of Fisheries Resources and Fishing Operations in Hong Kong Waters. However, since impacts to fisheries resources were predicted to be localised (affecting no more than 10% of the MBA at any one time) and temporary (occurring only during and shortly after sporadic disposal events), they are not expected to cause a long-term adverse impact to fisheries resources. Although up to approximately 650 fishing vessels from various homeports could be affected by the backfilling operations, which are expected to last for several years, disruption of fishing operations will be minimised through implementation of operational conditions. These include the requirement of disposal vessels to delay disposal when fishing operation are being undertaken within the gazetted MBAs.

Impacts to marine mammals could not be assessed as data regarding specific species, numbers and behaviour in this area is limited to stranding records. Nevertheless, as no substantial changes in vessel operations in the area are expected as a result of the proposed operations, impacts to marine mammals resulting from vessel disturbance are not predicted.

Impacts to ecological resources may be mitigated by limiting impacts to water quality. All identified impacts to ecological resources are expected to be mitigated to environmentally acceptable levels through implementation of the

Operations Plan and the supplemental mitigation measures given in the Water Quality section of the EIA. Therefore, backfilling of the ETLC MBAs is not predicted to result in any unacceptable ecological impacts as the only community predicted to be adversely impacted is the infaunal community within the MBA pits.

7.3 *Air Quality*

No exceedances of the Air Quality Objectives have been predicted and thus no major impacts to air quality are anticipated from backfilling operations at the ETLC MBAs. Consequently, no air quality mitigation measures or air quality monitoring programmes are necessary for the backfilling operations.

7.4 *Noise*

The proposed disposal operations at the ETLC MBAs will not lead to exceedances of the recommended daytime limit, or the NCO evening criteria, at any nearby sensitive receivers. However, noise modelling of the backfilling activities has shown that operations during night-time (2300-0700) may result in a 2 dB(A) exceedance of the NCO night-time criteria at NSRs on Tung Lung Chau.

The following mitigation measures have been incorporated to ensure that a full compliance with the night-time noise criterion at Tung Lung Chau is completed:

- restrict night-time disposal options to at most one dredger or barge/tug boat combination during any 5-minute period; and/or
- restrict night-time disposal operations to locations outside a 1585 m radius from the Tung Lung Chau NSR or south of the 811700 N and east of the 849900 E Hong Kong grid reference lines. This has been incorporated in the present Operations Plan.

Should the above mitigation measures be enforced, unacceptable noise impacts should not result from the proposed ETLC MBA backfilling activities. As, in the worst-case, no residual exceedances of the NCO night-time criteria have been predicted at nearby NSRs, no noise monitoring programme has been recommended for disposal operations at the ETLC MBA.

7.5 *Overall Conclusion*

The detailed assessment of environmental impacts upon water quality, marine ecology, air quality and noise arising from the backfilling of the Marine Borrow Areas at East Tung Lung Chau indicates that there are unlikely to be any insurmountable or unacceptable residual environmental impacts associated with the proposed operations.

The Study included the development of an Operations Plan which includes appropriate mitigation measures to reduce environmental impacts to acceptable levels. The key mitigation elements of the proposed backfilling Operations Plan are summarised as follows:

- Disposal locations will be specified according to the prevailing seasonal currents with disposal occurring in the northeastern (deep) MBA in the dry season, in the southwestern portion of the MBA in the wet season and in the central portion of the MBA in transitional seasons (mid-March to mid-May and mid-August to end September);

- Daily disposal rates for both the deep and southwestern-most portion of the shallow MBAs should be restricted to a maximum of $50{,}000m^3day^{-1}$, whereas the northeastern portion of the shallow MBA should have a reduced maximum rate of $25{,}000m^3day^{-1}$;

- To prevent mounding, only trailer dredged material will be disposed in the shallow MBA. The deep MBA shall be used for grab or trailer dredged materials;

- Backfilling will be prohibited during dredging, backfilling, disposal or reclamation at other locations in eastern waters;

- Backfilling will be limited to the level of the surrounding seabed in the northeastern (deep) MBA, and to not above -30mPD in southwestern (shallow) MBA. These levels are inclusive of any materials used to enhance the habitat.

- In order to allow consolidation of recently disposed material to densities which will better resist the erosive forces of storms, a mitigation measure requiring cessation of backfilling once the Typhoon Signal No 3 is hoisted has been incorporated;

- To prevent combinations of plumes from separate disposal events resulting in unacceptable elevations of suspended sediment concentrations, a minimum interval of 3.84 hours between trailer dredger disposal events is specified. Although no minimum interval for barge dumping is necessary, no more than 5 barge dumps should be undertaken in the two hour period following a trailer dump, and trailer dumps may follow barge disposal events only after an interval of 30 minutes;

- With the exception of the extreme southwestern part of the ETLC MBAs, the proposed backfilling area is not frequented by large marine vessels, therefore it is not expected that marine traffic shall be disrupted as a result of backfilling. However, priority shall be given to fishing operations through the requirement of disposal vessels to delay disposal if fishing operations are being undertaken within the gazetted MBAs.

Actual impacts during the backfilling operations will be monitored through an EM&A programme which is specified in an EM&A Manual released as a separate document to the EIA. The EM&A programme will provide management actions and supplemental mitigation measures to be employed should impacts arise, thereby ensuring the environmental acceptability of the project.

Annex A

Water Quality Monitoring Results

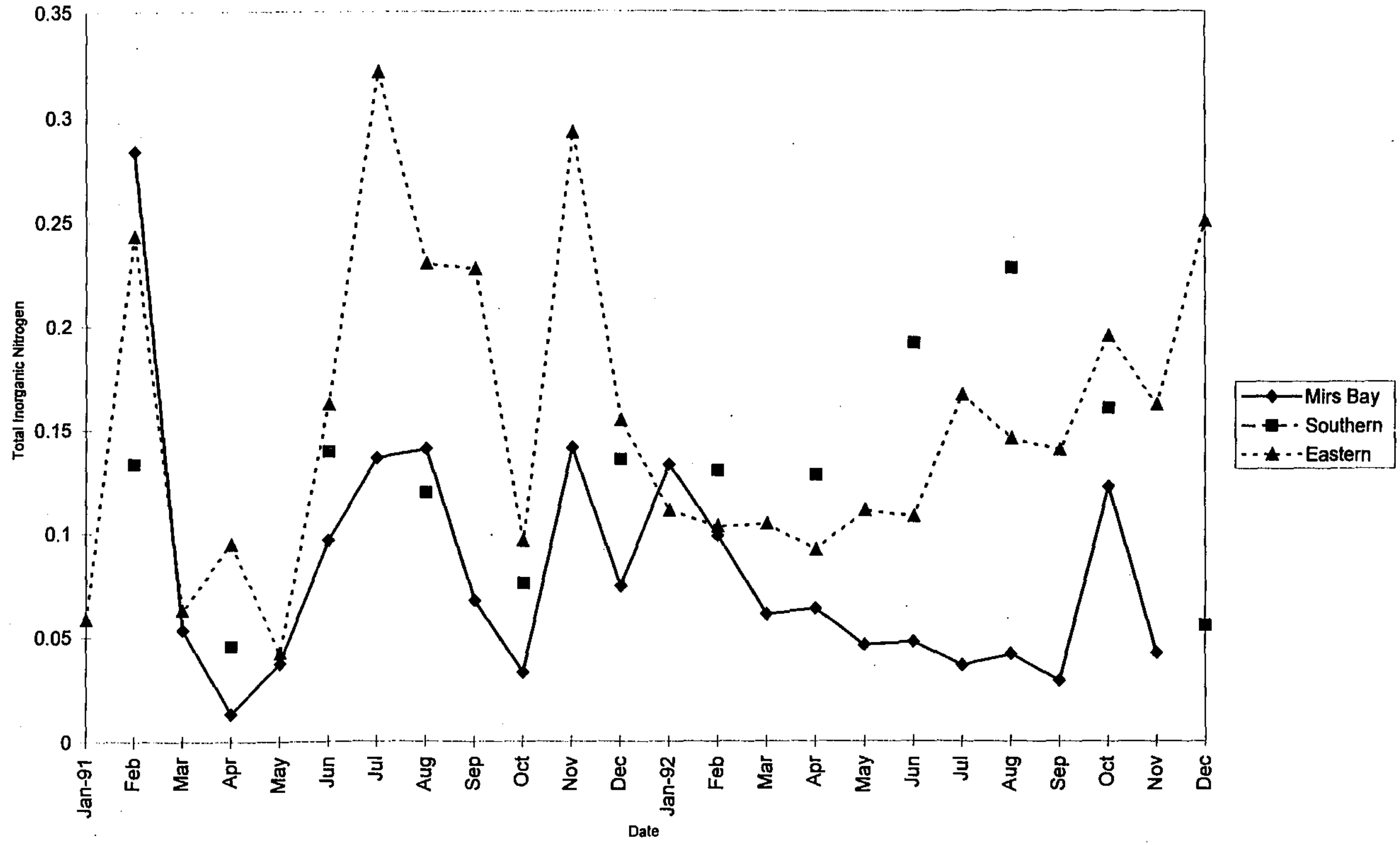

Figure A1 Total Inorganic Nitrate Water Quality Data for Mirs Bay, Southern and Eastern Water Quality Zones Jan 91- Dec 92

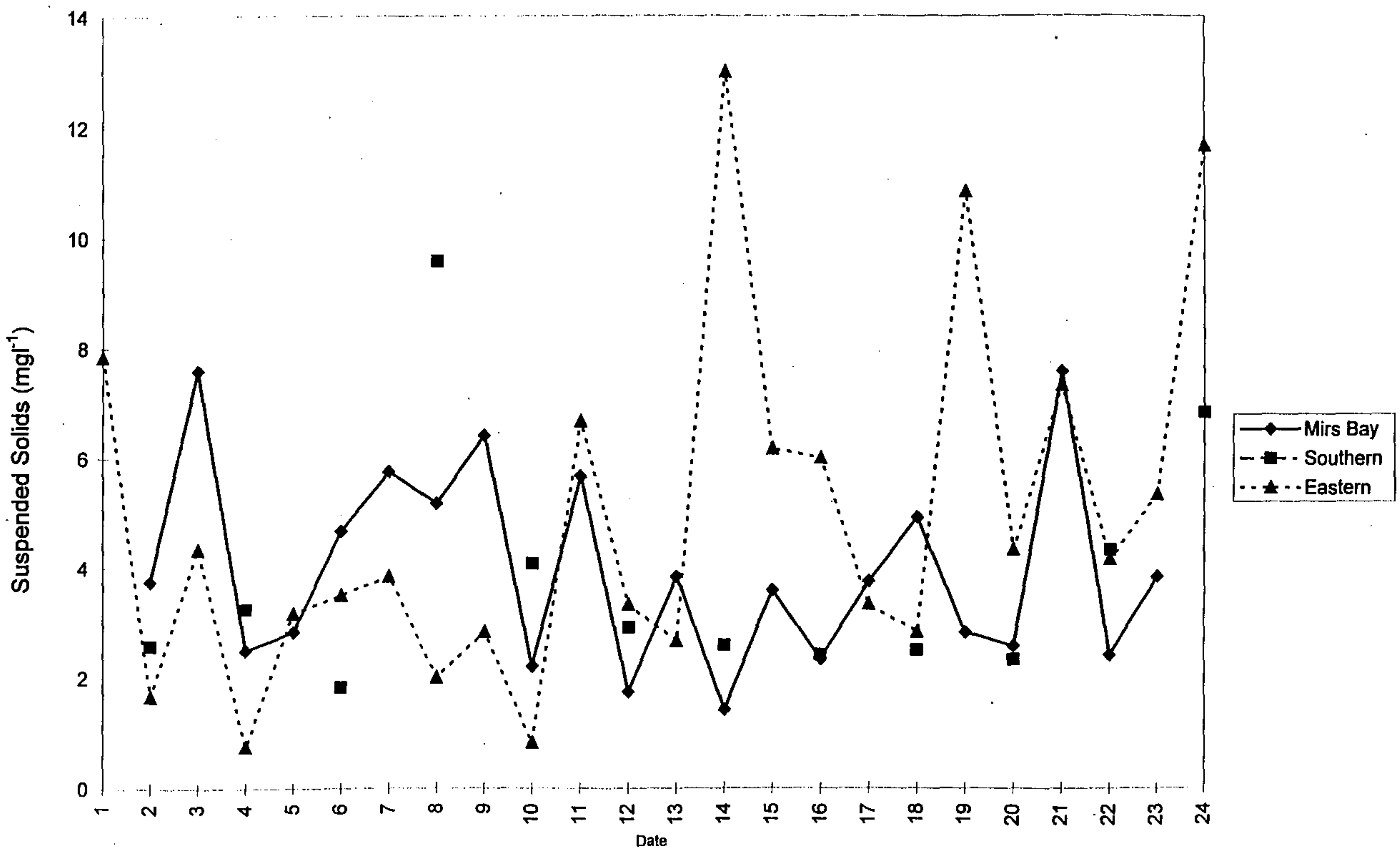

Figure A2 Suspended Solids Water Quality Data for Mirs Bay, Southern and Eastern Water Quality Zones Jan 91 - Dec 92

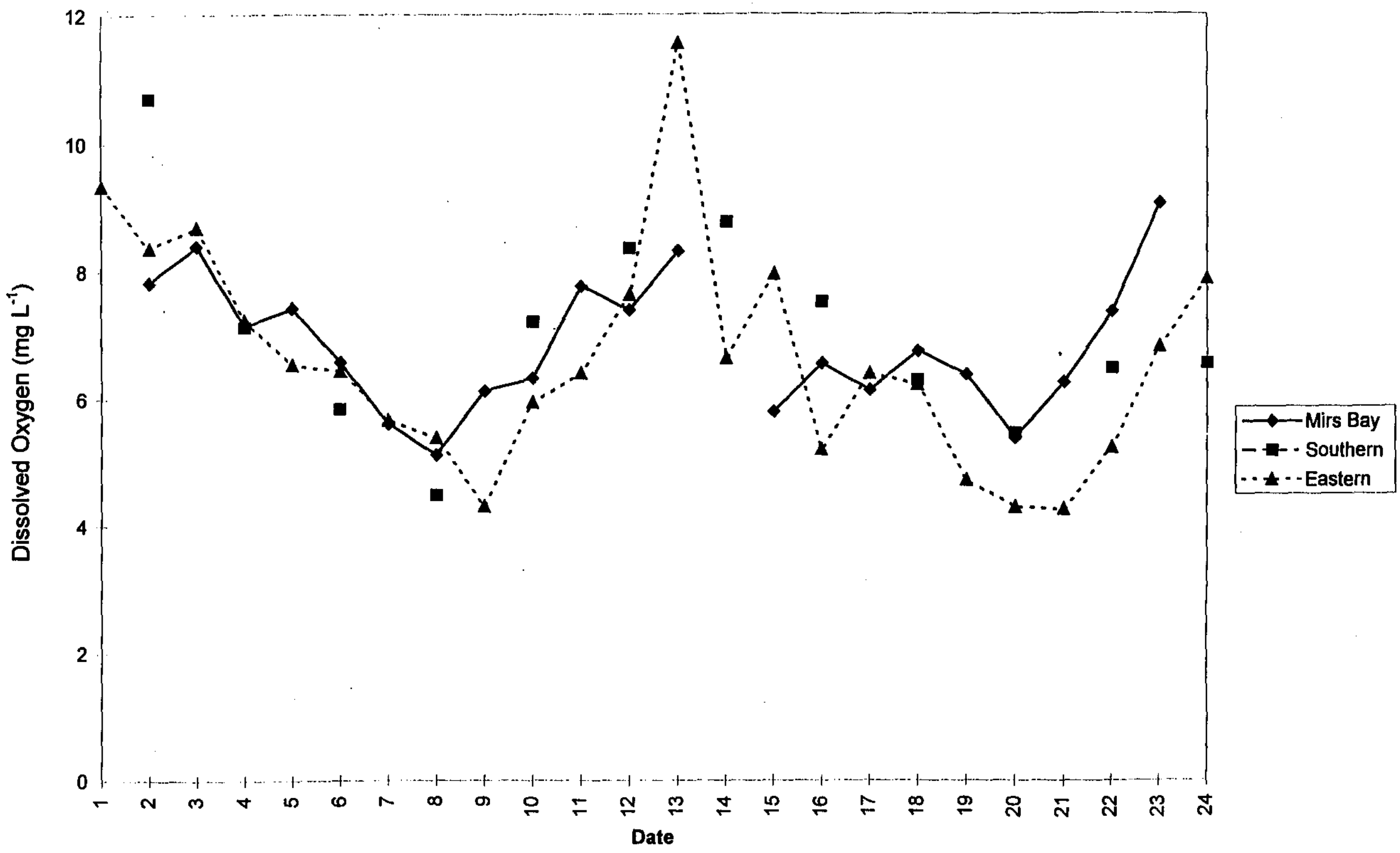

Figure A3 Dissolved Oxygen Water Quality Data for Mirs Bay, Southern and Eastern Water Quality Zones Jan 91- Dec 92

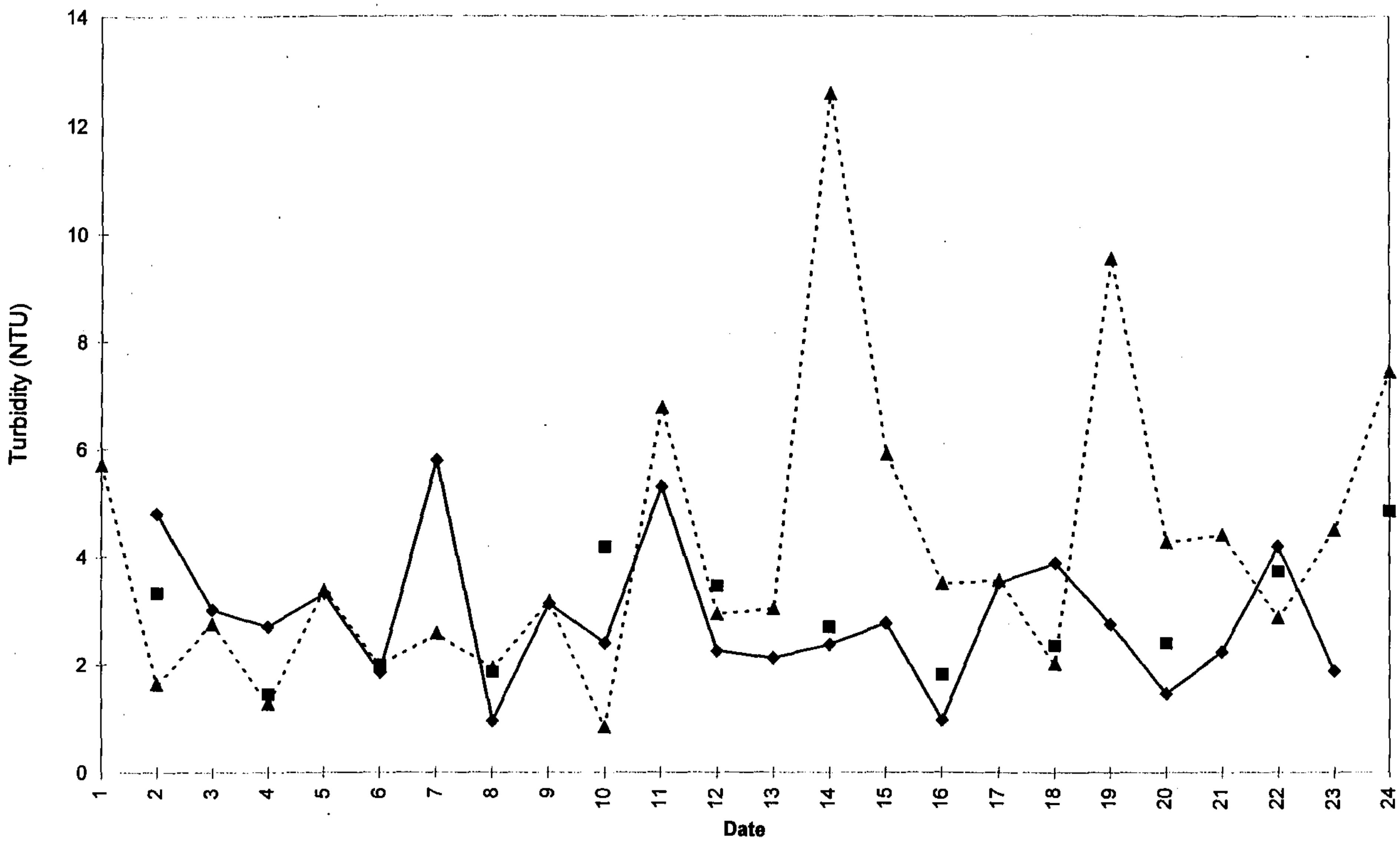

Figure A4 Turbidity Water Quality Data for Mirs Bay, Southern and Eastern Water Quality Zones Jan 91- Dec 92

Annex B

Details of Disposal Trials Conducted at ETLC MBAs

During the period 5-9 September a total of six trial dumps were made at two locations within the East Tung Chau MBA under the supervision of Dredging Research Ltd[1]. The trial dumps were made by two trailing suction hopper dredgers, the Krankeloon and the Pacifique.

Measurements were made of suspended sediment concentrations using boat mounted Acoustic Doppler Current Profilers (ADCP). Two survey boats were used for monitoring suspended sediment concentrations. One boat was stationed approximately 300 m downstream of the dumping site, the distance at which the majority of the air bubbles, which cause erroneous readings of suspended sediment concentrations by the ADCP, should have dissipated from the plume. This boat, the flux measurement boat, then sailed continuous transects across the plume at this location until all of the sediment had passed and the data from this boat was used to calculate the total quantity of sediment lost to suspension. The second boat sailed transects across the sediment plume by following floats which had been dropped into the water from the dredgers as they discharged their load. The data from this boat, the transect boat, showed the development of the plume with time and gave information on the transport and dispersion of suspended sediment and the area covered by the plume at any time instant.

September is in the transition period between the wet and dry season conditions with respect to the oceanographic conditions around Hong Kong. This period is when the dominant oceanic currents to the south of Hong Kong undergo periodic 180° reversals in direction. In the wet season the oceanic current flows in a north-easterly direction and in the dry season the current flows in a south-westerly direction. The currents in the East Tung Lung Chau MBA are dominated by the oceanic currents with some perturbations by the tidal currents. During the course of the trial dumps the currents were observed to reverse which meant that data was gathered for both wet and dry season current directions.

The two dredgers which were used for the trial dumps were found to dredge mud at different densities, the Krankeloon dredged at a higher density and the Pacifique at a lower density. This meant that the losses of sediment to suspension during the dumping operation would be higher for the Pacifique dumps than for the Krankeloon dumps. It is worth noting that for trailing suction dredgers operating in Hong Kong the Krankeloon and the Pacifique represent the extremes in terms of dredging densities.

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[1] Dredging Research Ltd (1996) *Op cit*

Annex C

Calibration of the SEDPLUME Model

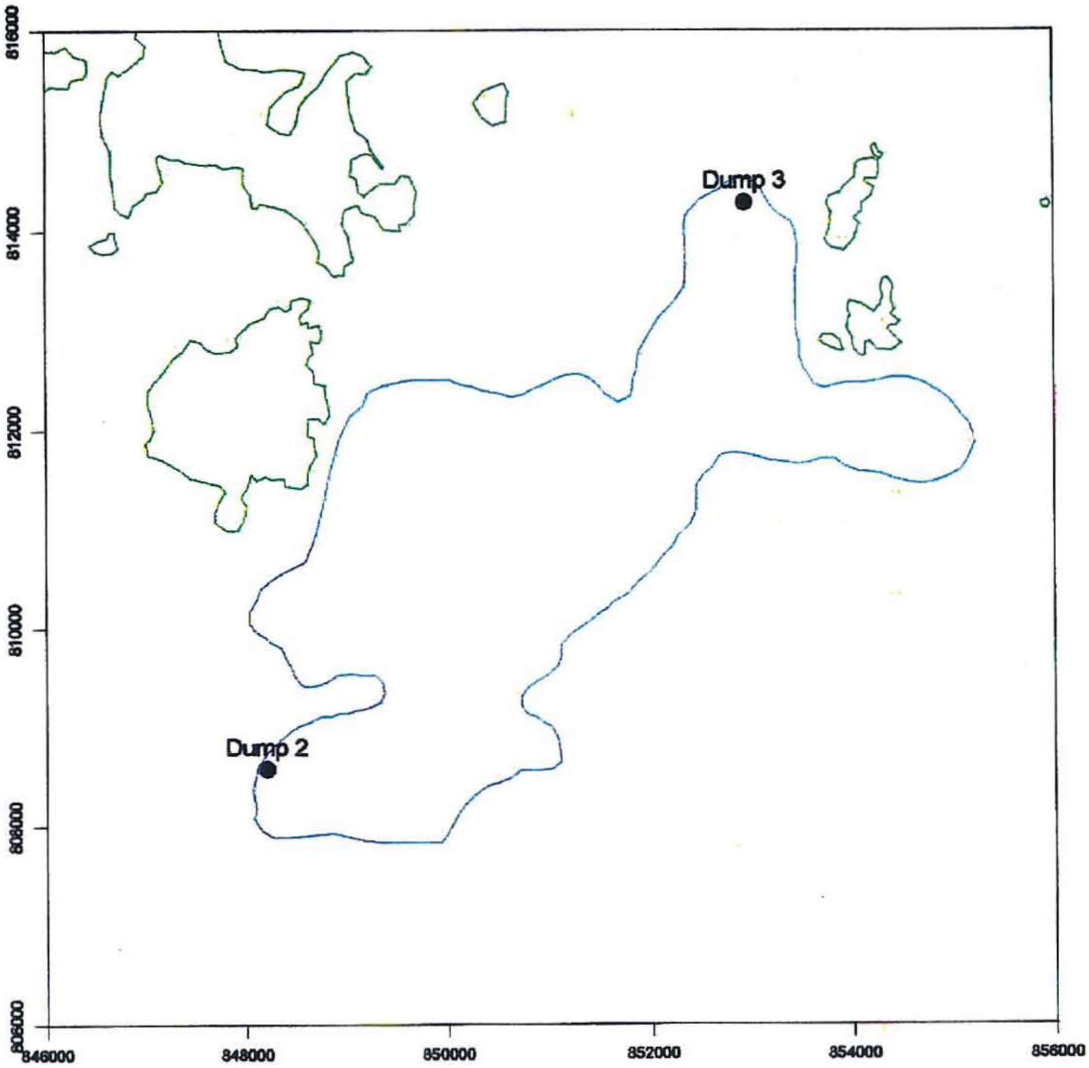

FIGURE C1a - LOCATION OF THE TRIAL DUMPS USED IN THE CALIBRATION EXERCISE

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C1 SELECTION OF CALIBRATION DATA

SEDPLUME was calibrated using data from the Trial Dump described in *Annex B*. Data from dumps by the Pacifique were used for two reasons: the Pacifique had a higher loss rate than the Krankeloon; and the decay of the suspended sediment concentrations was slower for the Pacifique dumps which meant that higher suspended sediment concentrations were maintained for longer periods of time. This means that simulations by the calibrated model should be conservative when simulating dumping from other dredgers which typically produce higher density material.

Of the dumps from the Pacifique, Dump 3 was found to have the most thorough data set upon which to base the calibration. Dump 3 took place in the northern, deep area, of the East Tung Lung Chau MBA shown in *Figure C1a* and the currents at the time of the dump were typical of stable wet season conditions. The other dumps from the Krankeloon, Dumps 4, 5 and 6 were found to be unacceptable; in Dump 4 the data field dat set was sparse and did not contain enough information for model calibration; at the time Dump 5 took place the tidal currents in the upper and lower portions of the water column were found to be flowing in opposite directions which is an atypical condition and is not represented in the flow model; and during the data collection following Dump 6, the tidal currents reversed mid-way through the survey period which is again atypical.

Dump 2, which was carried out by the Krankeloon, was chosen for comparison with the calibrated model. The aim of this comparison was to show that the calibrated model produced a conservative simulation for dumping from a dredger which produces higher density material. Dump 2 took place at the south-western limit of the East Tung Lung Chau MBA as presented in *Figure C1a* and the currents at the time of the dump were typical of stable dry season conditions.

C2 HYDRODYNAMIC DATA

Hydrodynamic data for the SEDPLUME calibration simulations were provided by the Extended WAHMO two-dimensional two-layer model of tidal flows which covers the whole of Hong Kong waters, the Pearl Estuary, the Lema Channel to the south of Hong Kong and Mirs Bay. The model has a horizontal resolution of 250m and a two-layer vertical structure with the upper layer being the top 8 m of the water column and the lower layer representing the remainder.

C2.1 DUMP 3

Dump 3 took place on 8 September at 11:40 which was 4.55 hours after high water. Tidal currents were observed to be flowing in a north easterly direction which is representative of wet season conditions and the tidal elevation curve for the day of the dump (presented in *Figure C4.1c*) most closely approximates the modelled tide curve for the wet season spring tide which is presented in *Figure C2.1a*.

Tidal current speeds at the time of the dump were measured in the field as being 0.15 - 0.20 ms^{-1}. 4.55 hours after high water, which corresponds to the stage in the tidal cycle that Dump 3 occurred, modelled current speeds are predicted to be 0.33 m/s in the upper layer and 0.22 ms^{-1} in the lower layer as presented in *Figure C2.1a*. They are then predicted to decrease to 0.19 ms^{-1} in the upper layer and 0.06 ms^{-1} in the lower layer at a time in the tidal cycle which corresponds to 4 hours after the dump took place. The comparison shows that initially predicted current speeds are higher than those measured in the field but that predicted currents speeds subsequently drop to below those measured. Measured current directions were found to be offset by 10° to the north in the lower layer compared to the surface layer and this feature was predicted in the model as shown in *Figure C2.1a* and *Figure C2.1b*.

C2.2 *DUMP 2*

Dump 2 took place on 5 September at 19:24 hrs which was 12.30 hours after high water. Tidal currents during Dump 2 were observed to be flowing in a south-westerly direction over the dump site which is representative of dry season conditions. The tidal elevation plot for the day of the dump (presented in *Figure C4.2c*) most closely approximates the model predicted elevation tidal curve for the dry season neap tide which is presented in *Figure C2.2a*.

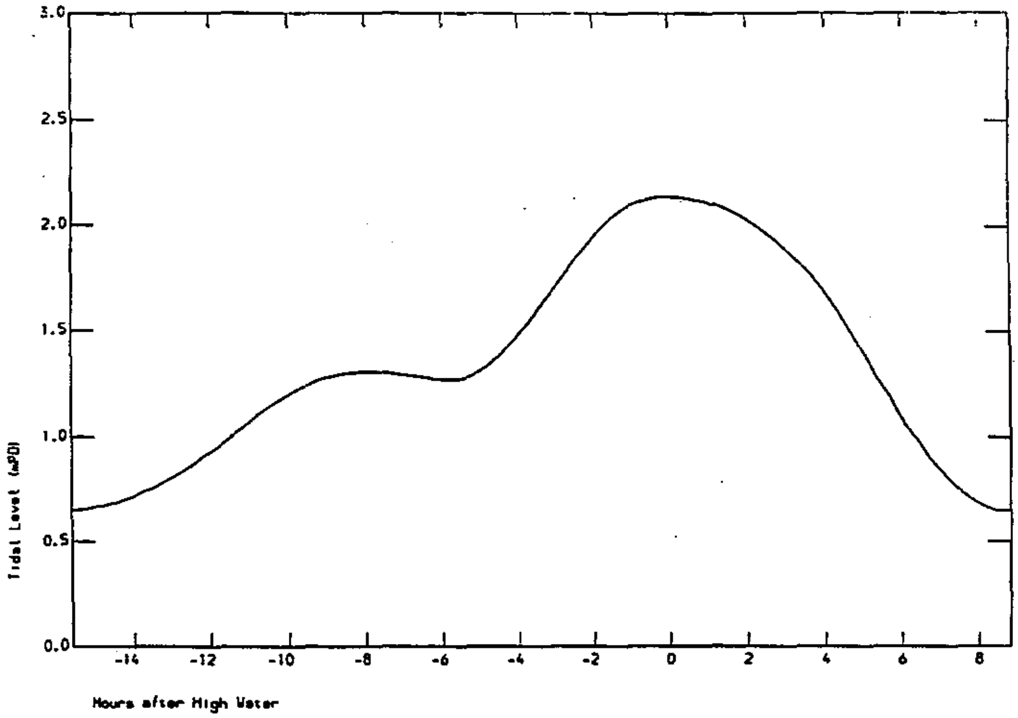
At the time of the dump tidal current speeds were observed to be 0.20 ms^{-1}. At the corresponding time in the tidal cycle of 12.30 hours after high water model predicted current speeds are 0.22 ms^{-1} in the upper layer and 0.18 ms^{-1} in the lower layer as shown in *Figure C2.2a*. Therefore predicted model current speeds are in reasonable agreement with measured current speeds as are the predicted and observed current directions of 225°, which is south-westerly. Predicted current velocities are shown in *Figure C2.2a* and *Figure C2.2b*.

C3 *SELECTION OF MODEL PARAMETERS*

Field data collected during the trial dumps consisted of averaged suspended sediment concentrations for two parts of the water column: the upper 15 m; and the remainder. In contrast SEDPLUME was set up with the same layer structure as the flow model, which has an upper layer of 8 m thick and a lower layer making up the rest of the water column. In order to make a direct comparison of SEDPLUME results with field data, the layer structure in the SEDPLUME model output calculation was modified to make it consistent with the data collected during the trial dumps.

C3.1 *GRID SIZE*

The flow model which provides hydrodynamic data to SEDPLUME has a horizontal grid size of 250m which is too coarse to resolve the features of the sediment plumes found during the trial dumps. Therefore a smaller gird was generated using a grid size of 32.5 m which was chosen to give the maximum possible resolution for the calibration exercise and because this size would also be appropriate for the DEIA disposal scenarios.



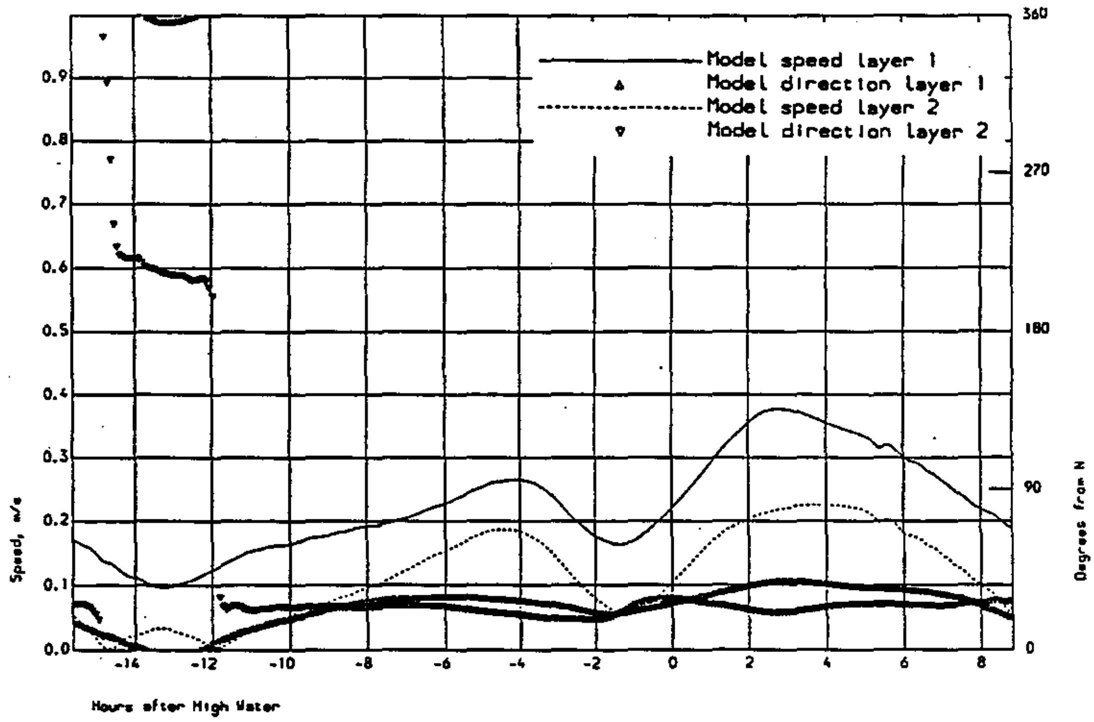


FIGURE C2.1a - PREDICTED TIDAL ELEVATION AND CURRENT VELOCITIES FOR DUMP 3 UNDER WET SEASON SPRING TIDE CONDITIONS

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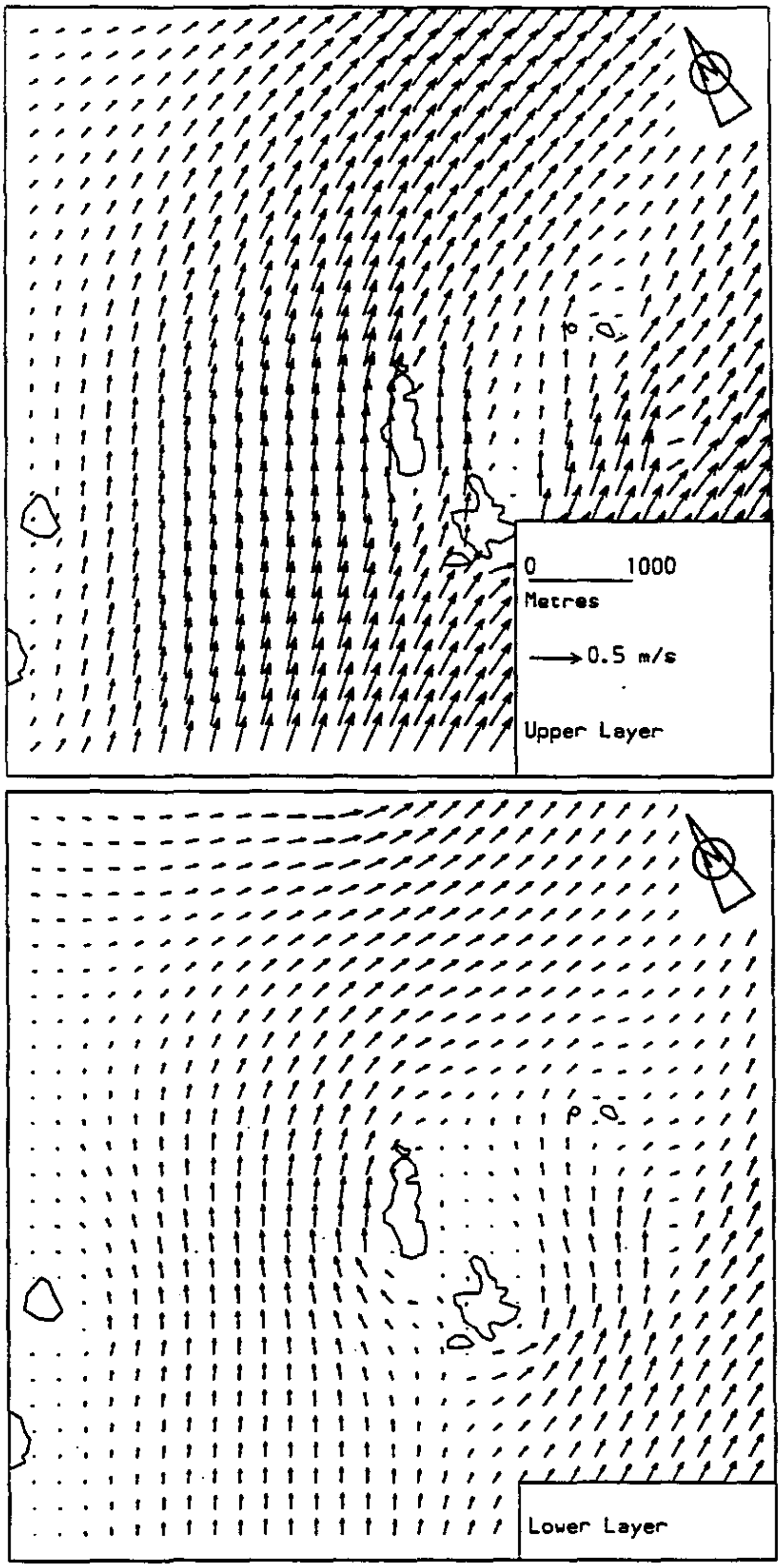

FIGURE C2.1b - CURRENT VECTORS FOR DUMP 3 UNDER WET SEASON SPRING TIDE CONDITIONS

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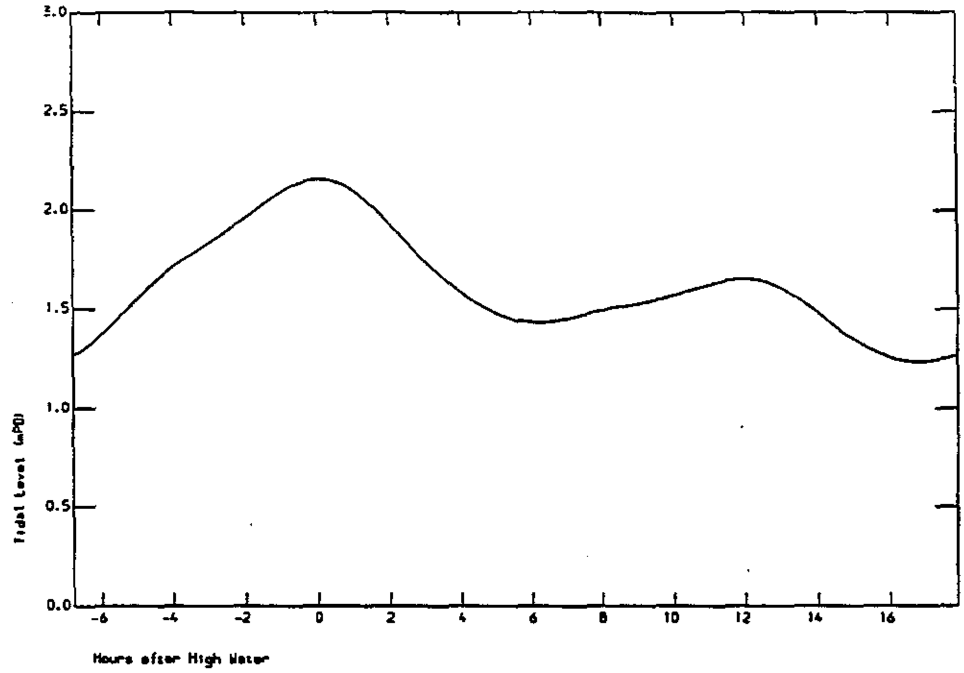

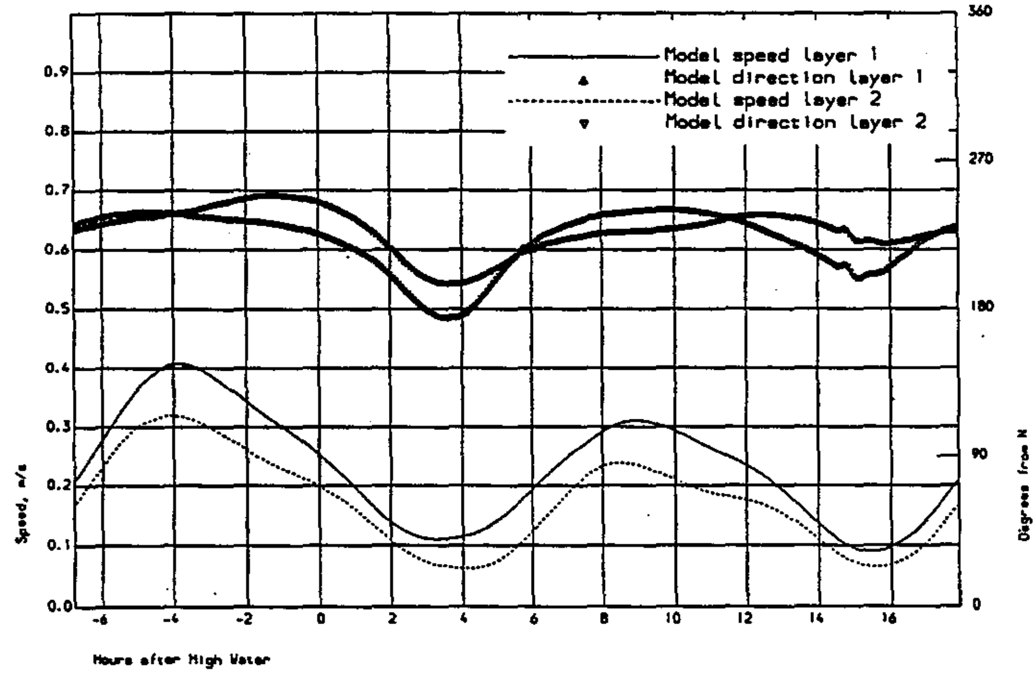

FIGURE C2.2a - PREDICTED TIDAL ELEVATION AND CURRENT VELOCITIES FOR DUMP 2 UNDER DRY SEASON NEAP TIDE CONDITIONS

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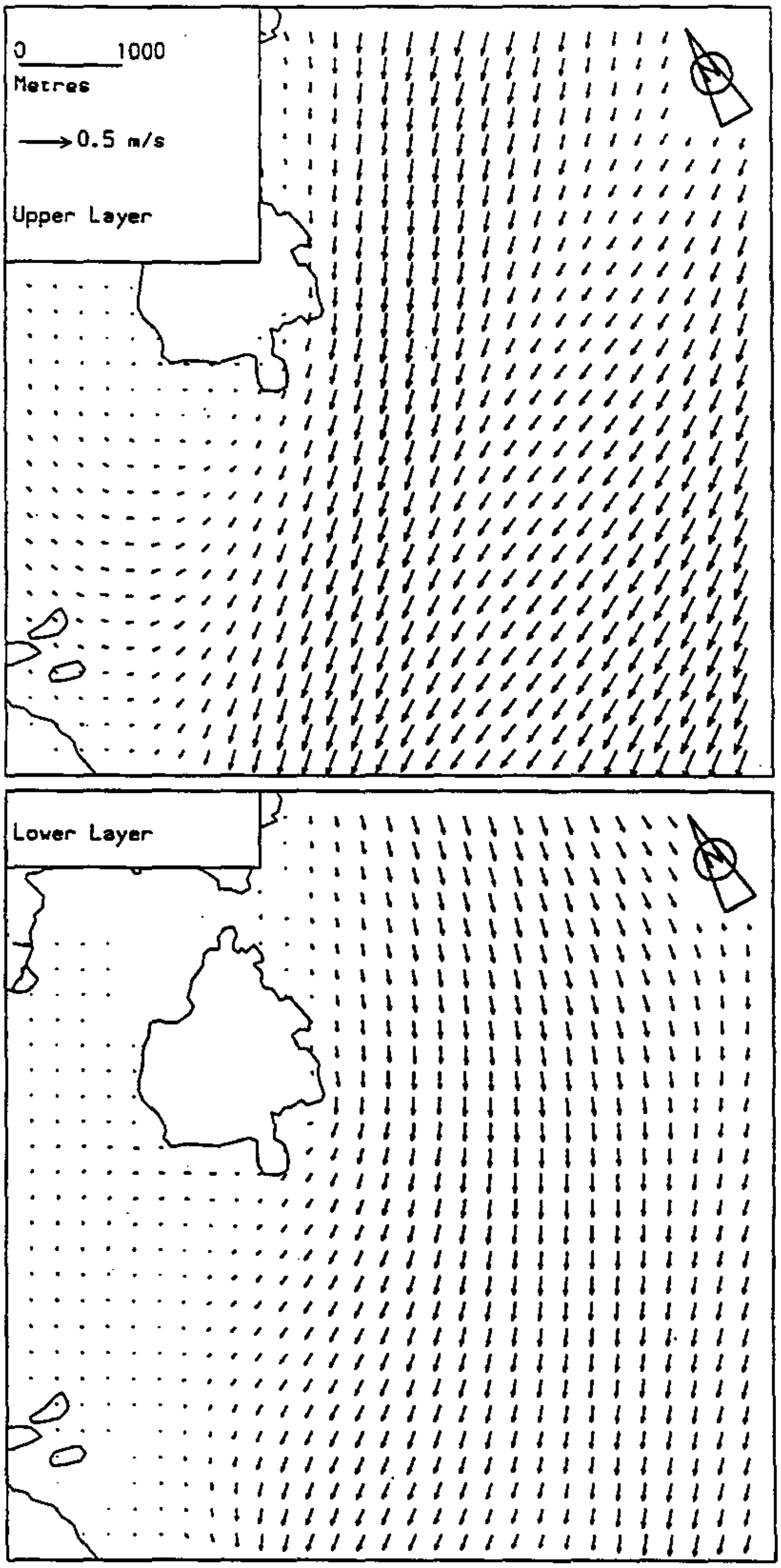

FIGURE C2.2b - CURRENT VECTORS FOR DUMP 2 UNDER DRY SEASON NEAP TIDE CONDITIONS

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C3.2 INTRODUCTION OF SEDIMENT INTO THE SEDPLUME MODEL

In previous simulations of dumping operations [1][2][3], in the absence of specific data and in order to ensure a conservative result, it was assumed that the sediment was input into the model as a point source at the water surface. These assumptions are not representative of the physical processes which lead to sediment being lost to suspension during the dumping process. The results of the trial dumps showed that the sediment was spread over the water depth with the majority of the sediment being found in the lower 75% of the water column. The sediment was also found to be spread horizontally over an area which approximated a circle in plan. The diameter of the circle was determined to be 60 m which is approximately the dimension of the hopper doors through which the mud was discharged. The input for the sediment model was therefore set to be a cylinder of diameter 60 m over the lower 75% of the water column.

C3.2.1 *Loss of Disposal Material to the Water Column*

During the trial dump the flux boat, which measured the total quantities of sediment lost to suspension (see *Section* C2), was positioned 300 m downstream of the dumping site. This distance allowed time for the initial dynamic, turbulent phase of the plume to be completed before sediment concentrations were measured and it is from this point that SEDPLUME would begin the simulation. The loss point for the model was therefore set to be 300 m downstream of the dump site. The masses of sediment input into the model were derived from the data collected by the flux boat. For Dump 3 the mass of sediment input into the model was 166,380 kg which represented 8.42% of the total discharged by the Pacifique. For Dump 2 the mass of sediment input into the model was 36,680 kg which represented 2.09% of the total discharged by the Krankeloon.

C3.3 SUSPENDED SEDIMENT CONCENTRATION TO SETTLING VELOCITY RELATIONSHIP

The standard settling velocity to suspended sediment concentration relationship used in SEDPLUME had previously been derived from a series of laboratory experiments on a sample of mud from Chek Lap Kok Bank[4]. This relationship had been successfully applied in calibrating the MUDFLOW model[5]. The standard settling velocity was determined as follows:

$$W_{set} = \beta \times C^{n}$$

where:	W_{set}	= settling velocity
	β	= empirical constant = 0.01
	C	= suspended sediment concentration
	n	= empirical constant = 1

This relationship was applied for suspended sediment concentrations above 100

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(1) ERM Hong Kong (1995) Backfilling of South Tsing Yi and North Lantau MBAs : Final. Environmental Impact Assessment.

(2) Hyder Environmental (1996) *Op Cit*

(3) HWR (1995) Disposal of Surplus Material at the South Tsing Yi Marine Borrow Area. Simulation of Sediment Plumes.

(4) HR Wallingford (1990) Port and Airport Development Strategy. Enhancement to WAHMO Mathematical Models. Physical Properties of a Bed Sample from the North West New Territories.

(5) HWR (1991) Port and Airport Development Strategy. Enhancement to WAHMO Mathematical Models. Calibration of the North West New Territories Coastal Water Mud Transport Model for Normal Wet and Dry Season Conditions.

ppm. Below 100 ppm the settling velocity was maintained at 1 mms^{-1} which corresponds to the settling velocity for 100 ppm. The settling velocity curve that results is presented in *Figure C3.3a*. Simulations using the above relationship showed that the initial settling of the sediment, at higher concentrations, was too low compared to field data, and the later settling, at lower concentrations, was too high compared . From the comparisons with the field data the parameter n in was given a new value of 0.6 with no minimum settling velocity but with the maximum settling velocity set to be that value for concentrations of 150 ppm, the new settling velocity curve is also presented in *Figure C3.3a*. The use of a modified settling velocity is justified because the sediment lost to suspension during dumping is not natural sediment, it has been completely disturbed and reworked, and as such will not behave in the same way as naturally occurring and flocculating sediment suspensions.

C3.4 *RANDOM WALK STEP*

Horizontal dispersion is represented by a single parameter in the model and which defines the length of turbulent particle displacements. The standard value in the SEDPLUME was 0.2 but initial simulations with this value showed that the horizontal spread of the plume was too low resulting in a narrower plume than was measured in the field. The optimum value from these simulations was found to be a value of 1.0. This is reasonable because the relatively coarse resolution of the flow model, 250m, would not be able represent small scale eddies which would be generated by the presence of a number of islands in the East Tung Lung Chau MBA area.

C4 *COMPARISON OF CALIBRATED SEDPLUME PREDICTIONS WITH INDEPENDENT FIELD DATA*

The calibration of SEDPLUME was based on Dump 3 which was carried out in the northern part of the East Tung Lung Chau MBA under wet season flow conditions. Calibrated model results were subsequently compared with Dump 2 which was carried out in the south-western extremity of the East Tung Lung Chau MBA under dry season flow conditions.

Field data from the trial dumps were processed to show suspended sediment concentrations along the lines sailed by the tracking boat and to show maximum recorded sediment concentration against time. Results from the SEDPLUME simulations were processed to give the maximum suspended sediment contours and to give sediment concentration against time so that they could be compared directly to the field data following a conversion to account for background levels of suspended sediment. For Dump 3 the background concentrations were determined to be approximated by 5 ppm above 15 m, and 1 ppm below 15 m. For Dump 2 the background values were determined to be approximately 2.5 ppm above 15 m and 1 ppm below 15 m.

C4.1 *DUMP 3*

Dump 3 was used to calibrate the model with the various model parameters being modified, as described in *Section C3*, to give the best possible agreement between the model results and the field data.

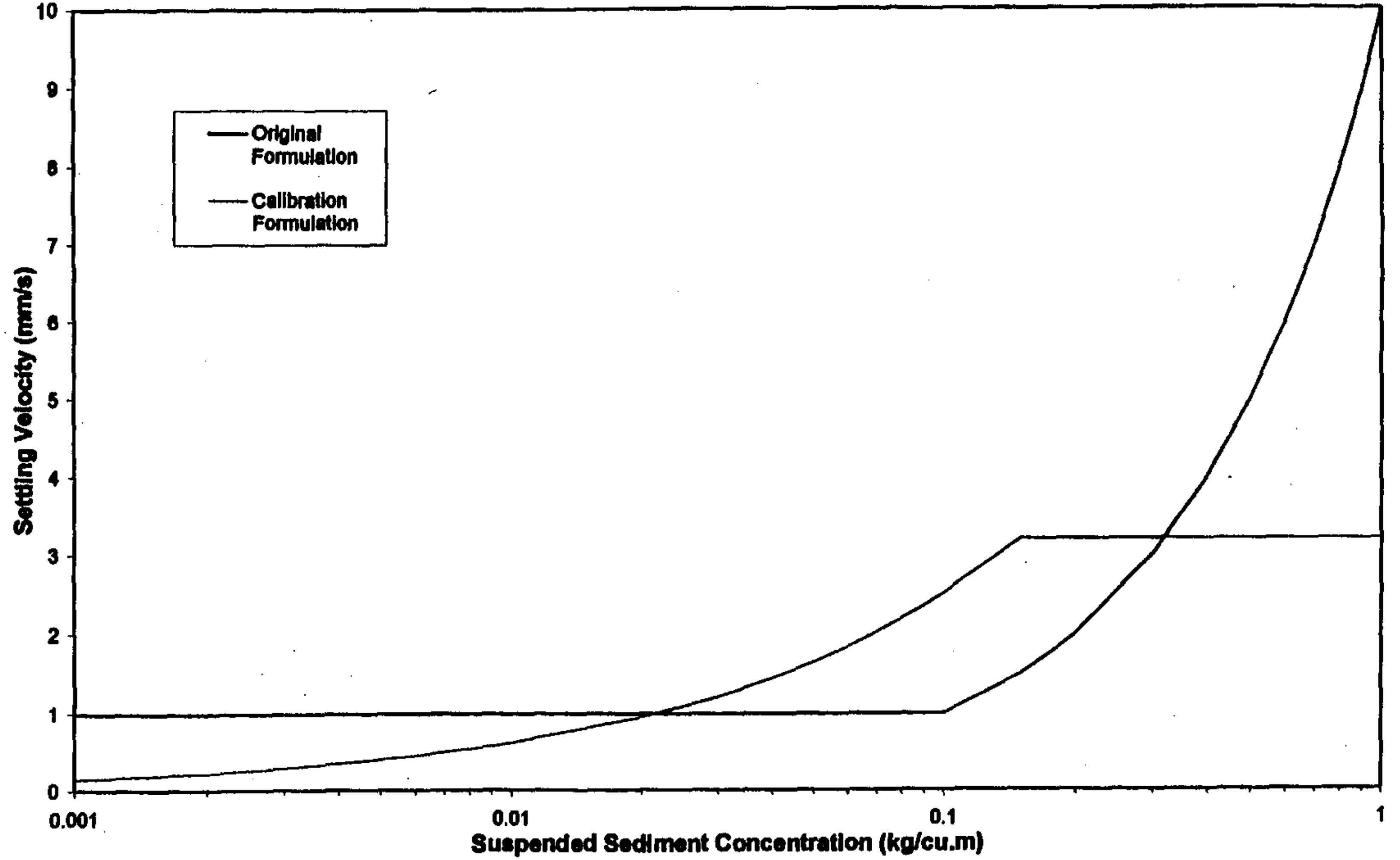

FIGURE C3.3a - GRAPH OF SETTLING VELOCITY AGAINAT SUSPENDED SEDIMENT CONCENTRATIONS WITH TIME FOR DUMP 3

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Figure C4.1a shows the comparison between field data and model predictions in terms of the maximum suspended sediment concentrations in the centre of the plume at selected time intervals. It can be seen that the model reproduces the observed suspended sediment concentrations both in terms of absolute values and in terms of the reduction of suspended sediment concentrations with time. Initial values for predicted suspended sediment concentrations are very similar to those observed in the field. The model slightly under-predicts suspended sediment concentrations in the upper layer, the top 15 m, until 2 hours after the dump but the slope of the model curve matches that from the field data well. In the lower layer, below 15 m depth, the model over-predicts the concentrations slightly but again the slopes of the curves are closely matched. Between 2 hours and 4 hours after the dump the field data shows a series of spikes in the upper layer which may have been caused by the propeller of the survey boat generating turbulence. The model does not reproduce this feature, but the model curve is shown to pass through the field data curve and still follows the general reduction in the observed suspended sediment concentrations. In the lower layer the model results between 2 hours and 3 hours 20 minutes after the simulated dump very closely match the field data collected at the equivalent time. Measured concentrations were observed to reduce sharply after 3 hours and 20 minutes after the dump and this is not reproduced in the model. The reasons for this sudden reduction are unclear but may have been caused by the survey boat being missing the centre of the plume given that it would have been very diffuse by this time.

Figure C4.1b shows the maximum suspended sediment concentrations from the SEDPLUME simulation and is directly comparable with *Figure C4.1c* and *Figure C4.1d* which show measurements by the transect boat for the upper 15 m of the water column and the water column below 15 m depth. In terms of both the longitudinal and lateral spread of sediment, the model reproduces the field data at the higher concentrations, above 25 ppm, in both the upper and lower layers. In the upper layer the 10-25 ppm contour is also well reproduced in the model. Below 10 ppm the absolute extent of the model predictions is hard to compare with the field data given the variability of the natural suspended sediment concentrations but the model can be seen to reproduce the overall trend in the plume development. In the lower layer the lateral extent of the lower concentrations, below 25 ppm, is slightly smaller in the model than was measured in the field although the longitudinal extent is well reproduced.

C4.2 DUMP 2

The calibrated SEDPUME model was then used to simulate Dump 2 which took place at the south-western limit of the East Tung Lung Chau MBA under dry season flow conditions.

It should be appreciated that the dredger used for Dump 2, the Krankeloon, was a different one from that used for Dump 3, the Pacifique, and that the Krankeloon dredged at a higher density than the Pacifique which resulted in lower losses of sediment to suspension.

Figure C4.2a shows the comparison between the field data and the model results in terms of the maximum suspended sediment concentrations at selected time intervals. Comparison of the model results with the field data shows that the model over-predicts the sediment concentrations in both the upper and lower layers, above and below 15 m depth. Initial concentrations predicted by the model are similar to those measured in the field showing that the method of introducing sediment into the model is representative. The over-prediction in the model predictions occur because the settling of sediment in the first hour after the dump is under-estimated in the model even though the settling velocity in the model is now higher as a result of the calibration based on Dump 3.

The differences in the rates of settling of sediment following Dump 3 and Dump 2 are a result of the fact that the nature of the disposal material varied. This was because the material was generated by different dredgers. For Dump 2 the Krankeloon was used which dredged at a higher density which meaning that there would have been larger aggregates of sediment in the plume initially than for the plume following Dump 3; hence the higher settling velocity for Dump 2. The predicted decay of suspended sediment concentrations in both the upper and lower layers after 1 hour matches the field data well. Field data collected in excess of 2 hours after the disposal event should be discounted because increasing wave activity gave rise to air entrainment in the water and corruption of the data.

Figure C4.2b shows the maximum suspended sediment concentrations from the SEDPLUME simulation and is directly comparable with *Figure C4.2c* and *Figure C4.2d* which show the measurements by the transect boat for the upper 15 m of the water column and the remaining depth of the water column. The model reproduces the spread of sediment well when compared with the field data although the values are higher than the field observations for the reasons discussed in the preceding paragraph. The model simulates particularly well the relatively large spread of sediment in the upper layer, the top 15 m, when compared with the lower layer, below 15 depth.

C5 SUMMARY AND CONCLUSIONS

As part of the modelling work, the SEDPLUME was calibrated against field measurements of suspended sediment concentrations from a series of trial dumps.

The trial dumps took place in early September 1995 at the northern and south-western limits of the East Tung Chau Marine Borrow Area. The third of the dumps conducted, Dump 3, was chosen to provide the calibration data for SEDPLUME because it had the highest loss of sediment to suspension and a very complete data set upon which to base the calibration. By modifying the way in which the sediment was input into the model and certain of the model parameters a good agreement was obtained between the model and the field data. None of the parameters which were modified were given values which were unreasonable in terms of the physical processes which were being simulated and in terms of the values used in other studies.

Field data following the second of the trial dumps, Dump 2, was chosen for comparison with the predictions from the calibrated model. The model was shown to over-predict the suspended sediment concentrations, and hence produce conservative predictions. The over-prediction occurs because the initial settling of sediment for Dump 2 was much higher than in Dump 3. This is a result of the dredger which was used for Dump 2 producing material of a higher density than that produced by dredger that was used for Dump 3. Consequently larger aggregates of sediment were thought to be present in the initial phases of the plume following Dump 2 than following Dump 3 which resulted in more

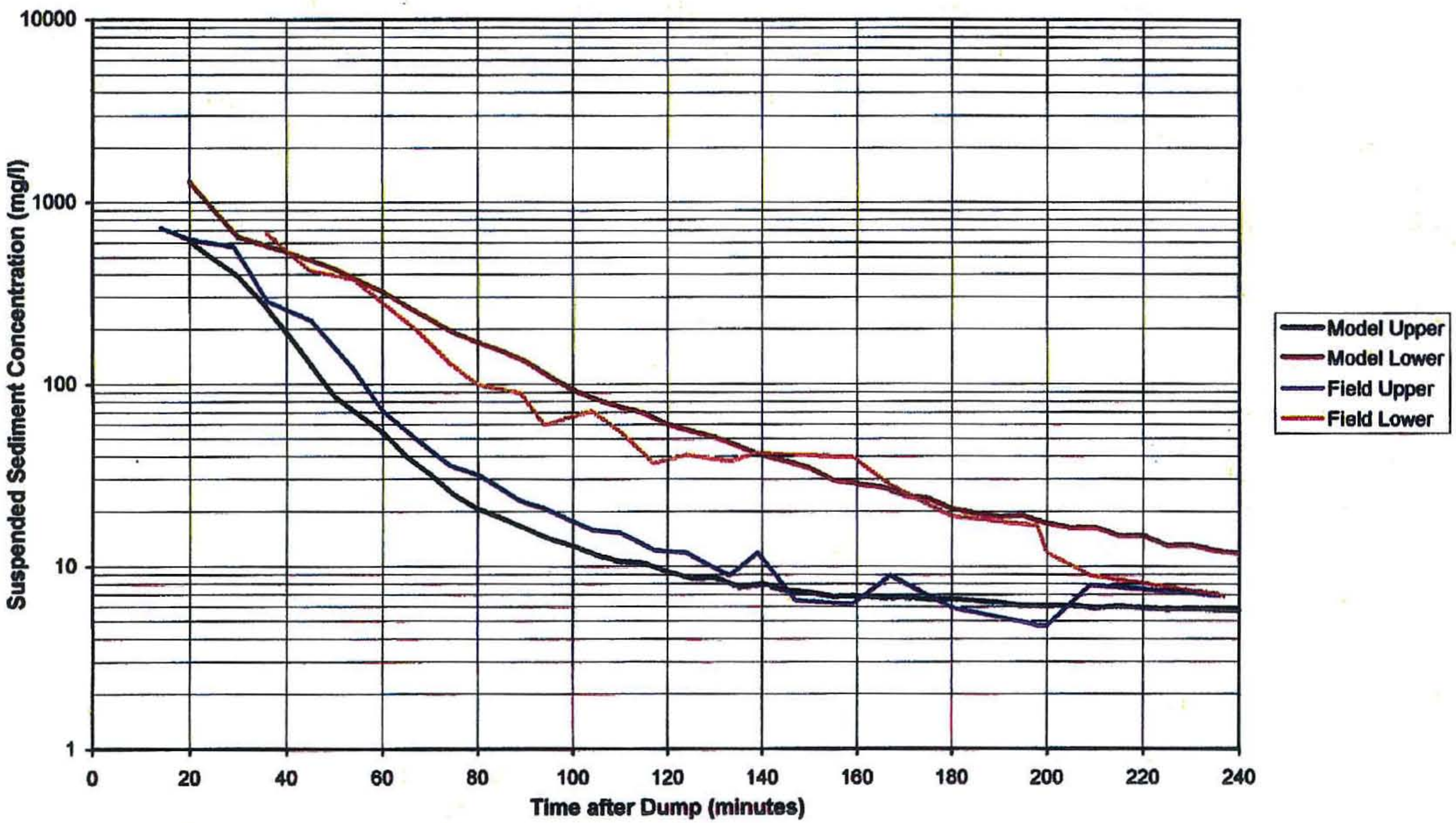

FIGURE 4.1a - COMPARISON OF PREDICTED AND OBSERVED SUSPENDED SEDIMENT CONCENTRATIONS WITH TIME FOR DUMP 3

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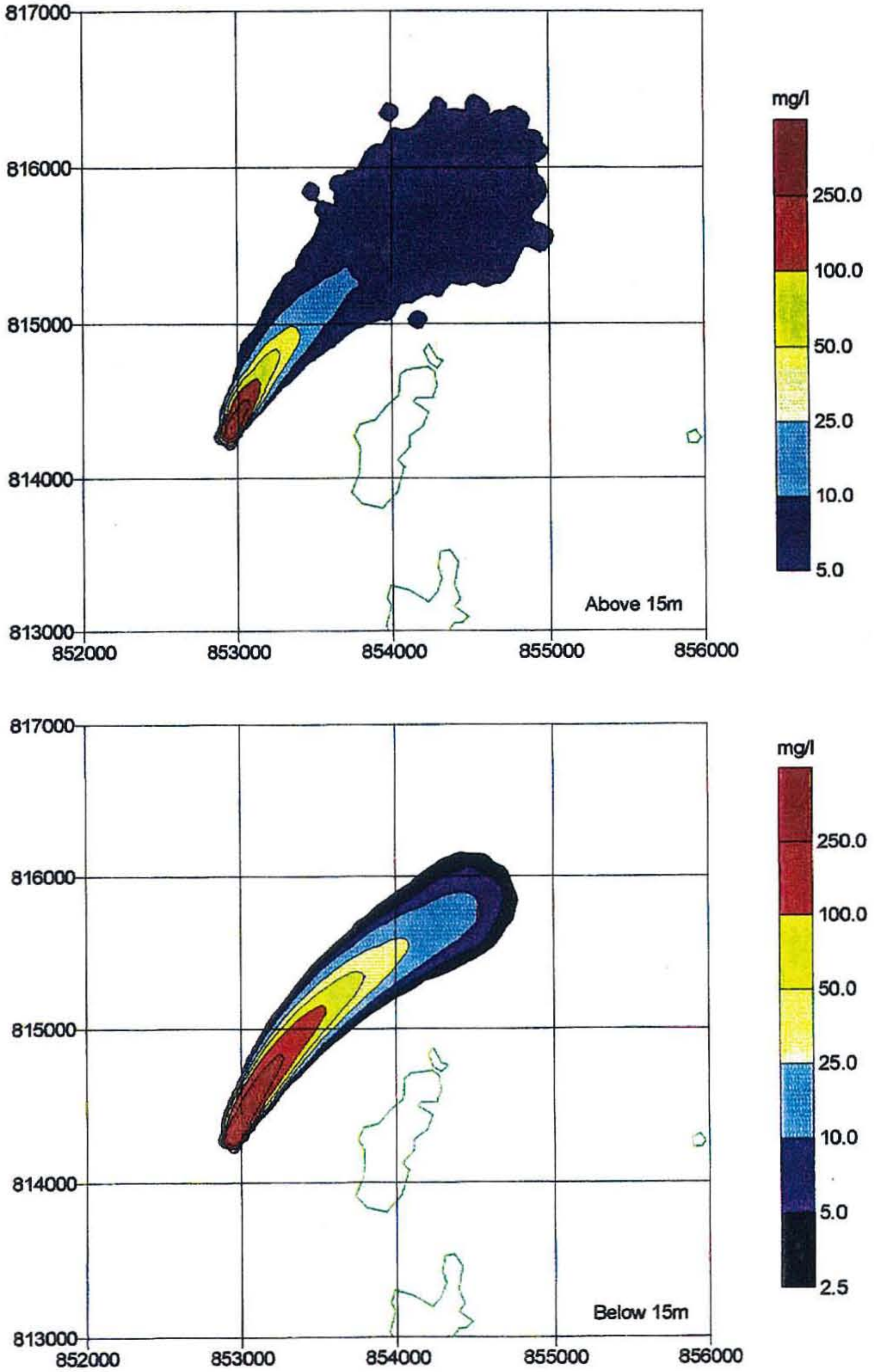

FIGURE 4.1b - PREDICTED MAXIMUM SUSPENDED SEDIMENT CONCENTRATION PLOTS FOR DUMP 3

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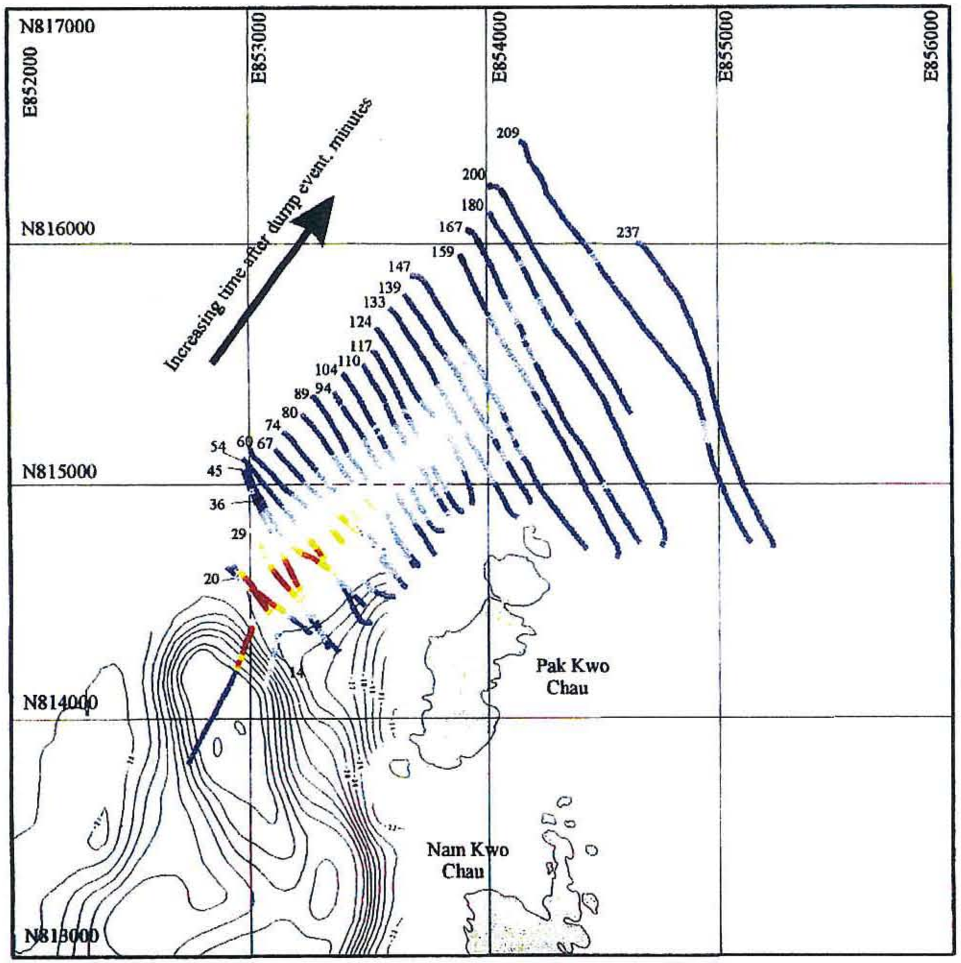

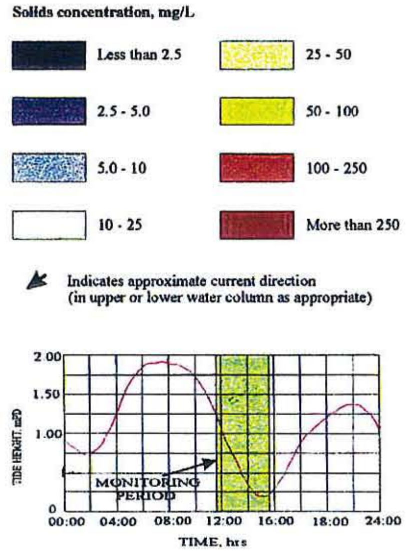

IMPORTANT NOTES:

This plan shows concentrations observed along survey lines which were sailed in sequence. The plan is therefore a time-series plot and does NOT represent the extent of the plume at any given time. The plot indicates only the area affected by the plume during the survey period and, approximately, the maximum transient solids concentrations within that area.

Solids concentrations in excess of 250 mg/l very close to the dump location may include effects of entrained air.

DUMP 3

DEPTH-AVERAGED SOLIDS

CONCENTRATION IN UPPER 15 METRES

FIGURE 3/1

FIGURE C4.1c - MEASURED SUSPENDED SEDIMENT CONCENTRATIONS FOR DUMP 3: UPPER LAYER OF THE WATER COLUMN

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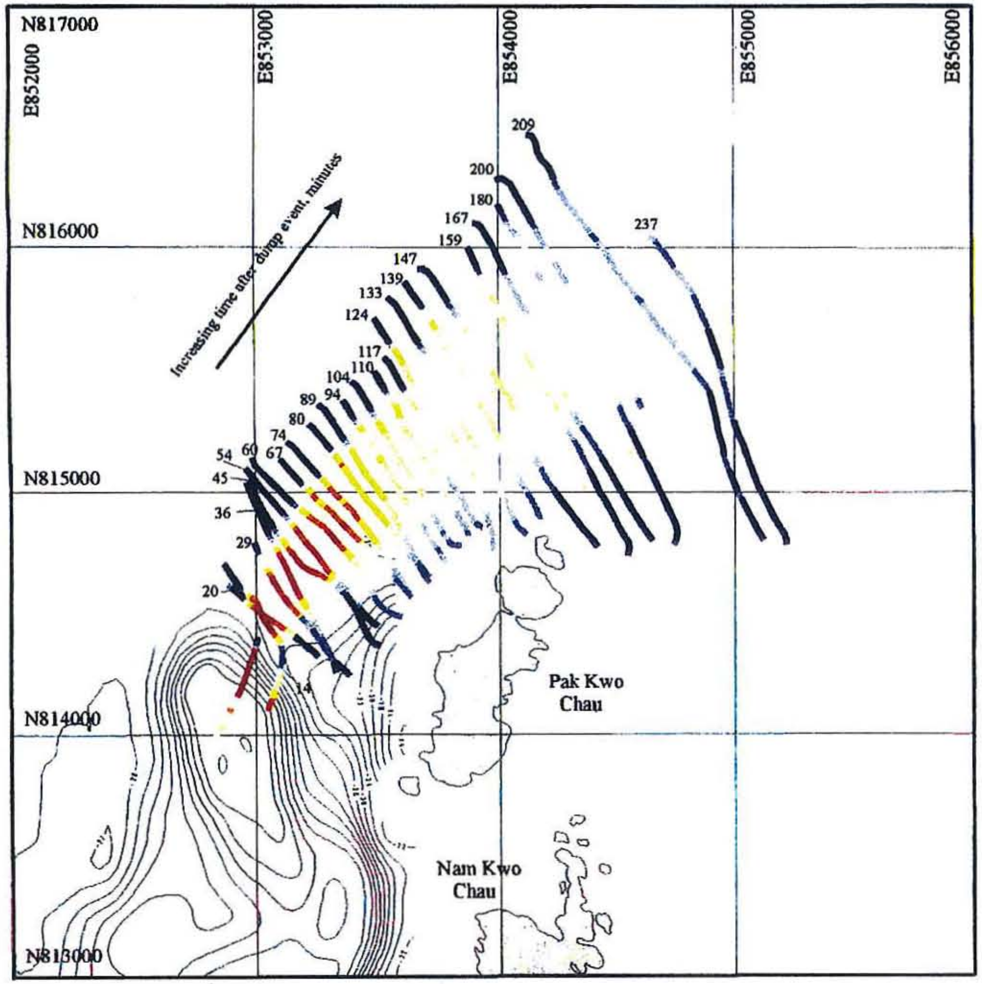
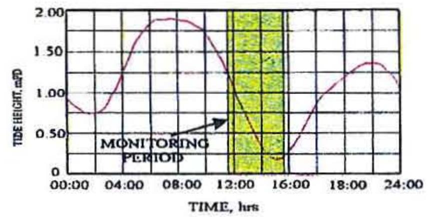


Solids concentration, mg/L

- Less than 2.5
- 2.5 - 5.0
- 5.0 - 10
- 10 - 25
- 25 - 50
- 50 - 100
- 100 - 250
- More than 250

Indicates approximate current direction (in upper or lower water column as appropriate)



IMPORTANT NOTES:

This plan shows concentrations observed along survey lines which were sailed in sequence. The plan is therefore a time-series plot and does NOT represent the extent of the plume at any given time. The plot indicates only the area affected by the plume during the survey period and, approximately, the maximum transient solids concentrations within that area.

Solids concentrations in excess of 250 mg/l very close to the dump location may include effects of entrained air.

DUMP 3
DEPTH-AVERAGED SOLIDS
SOLIDS CONCENTRATION BELOW
15 METRES DEPTH

FIGURE 3/2

FIGURE C4.1d - MEASURED SUSPENDED SEDIMENT CONCENTRATIONS FOR DUMP 3 : LOWER LAYER OF THE WATER COLUMN

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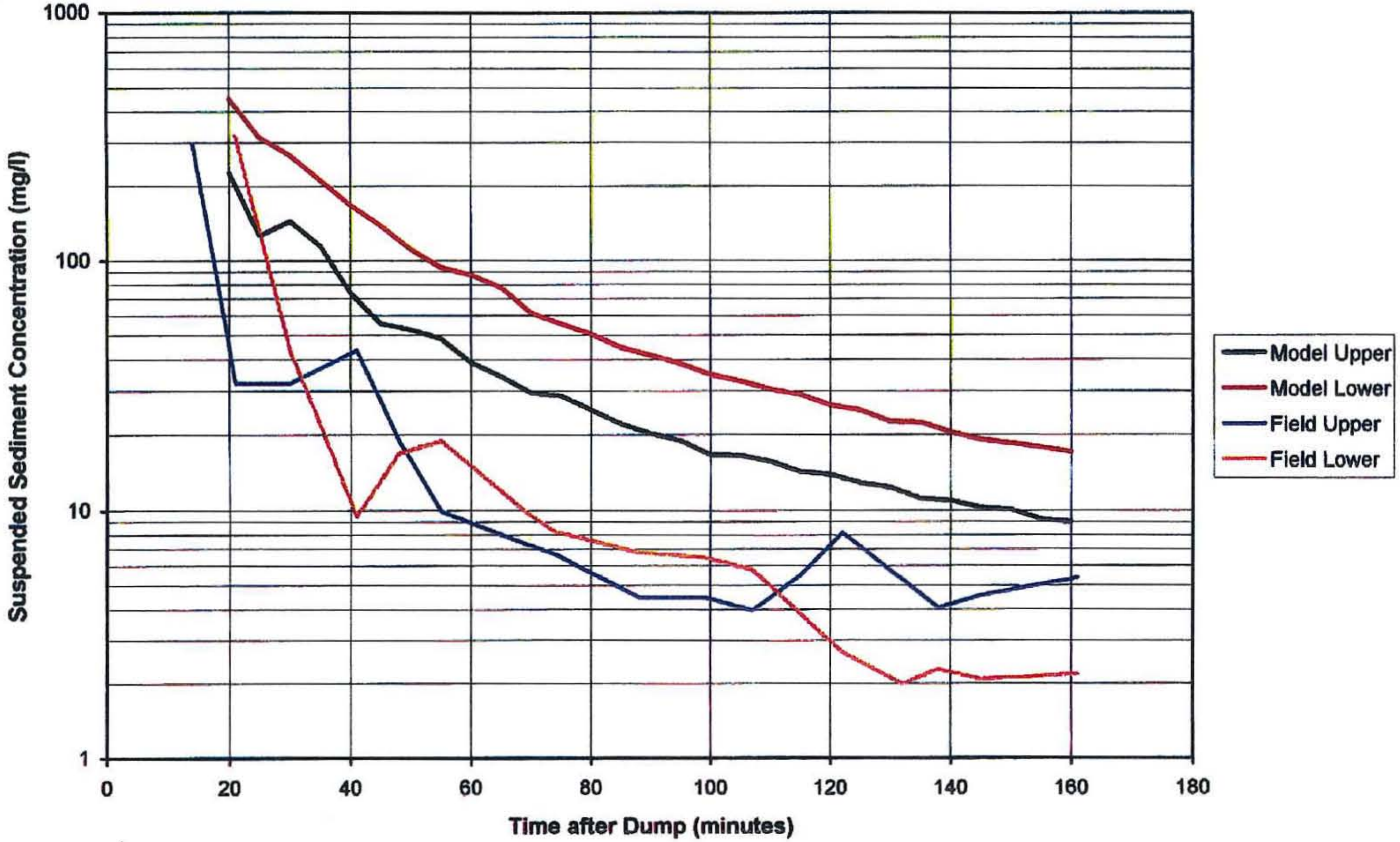

FIGURE C4.2a - COMPARISON OF PREDICTED AND OBSERVED SUSPENDED SEDIMENT CONCENTRATIONS WITH TIME FOR DUMP 2

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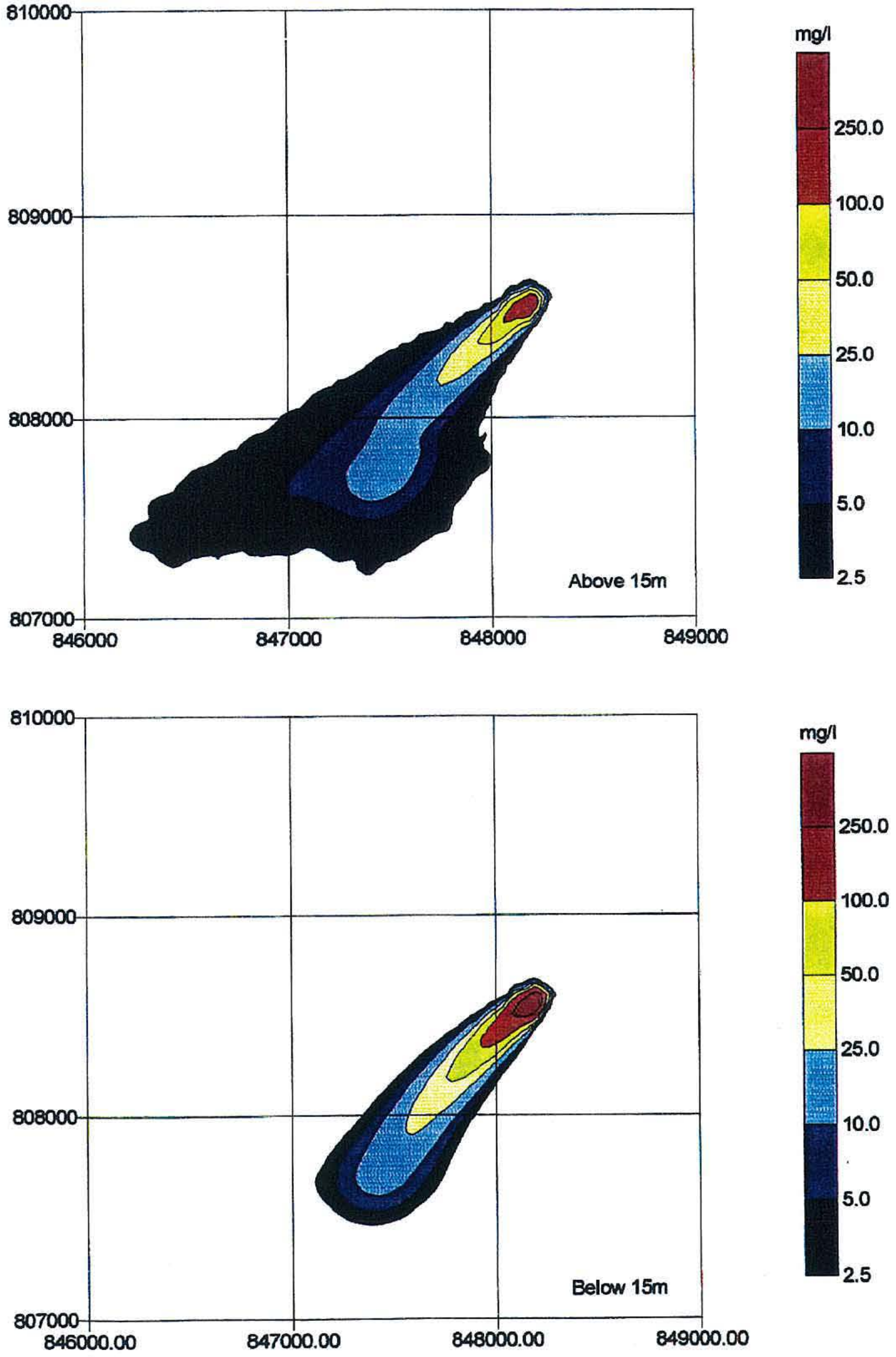

FIGURE 4.2b - PREDICTED MAXIMUM SUSPENDED SEDIMENT CONCENTRATION PLOTS FOR DUMP 2

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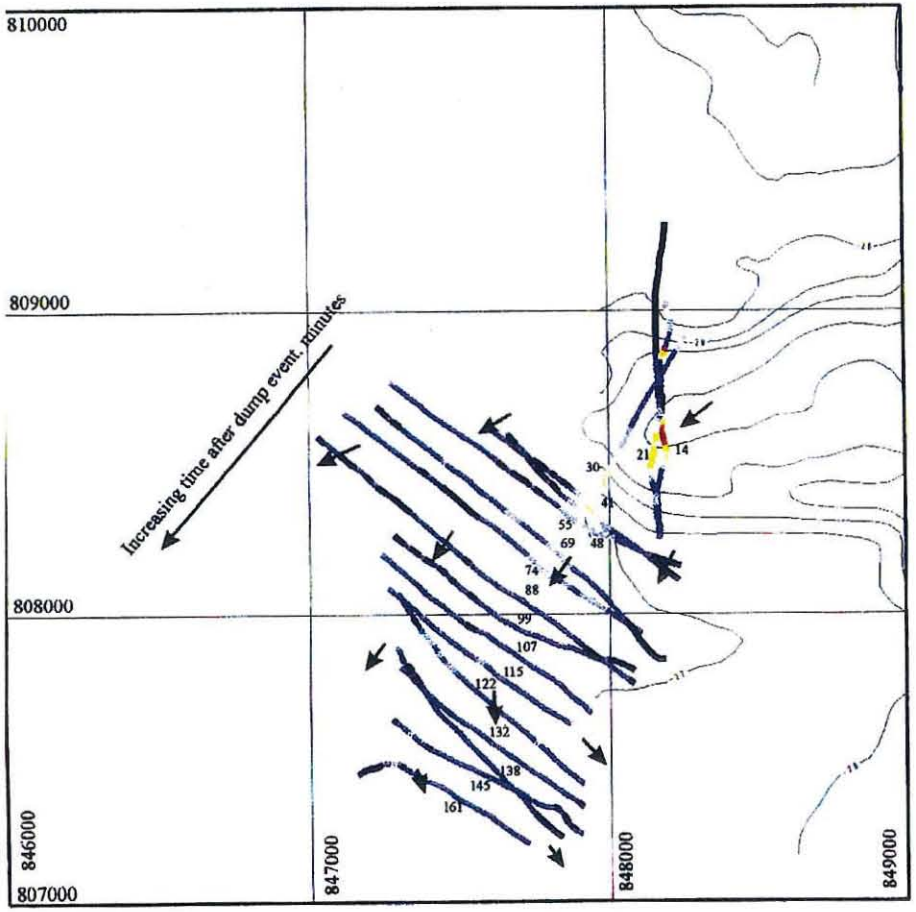
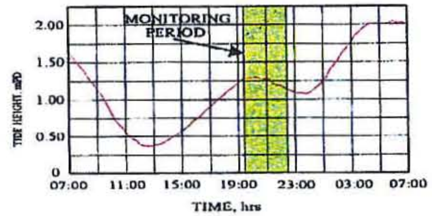


Solids concentration, mg/L

Less than 2.5	25 - 50
2.5 - 5.0	50 - 100
5.0 - 10	100 - 250
10 - 25	More than 250

Indicates approximate current direction (in upper or lower water column as appropriate)



IMPORTANT NOTES:

This plan shows concentrations observed along survey lines which were sailed in sequence. The plan is therefore a time-series plot and does NOT represent the extent of the plume at any given time. The plot indicates only the area affected by the plume during the survey period and, approximately, the maximum transient solids concentrations within that area.

Solids concentrations in excess of 250 mg/l very close to the dump location may include effects of entrained air.

DUMP 2
DEPTH-AVERAGED SOLIDS CONCENTRATION
IN UPPER 15 METRES

FIGURE 2/1

FIGURE C4.2c - MEASURED SUSPENDED SEDIMENT CONCENTRATIONS FOR DUMP 2 : UPPER LAYER OF THE WATER COLUMN

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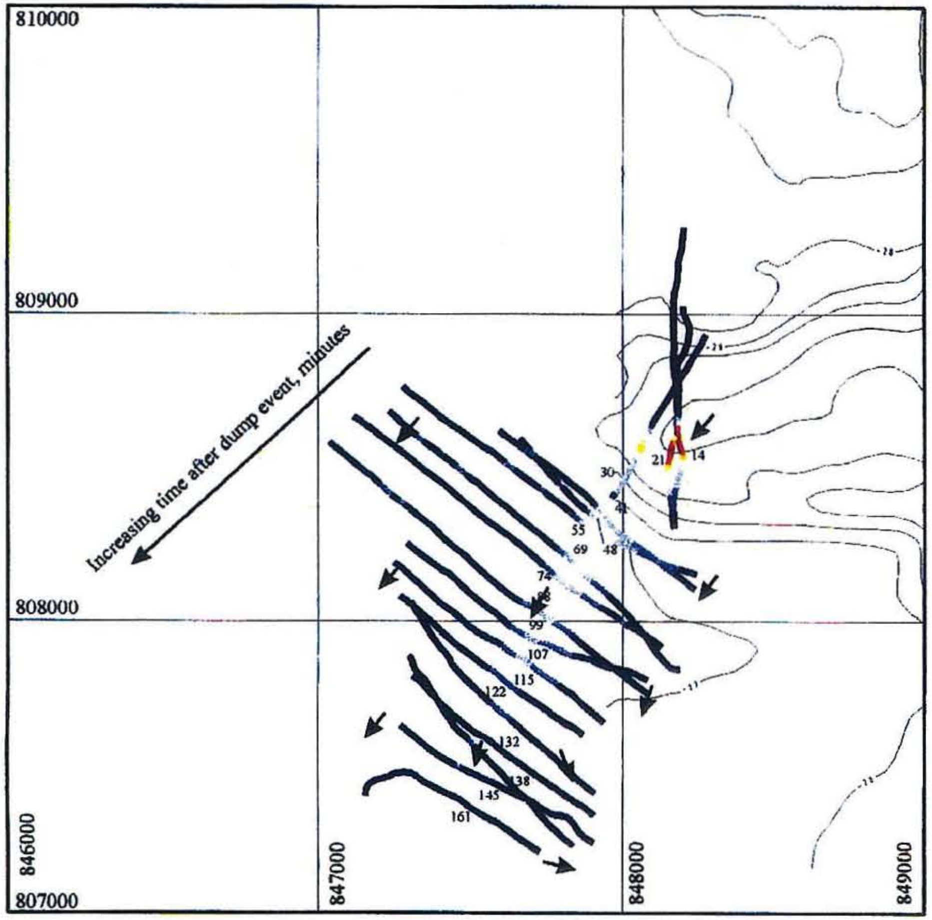
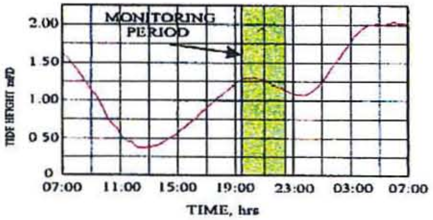


Solids concentration, mg/L

- Less than 2.5
- 2.5 - 5.0
- 5.0 - 10
- 10 - 25
- 25 - 50
- 50 - 100
- 100 - 250
- More than 250

Indicates approximate current direction (in upper or lower water column as appropriate)



IMPORTANT NOTES:

This plan shows concentrations observed along survey lines which were sailed in sequence. The plan is therefore a time-series plot and does NOT represent the extent of the plume at any given time. The plot indicates only the area affected by the plume during the survey period and, approximately, the maximum transient solids concentrations within that area.

Solids concentrations in excess of 250 mg/l very close to the dump location may include effects of entrained air.

DUMP 2
DEPTH-AVERAGED SOLIDS CONCENTRATION
BELOW 15 METRES

FIGURE 2/2

FIGURE C4.2d - MEASURED SUSPENDED SEDIMENT CONCENTRATIONS FOR DUMP 2 : LOWER LAYER OF THE WATER COLUMN

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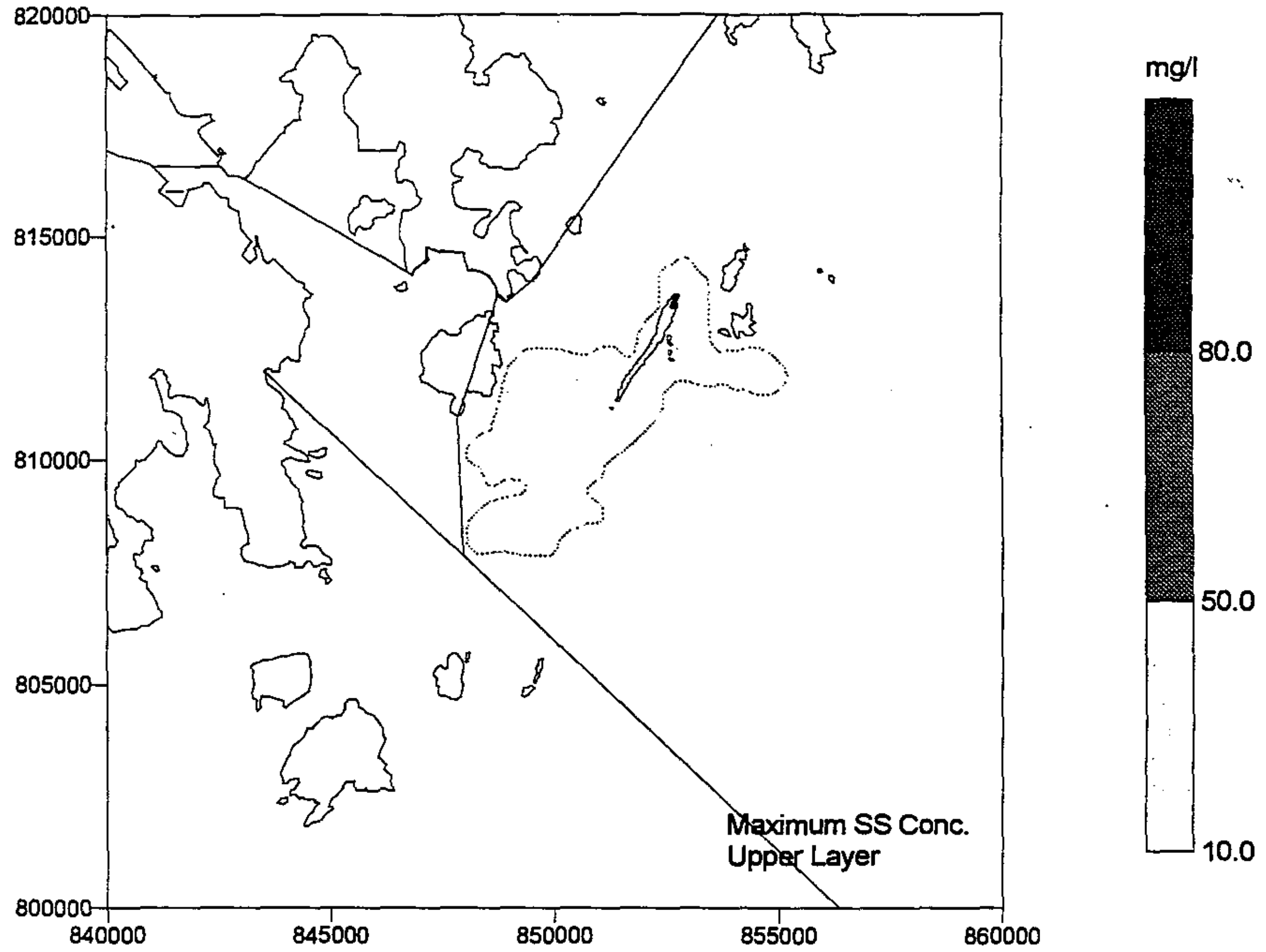
rapid settlement.

It should be emphasised that SEDPLUME was calibrated against field data for a dredger which, when dumping, gave rise to high suspended sediment concentrations which persisted for a longer period of time. The calibrated model was then compered against field data from a dredger which gave rise to lower, shorter duration, suspended sediment concentrations and was shown to give a conservative simulation.

The two dredgers involved in the trial dumps spanned the range of dredgers operating in Hong Kong in terms of dredged material densities and by calibrating the model against the "worst" of these it may be used for future simulations with confidence that the model will not under-predict the impacts.

Annex D

Dry Season Water Quality Modelling Results



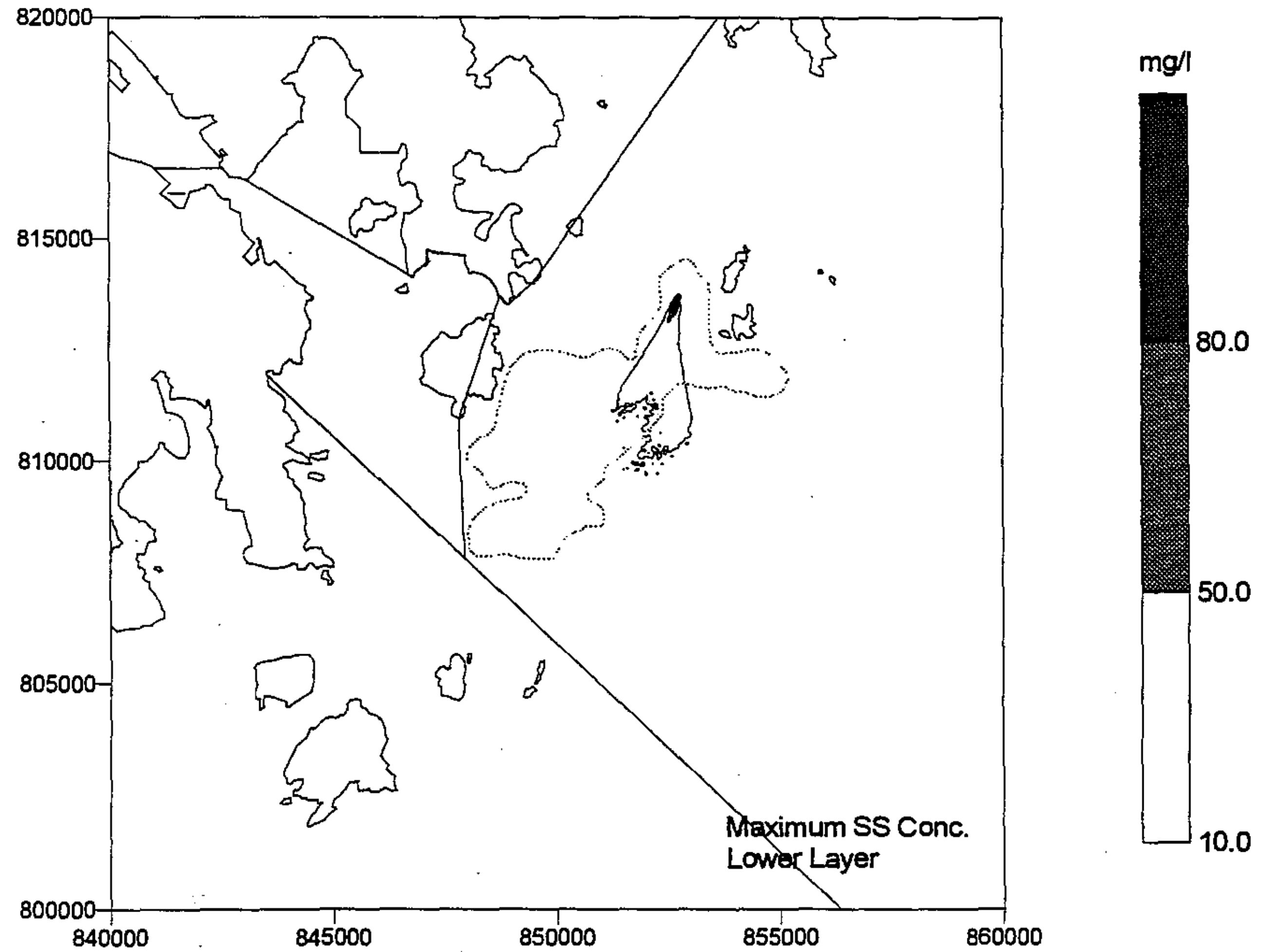


FIGURE D1 - SCENARIO 1: PREDICTED MAXIMUM SUSPENDED SEDIMENT CONCENTRATIONS

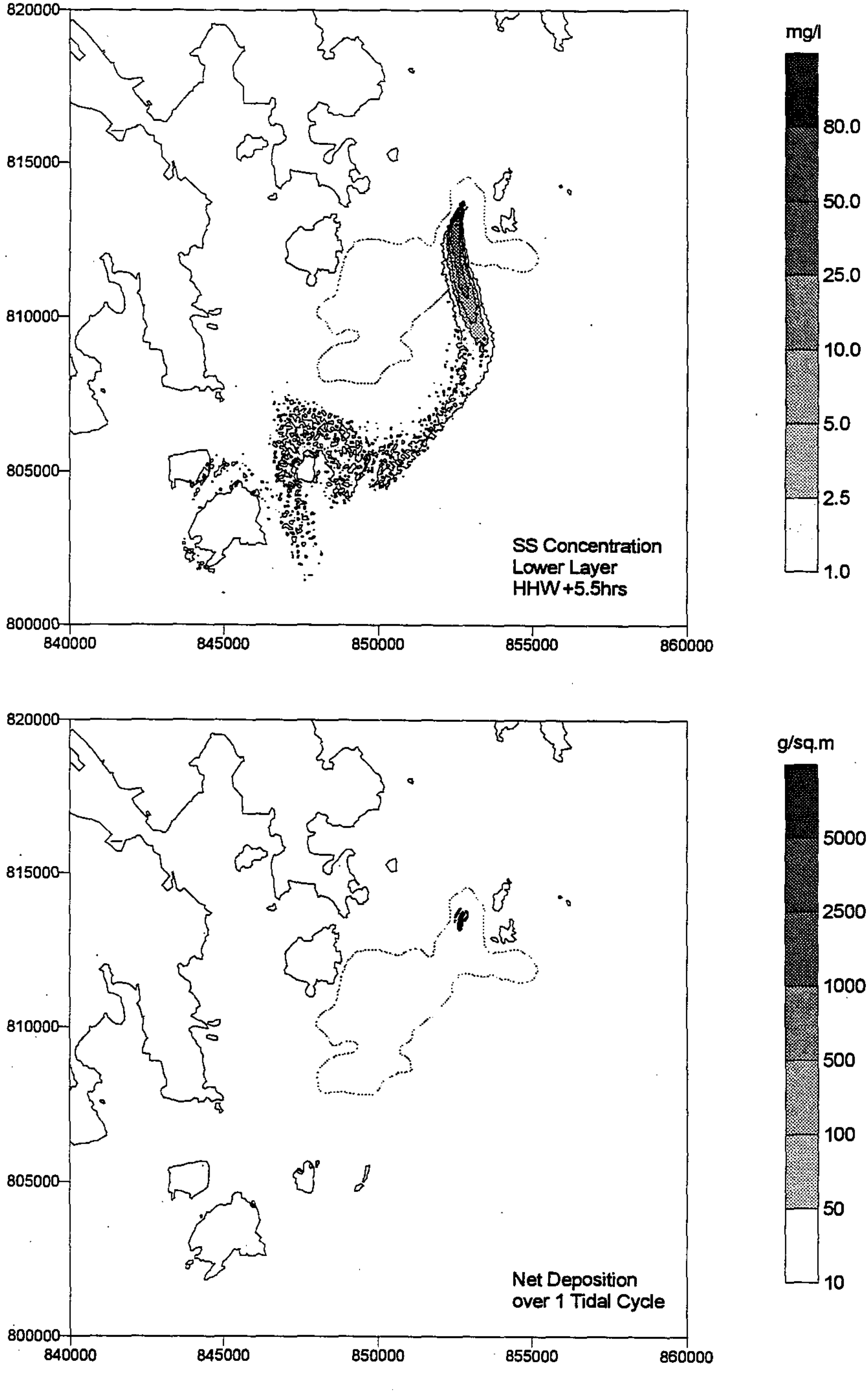


FIGURE D2 - SCENARIO 1: PREDICTED SEDIMENT TRANSPORT AND DEPOSITION

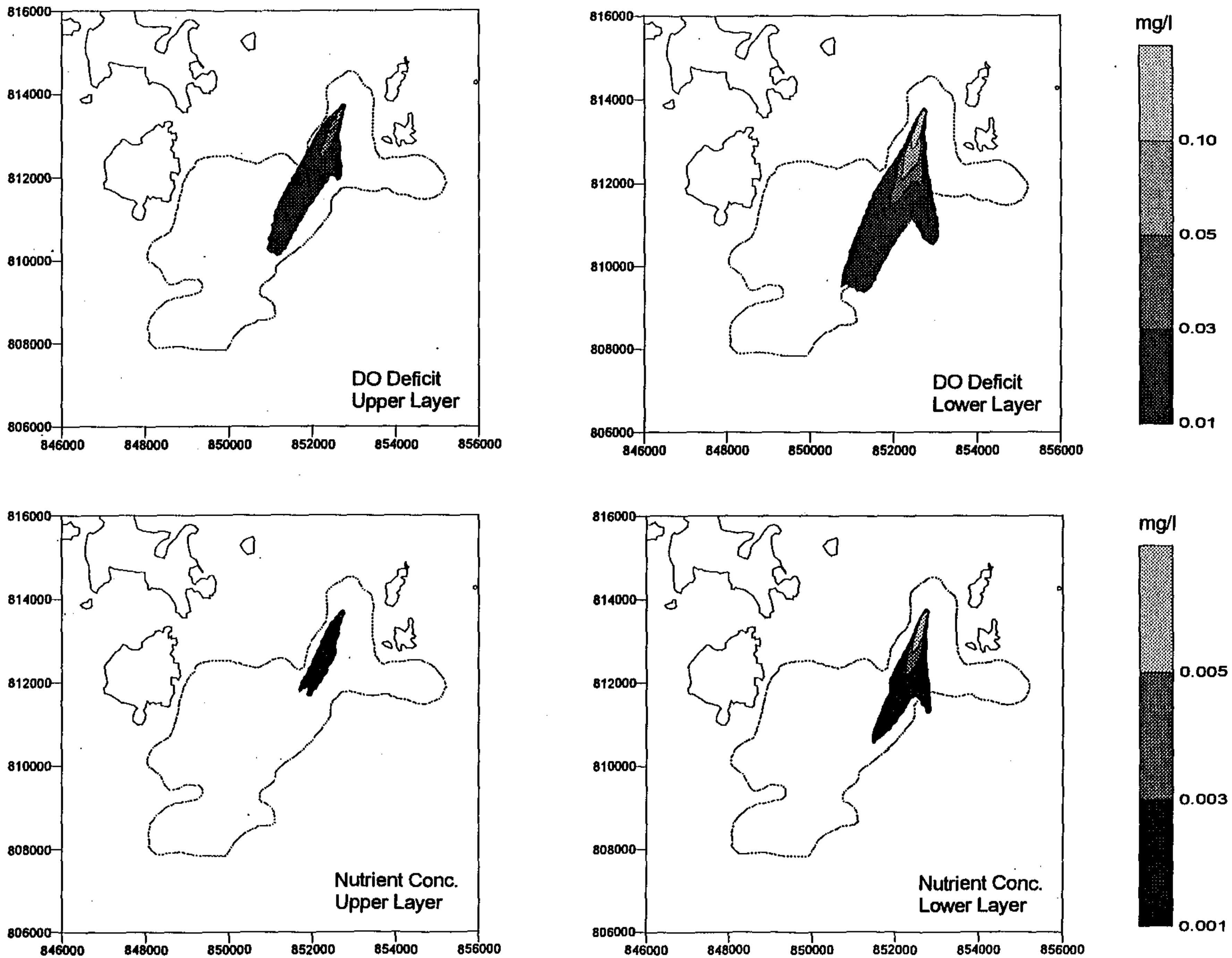


FIGURE D3 - SCENARIO 1: PREDICTED DO DEPLETION AND NUTRIENT ELEVATION

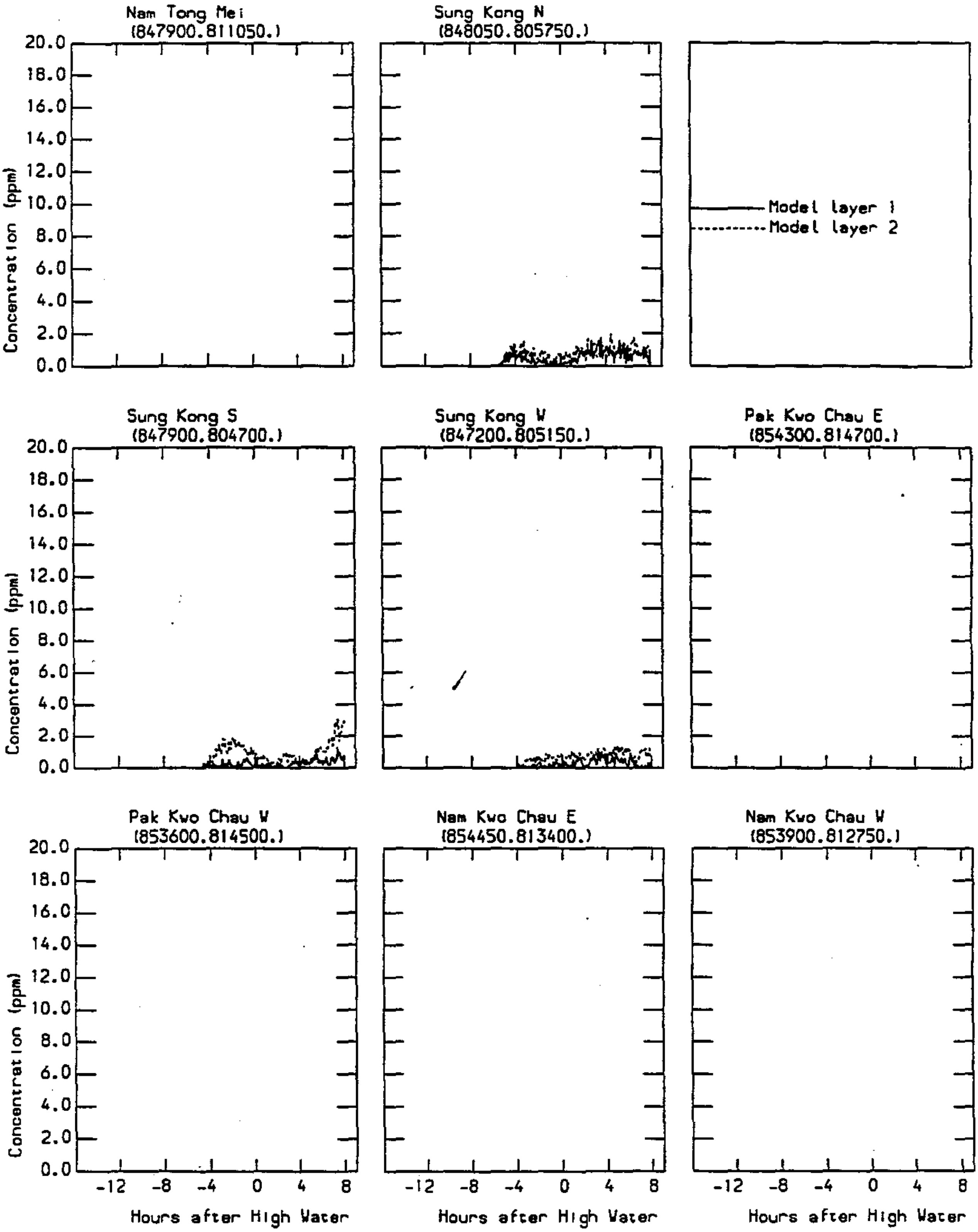


FIGURE D4 - SCENARIO 1: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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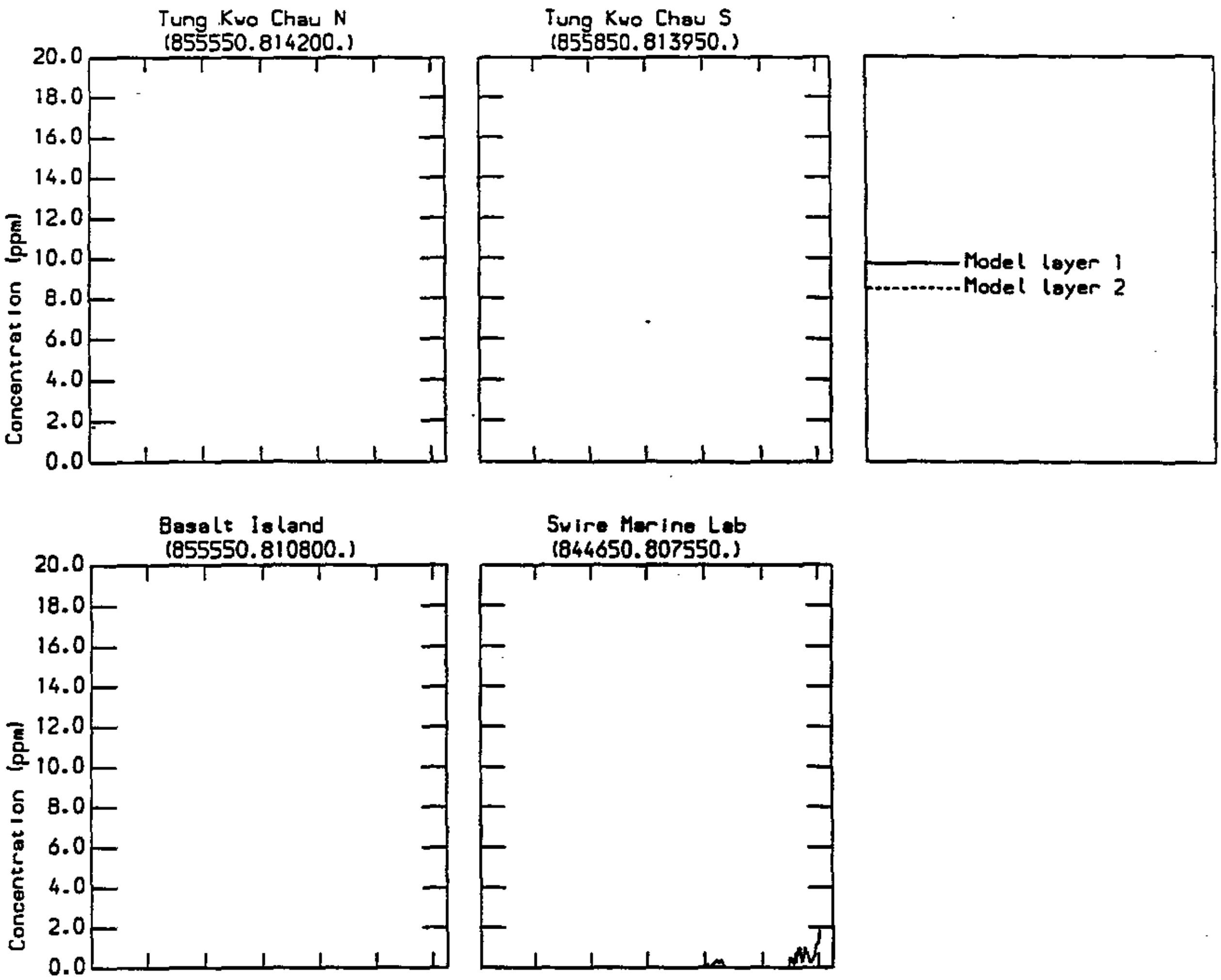

FIGURE D5 - SCENARIO 1: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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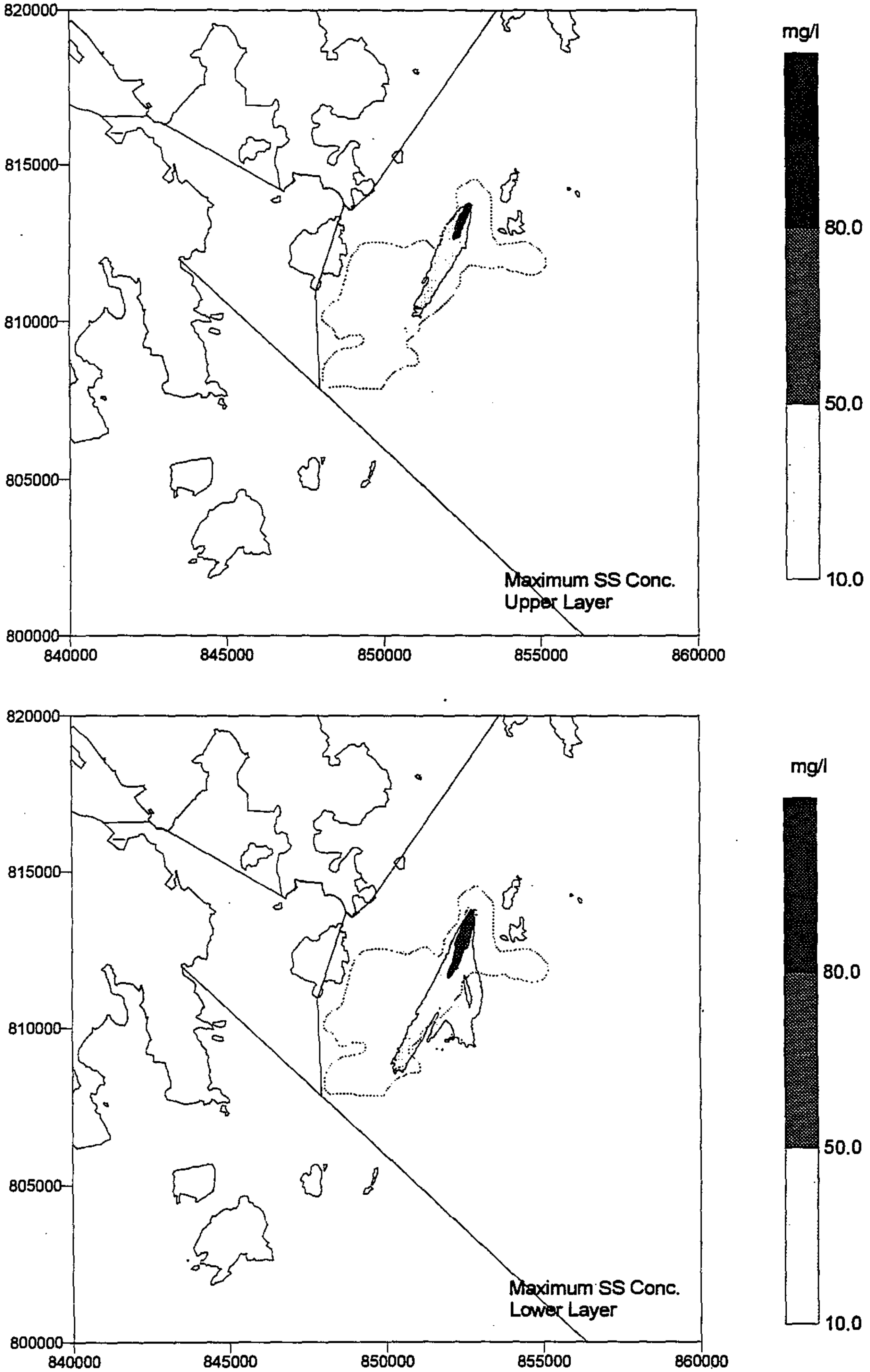
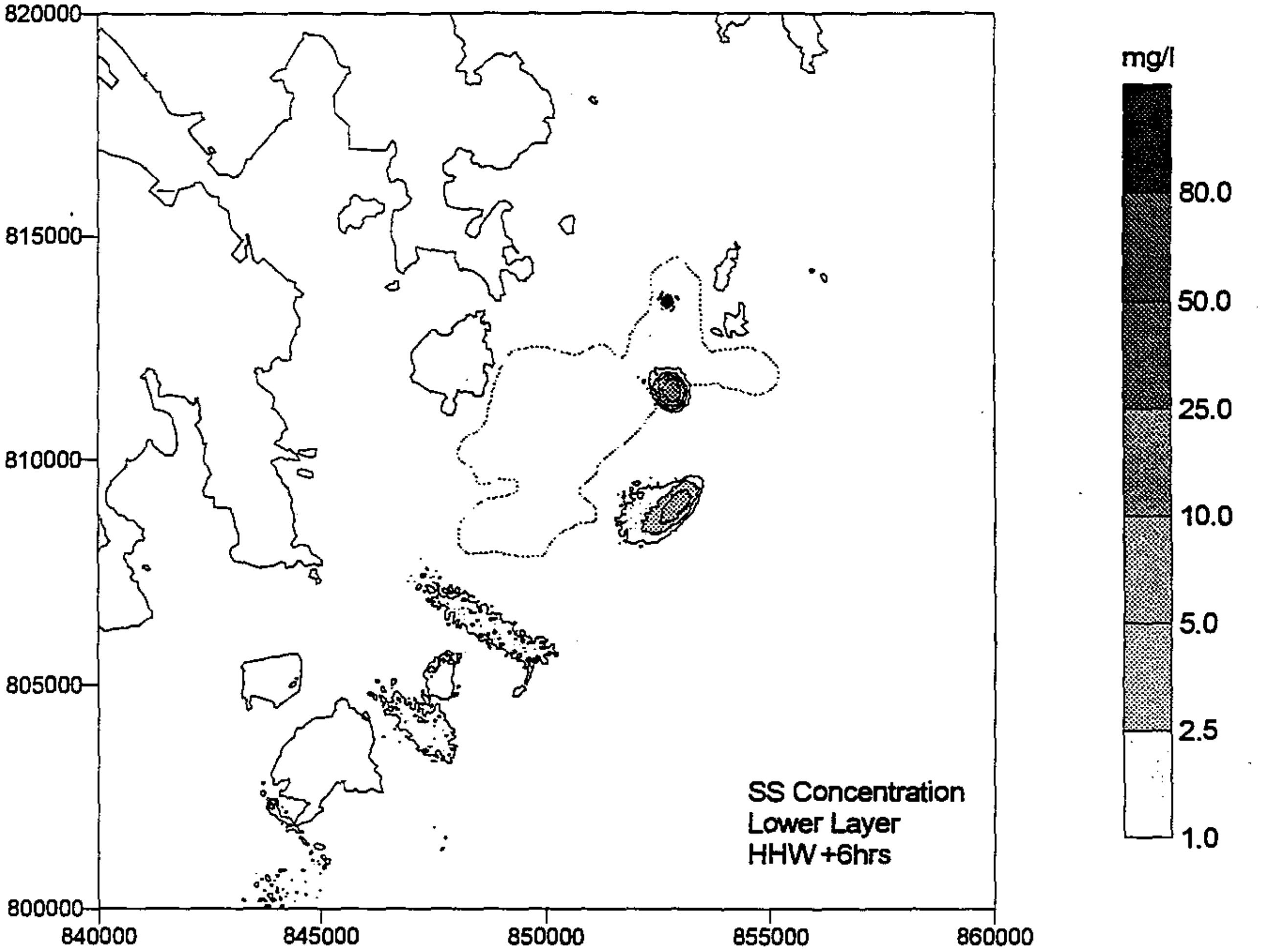


FIGURE D6 - SCENARIO 2: PREDICTED MAXIMUM SUSPENDED SEDIMENT CONCENTRATION



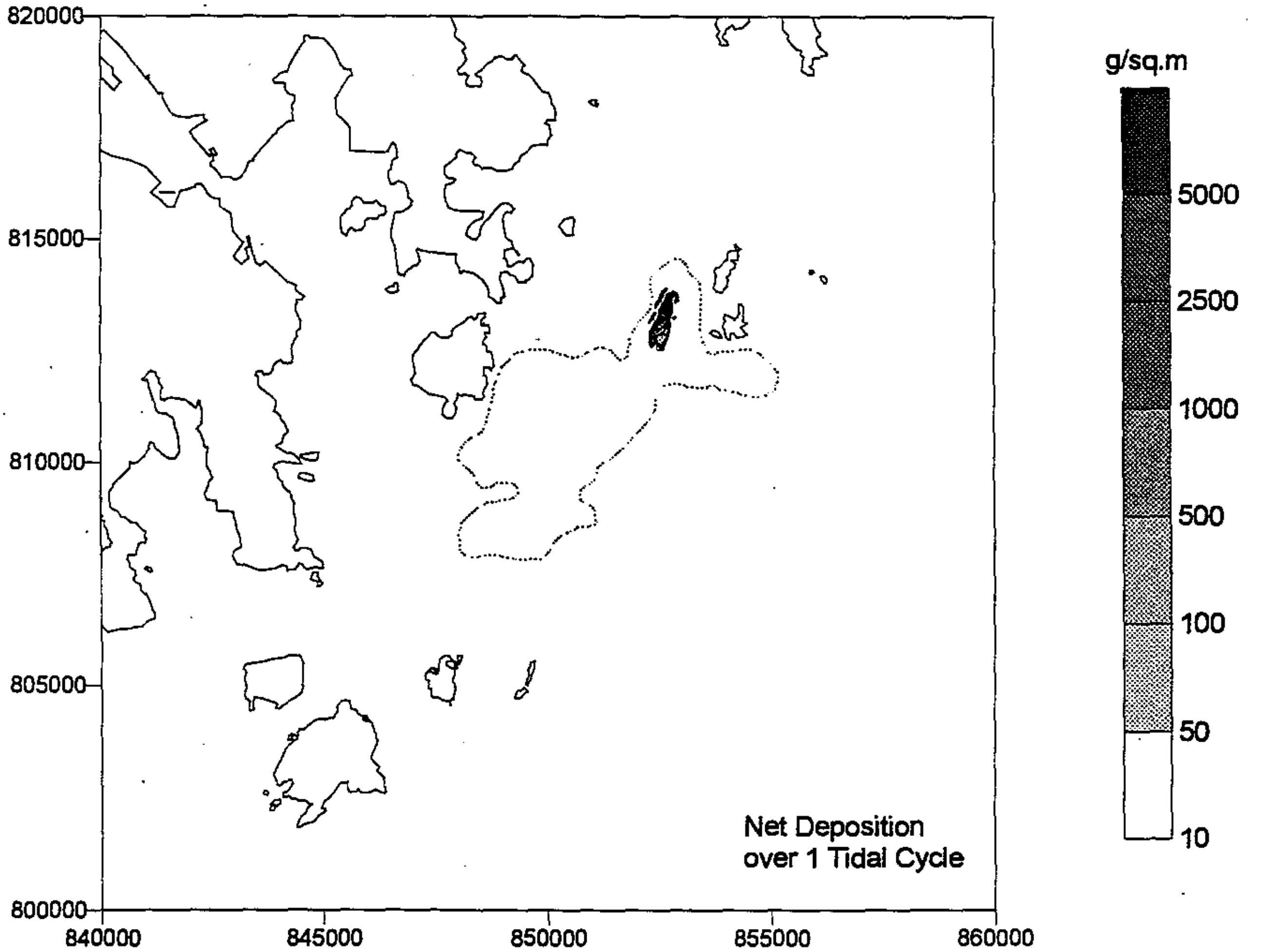


FIGURE D7 - SCENARIO 2: PREDICTED SEDIMENT TRANSPORT AND DEPOSITION

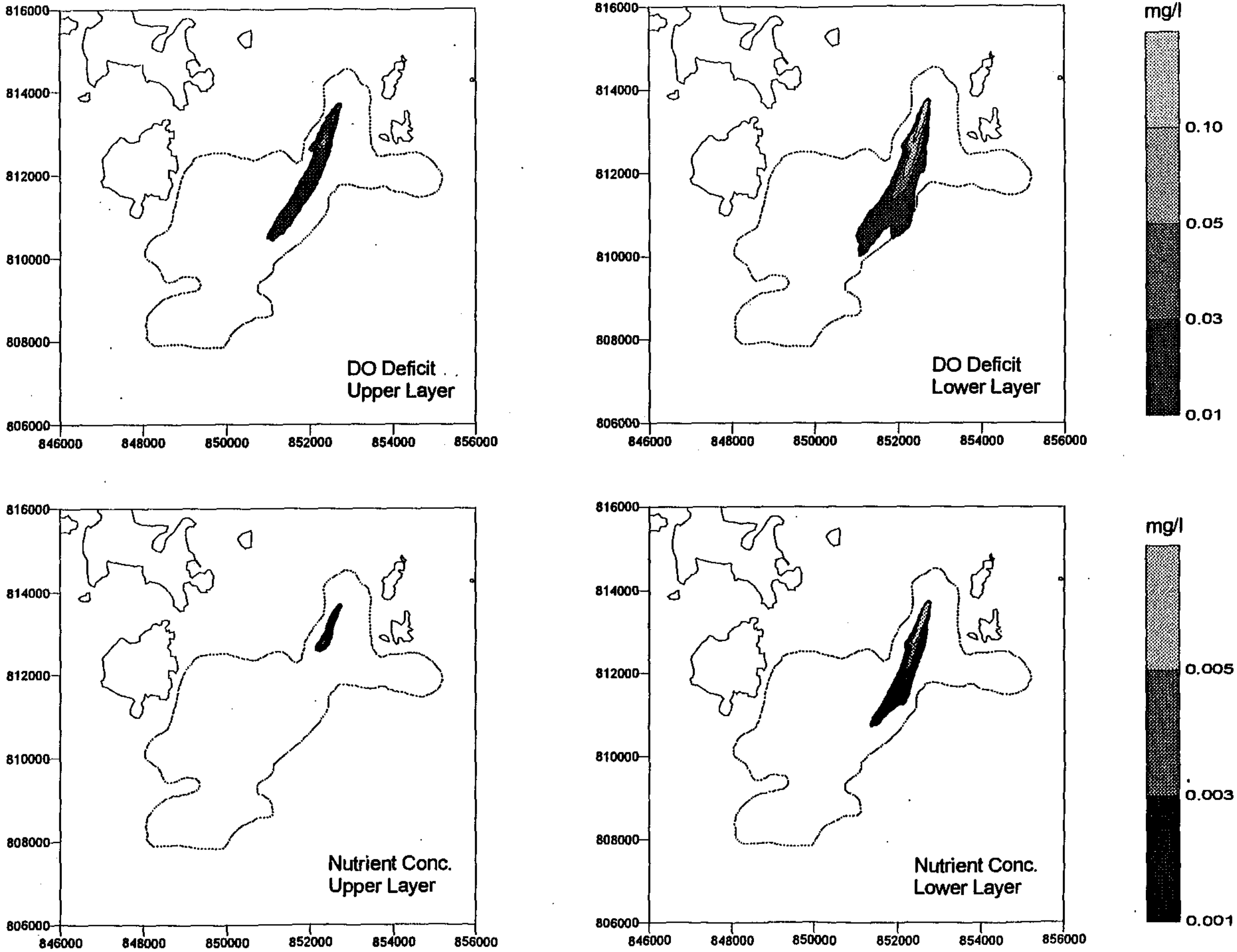


FIGURE D8 - SCENARIO 2: PREDICTED DO DEPLETION AND NUTRIENT ELEVATION

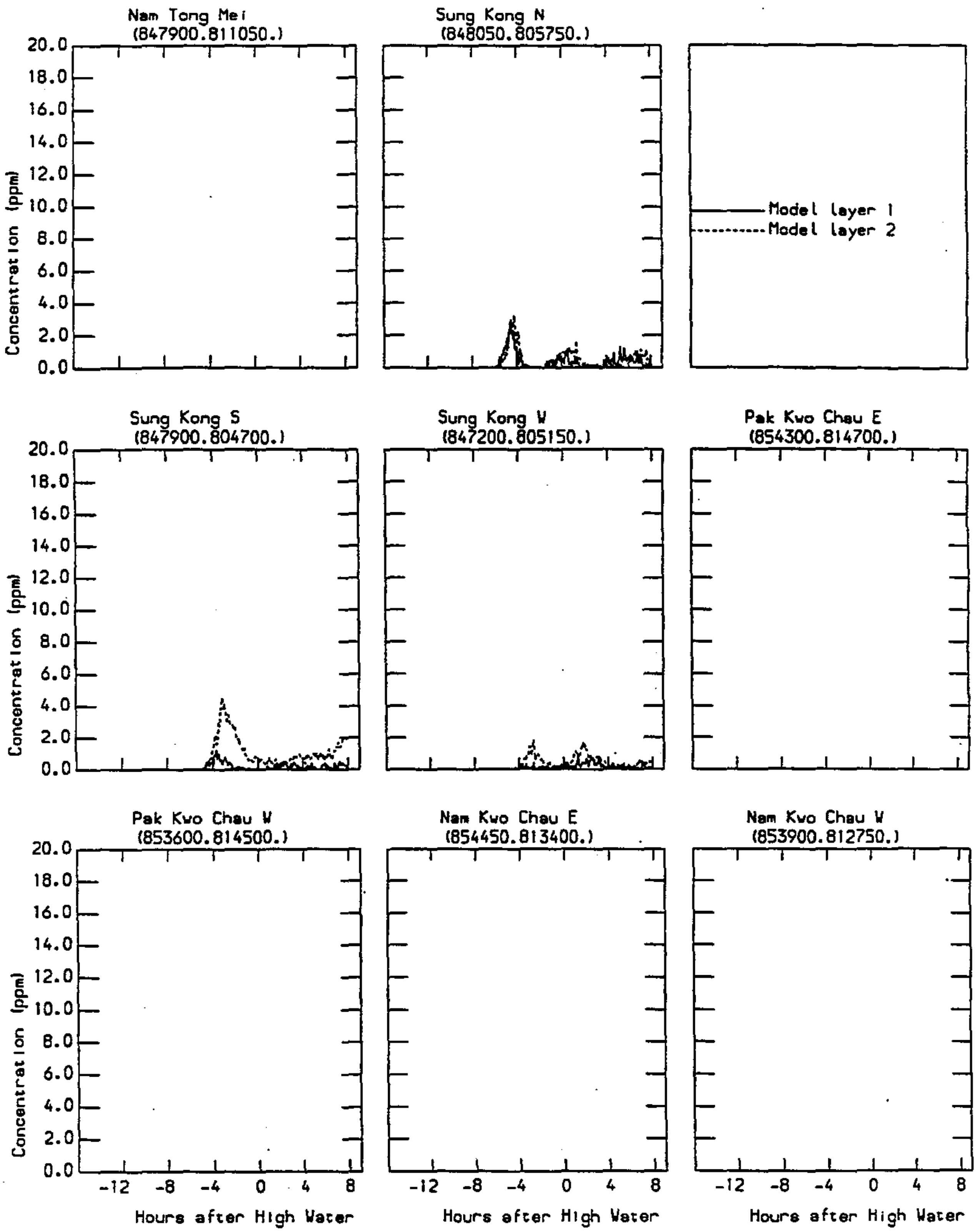


FIGURE D9 - SCENARIO 2: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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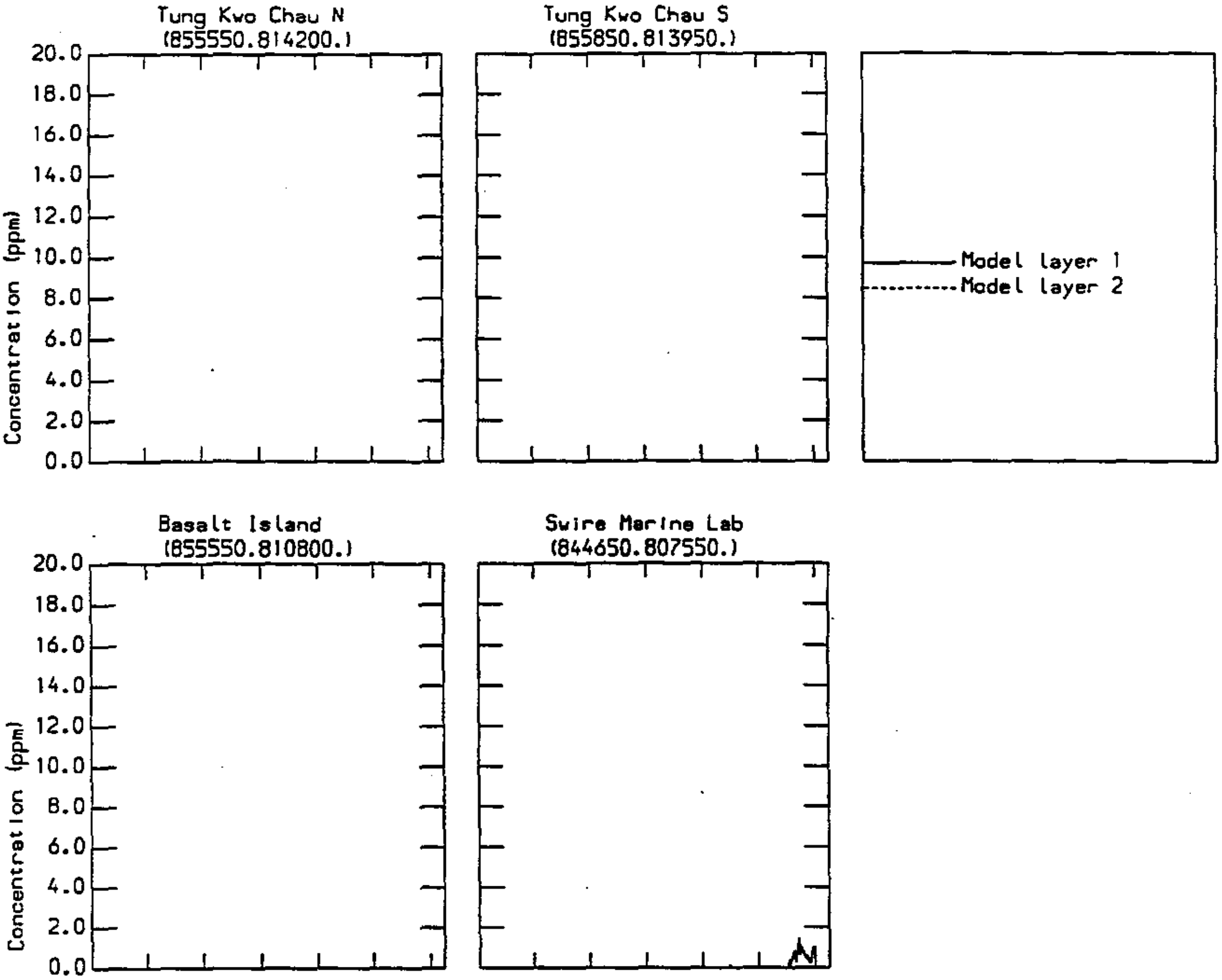

FIGURE D10 - SCENARIO 2: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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Hong Kong

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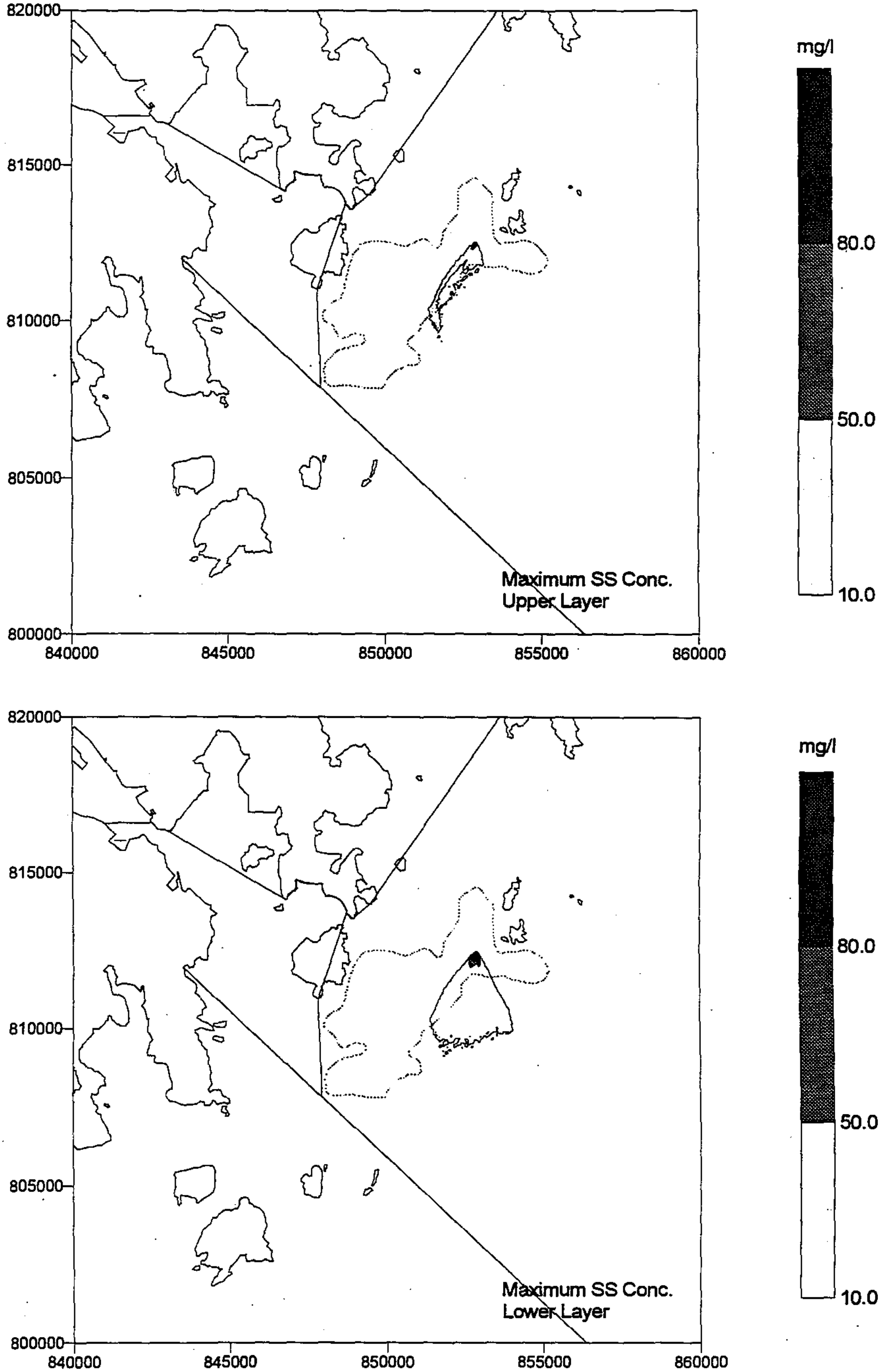
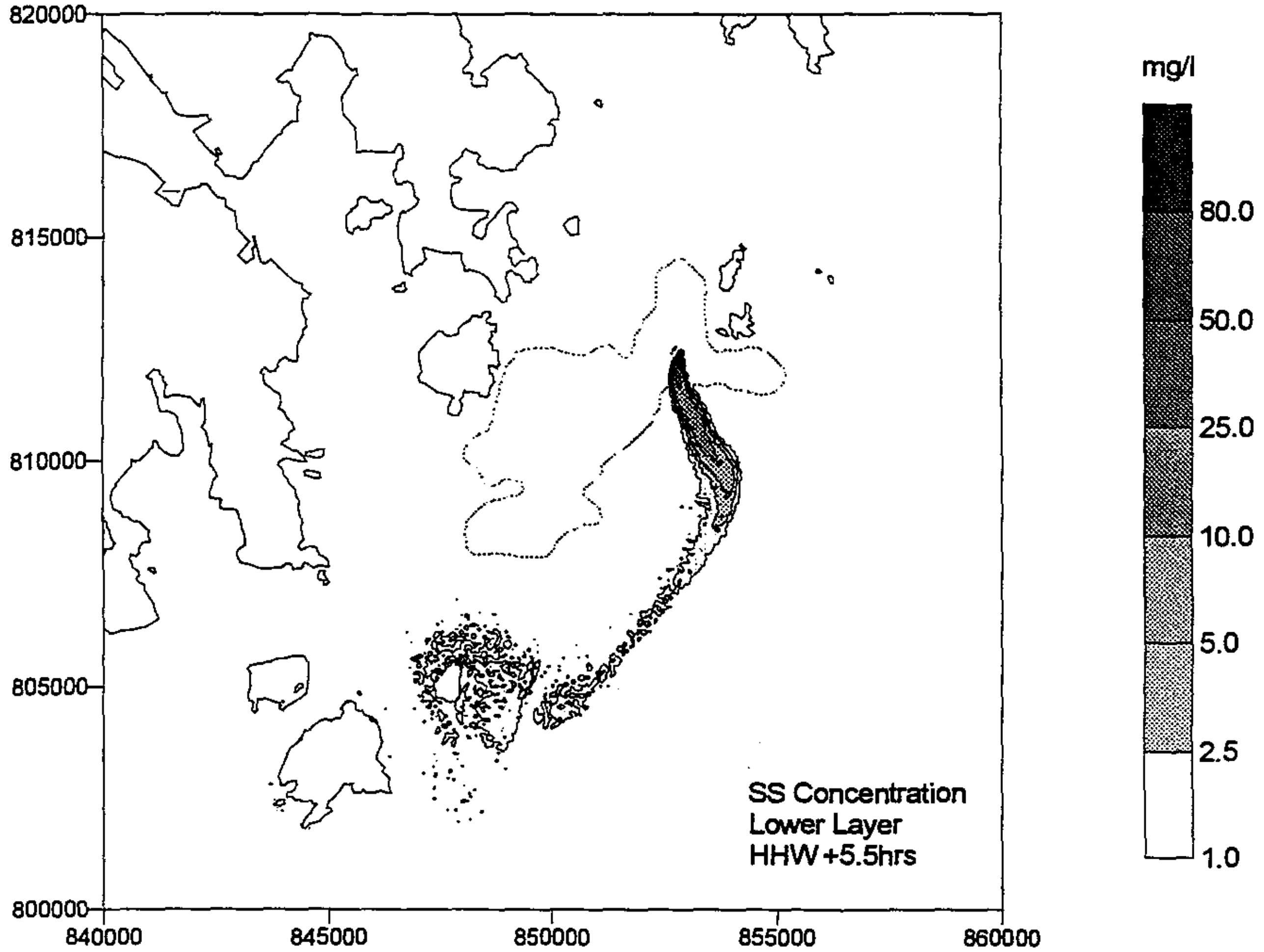


FIGURE D11 - SCENARIO 3: PREDICTED MAXIMUM SUSPENDED SEDIMENT CONCENTRATION



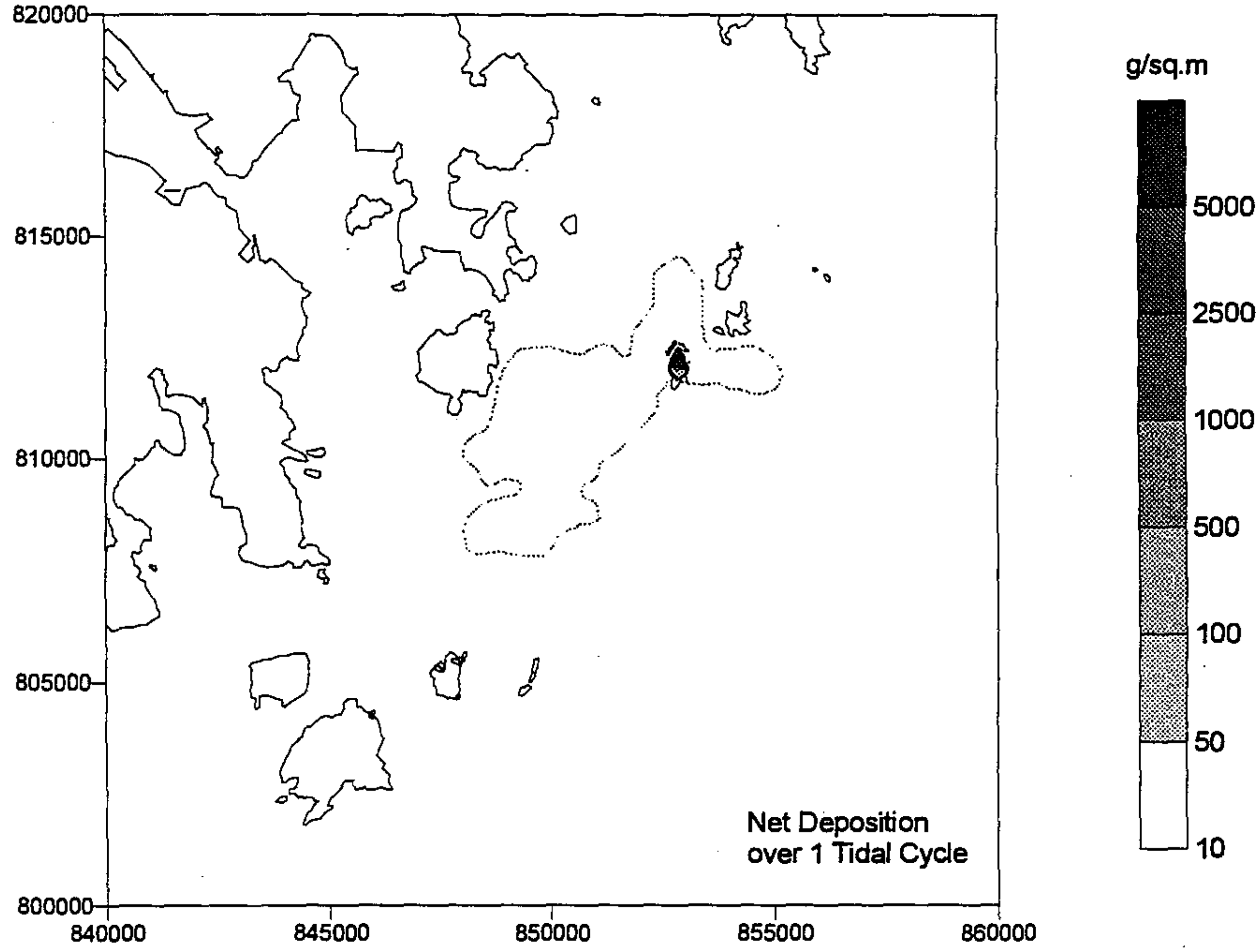
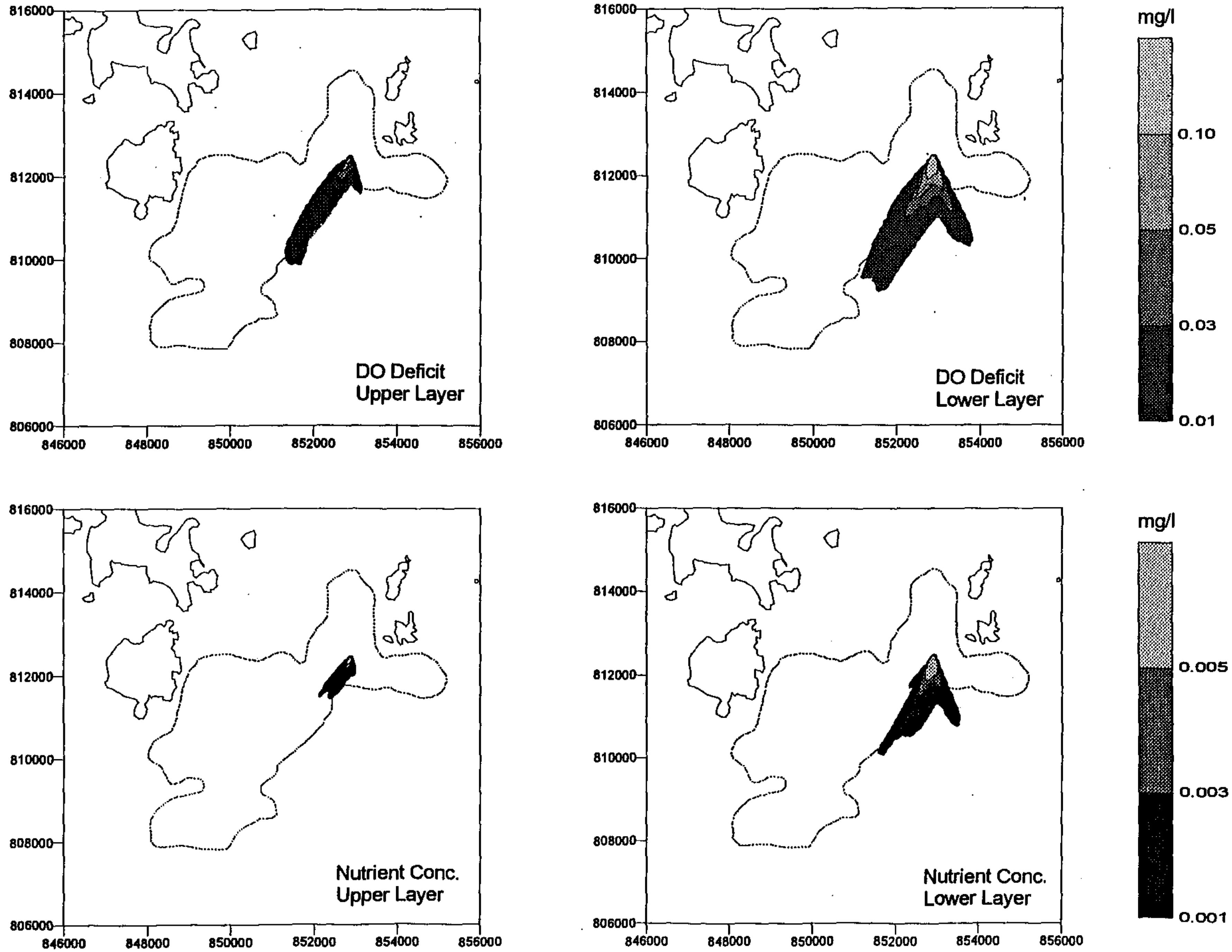


FIGURE D12 - SCENARIO 3: PREDICTED SEDIMENT TRANSPORT AND DEPOSITION

FIGURE D13 - SCENARIO 3: PREDICTED DO DEPLETION AND NUTRIENT ELEVATION



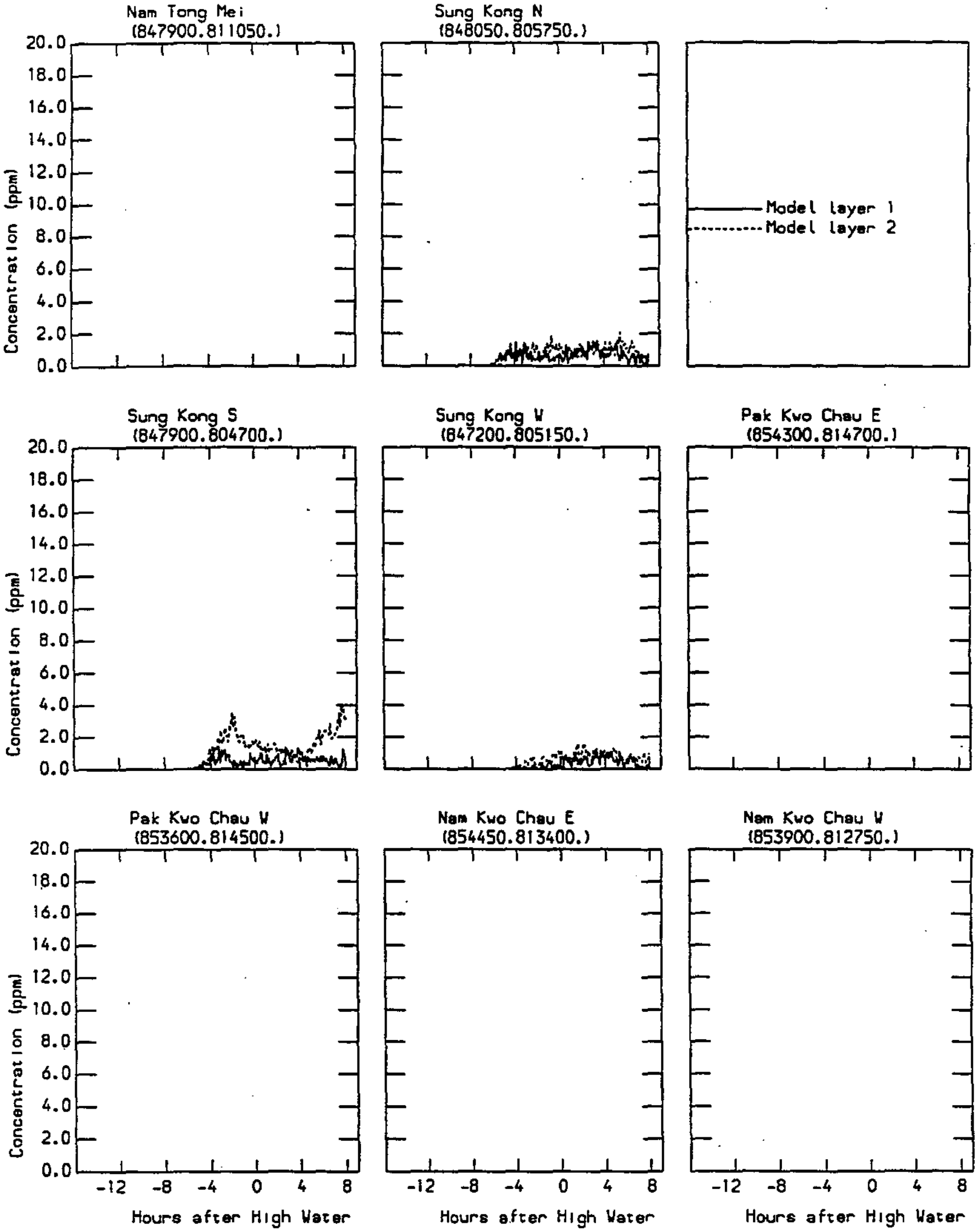


FIGURE D14 - SCENARIO 3: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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Hong Kong

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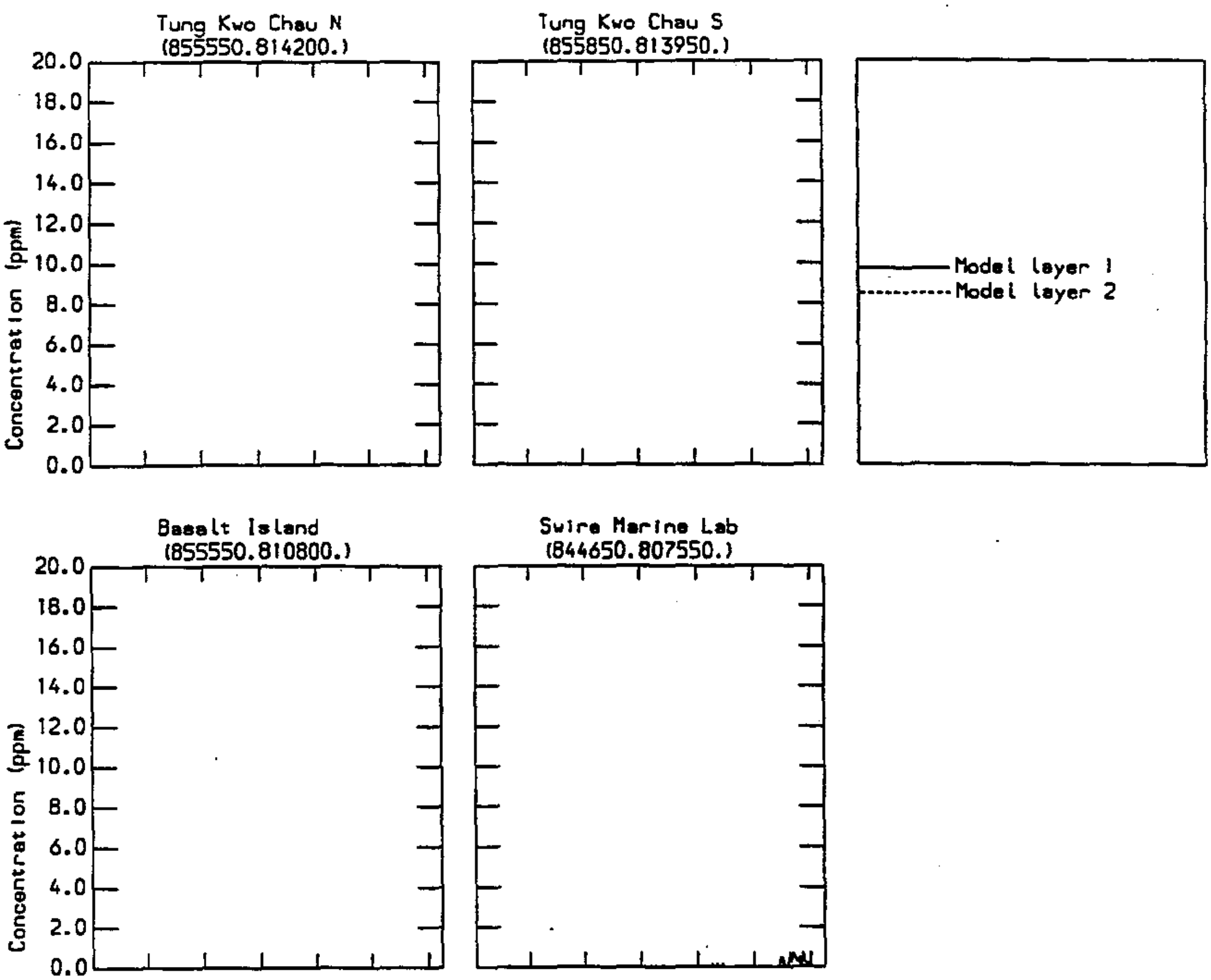

FIGURE D15 - SCENARIO 3: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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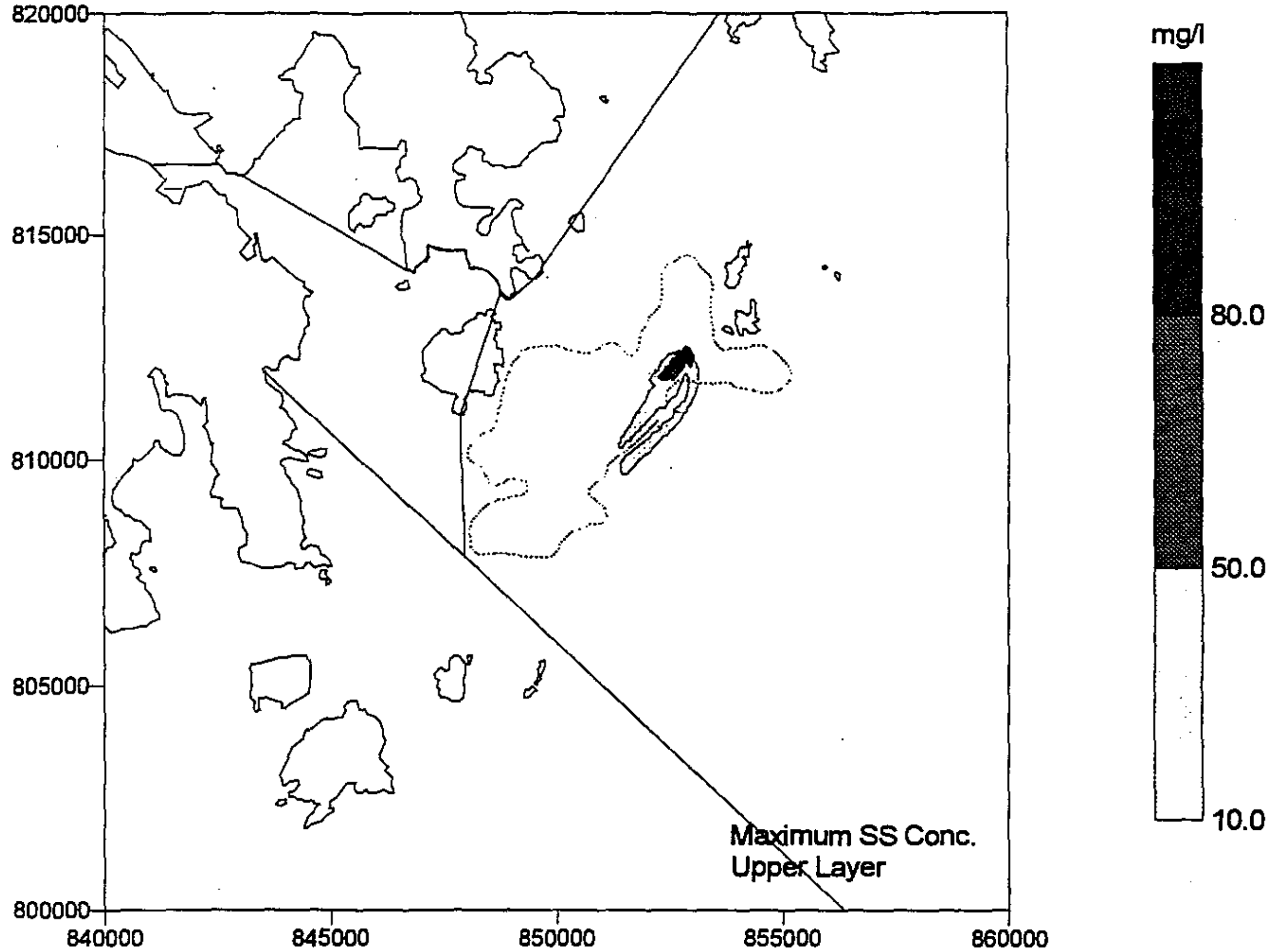
Hong Kong



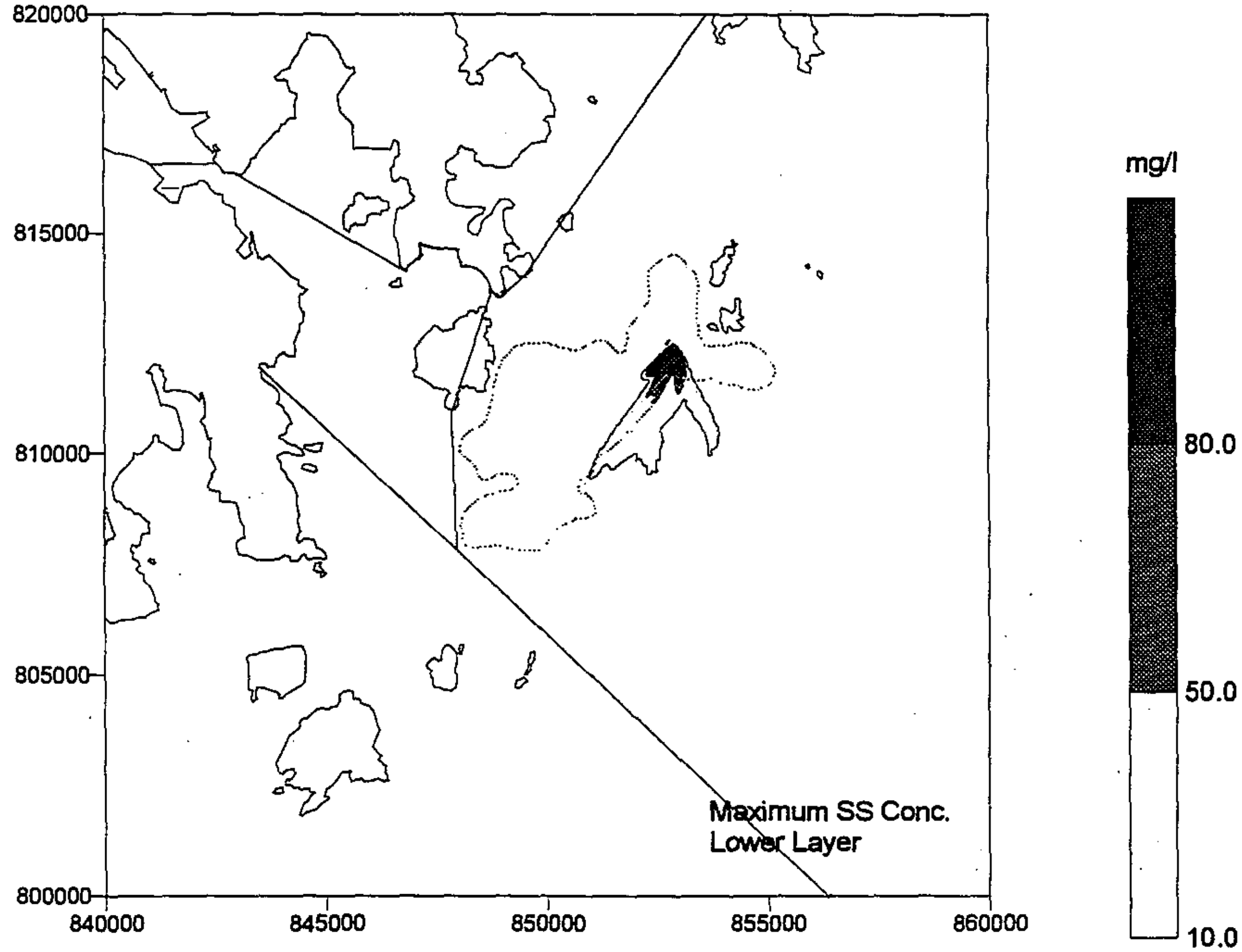
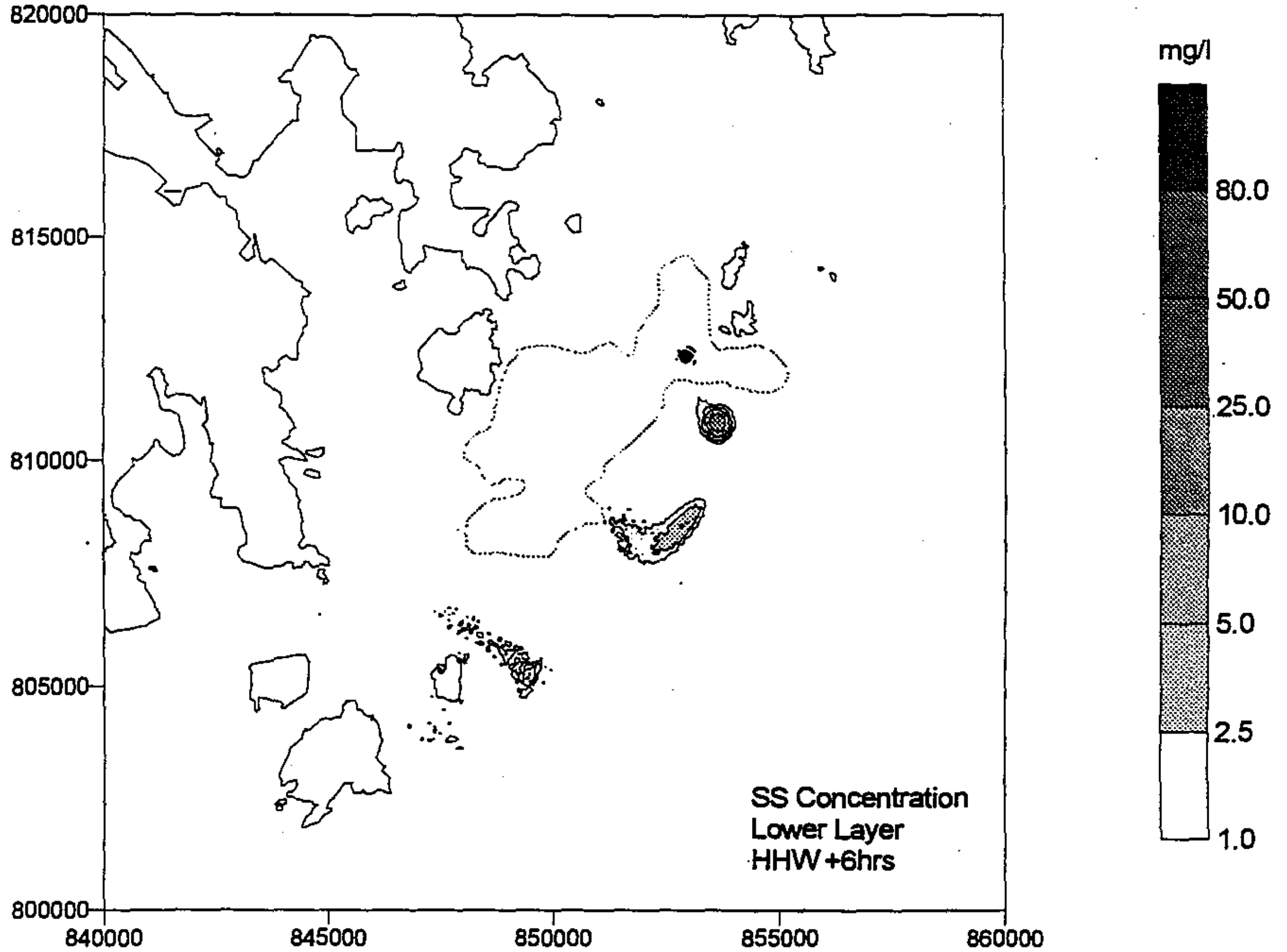


FIGURE D16 - SCENARIO 4: PREDICTED MAXIMUM SUSPENDED SEDIMENT CONCENTRATION



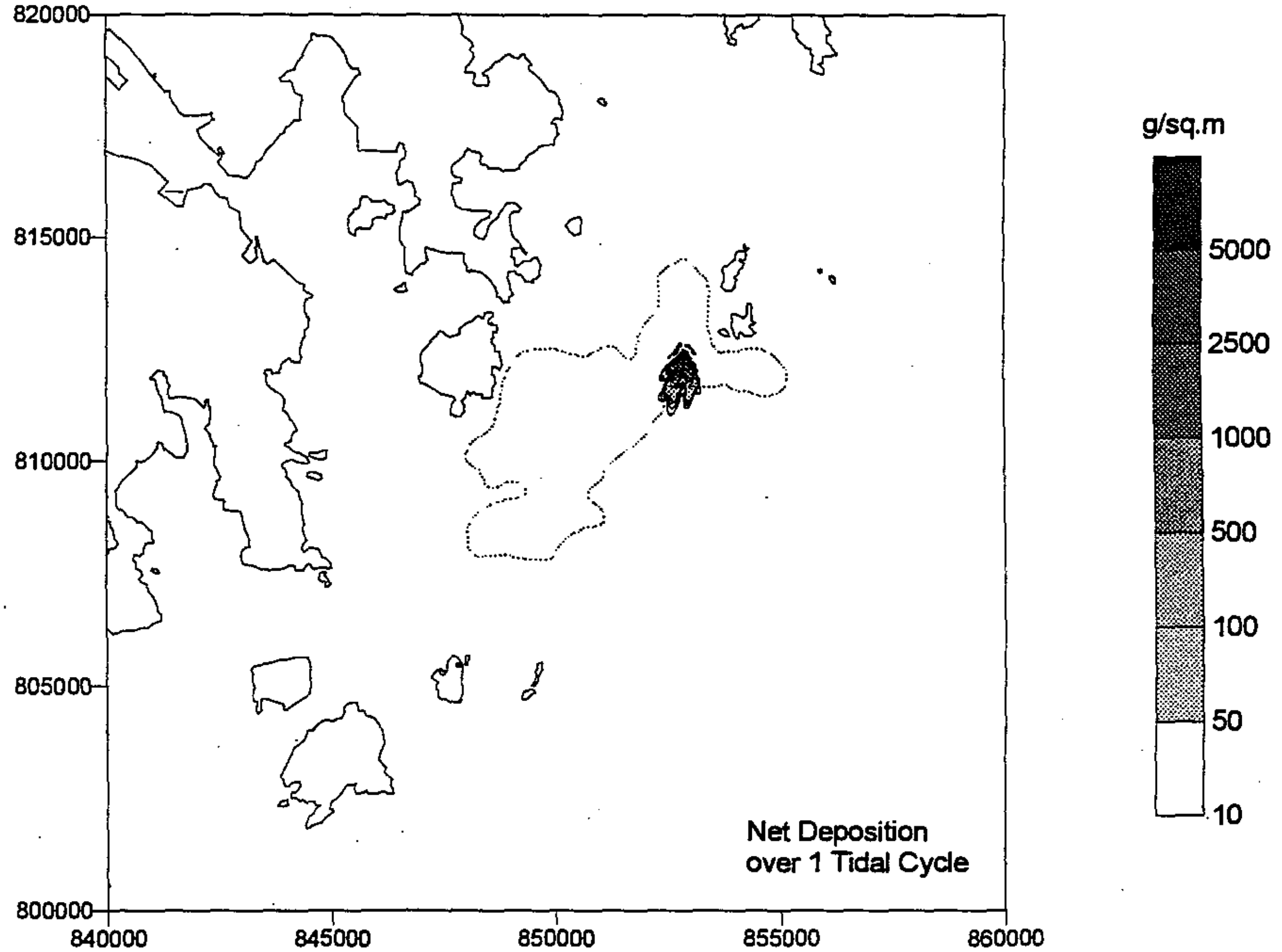


FIGURE D17 - SCENARIO 4: PREDICTED SEDIMENT TRANSPORT AND DEPOSITION

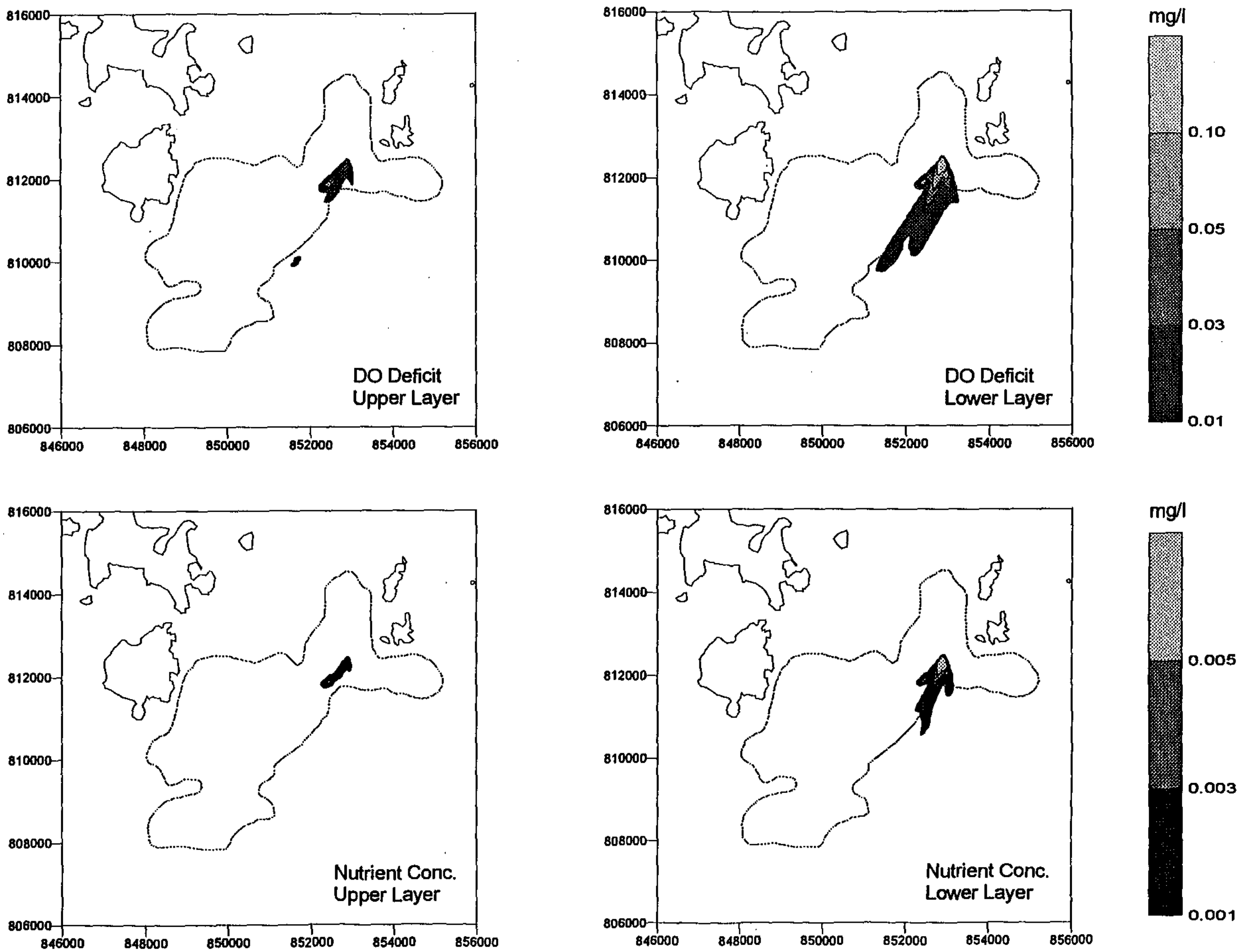


FIGURE D18 - SCENARIO 4: PREDICTED DO DEPLETION AND NUTRIENT ELEVATION

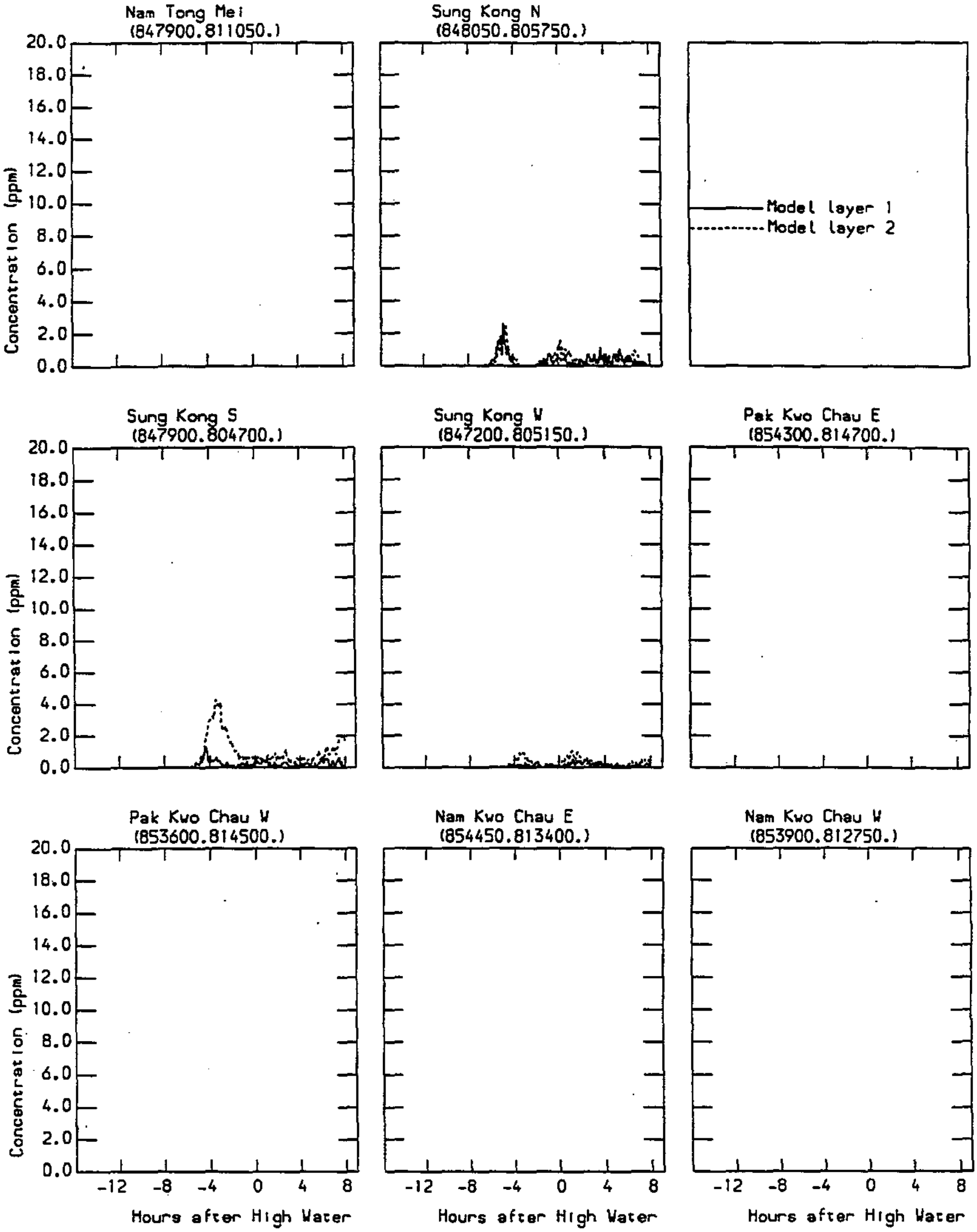


FIGURE D19 - SCENARIO 4: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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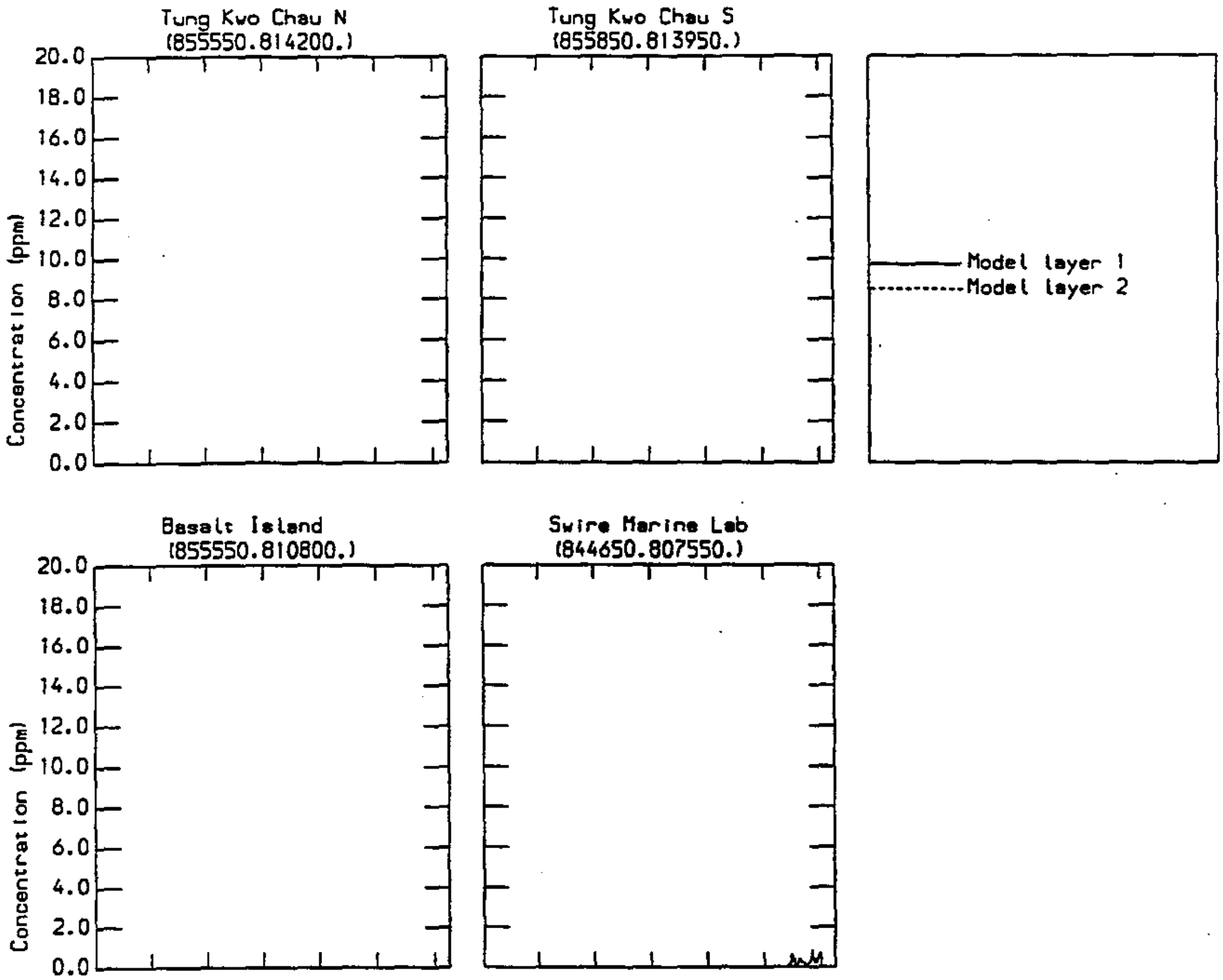

FIGURE D20 - SCENARIO 4: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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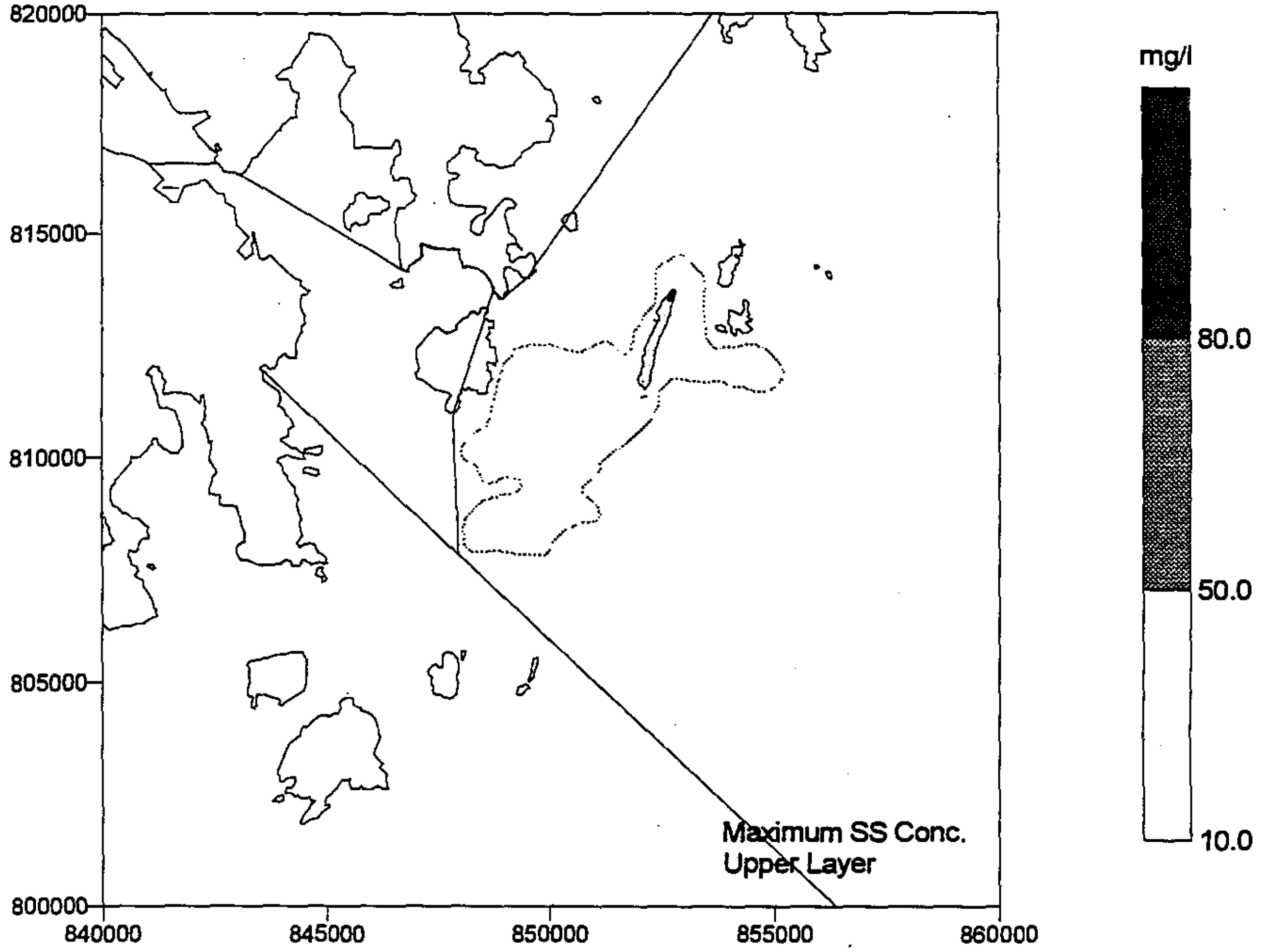


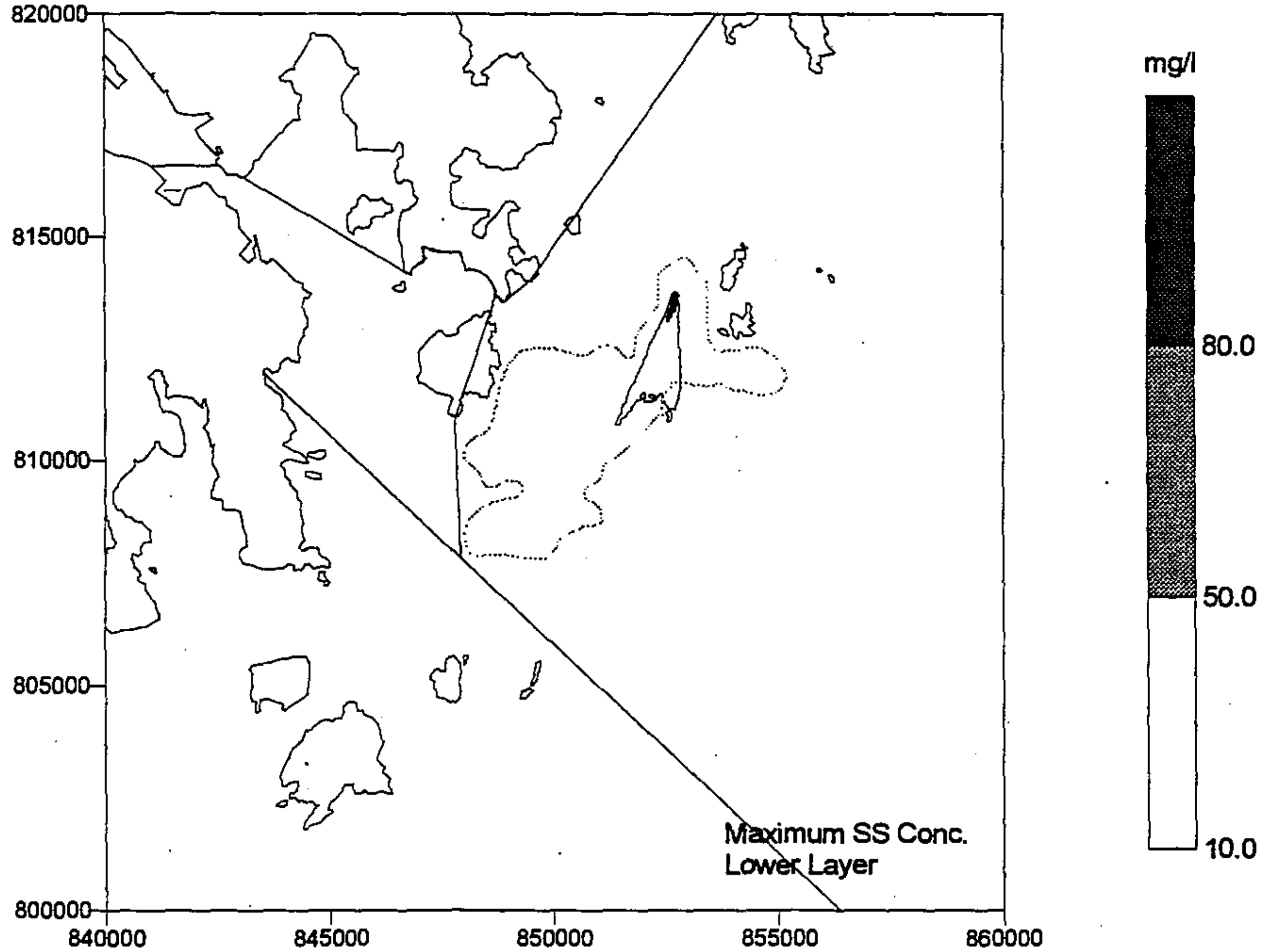


FIGURE D21 - SCENARIO 8: PREDICTED MAXIMUM SUSPENDED SEDIMENT CONCENTRATION

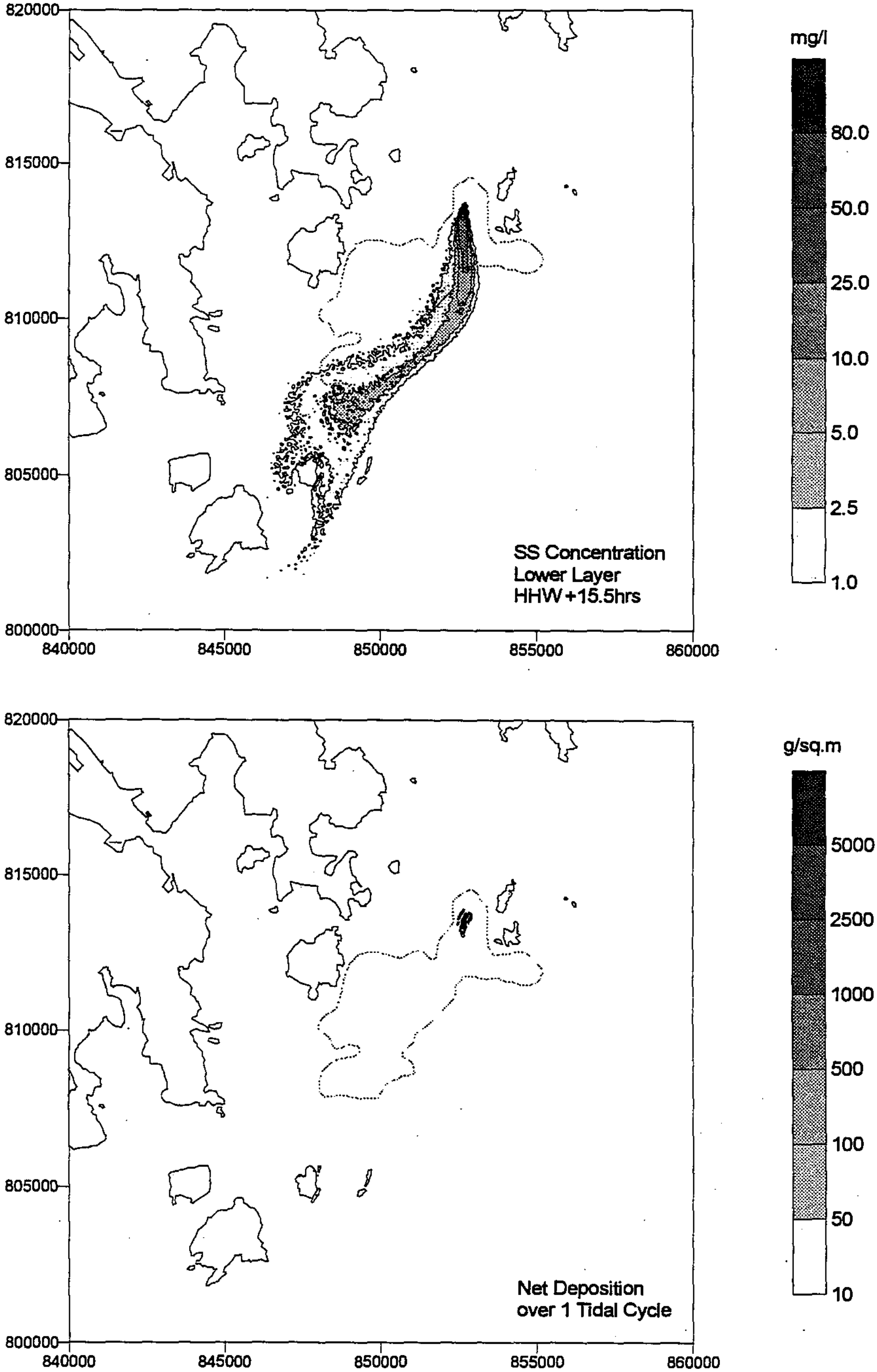
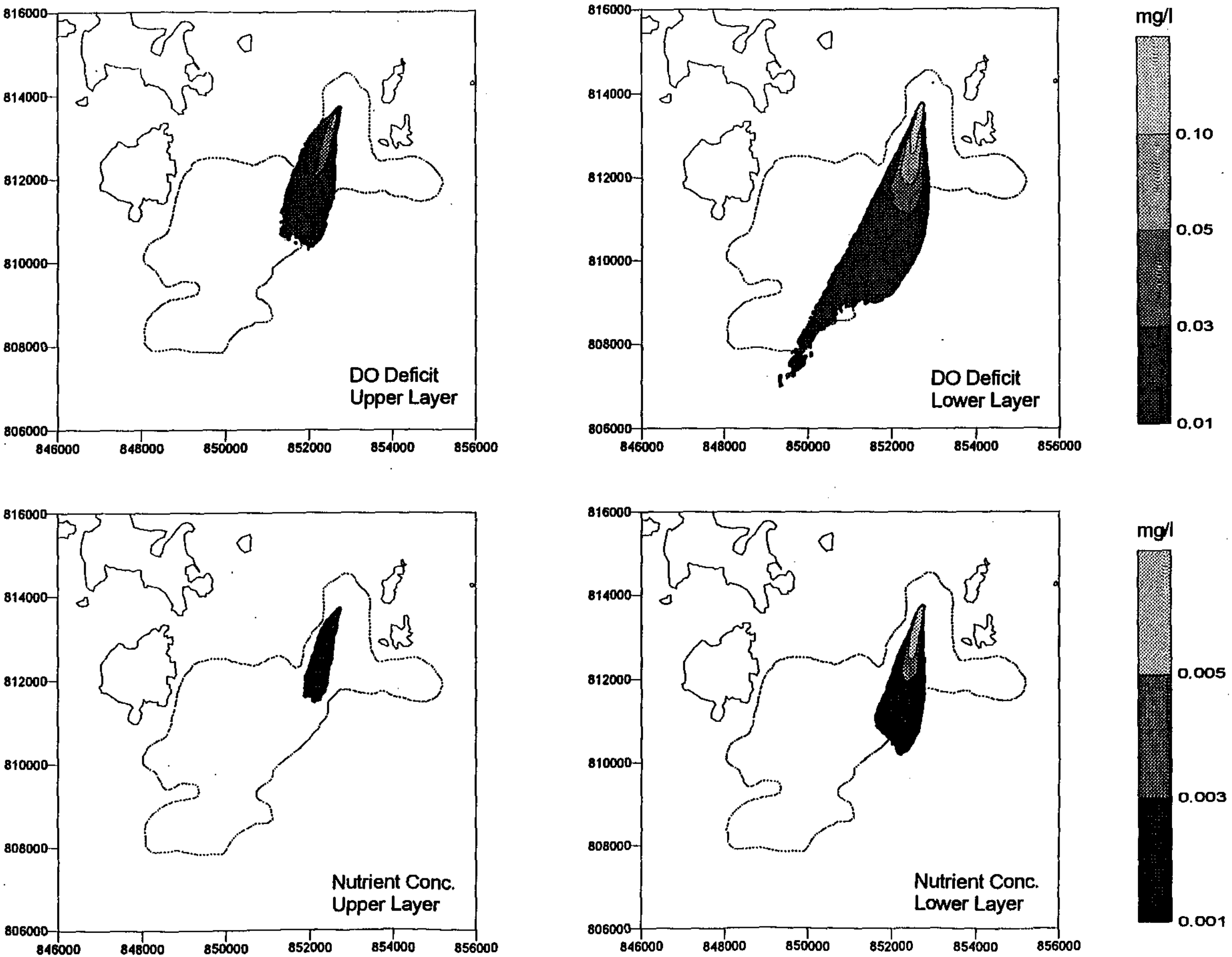


FIGURE D22 - SCENARIO 8: PREDICTED SEDIMENT TRANSPORT AND DEPOSITION

FIGURE D23 - SCENARIO 8: PREDICTED DO DEPLETION AND NUTRIENT ELEVATION



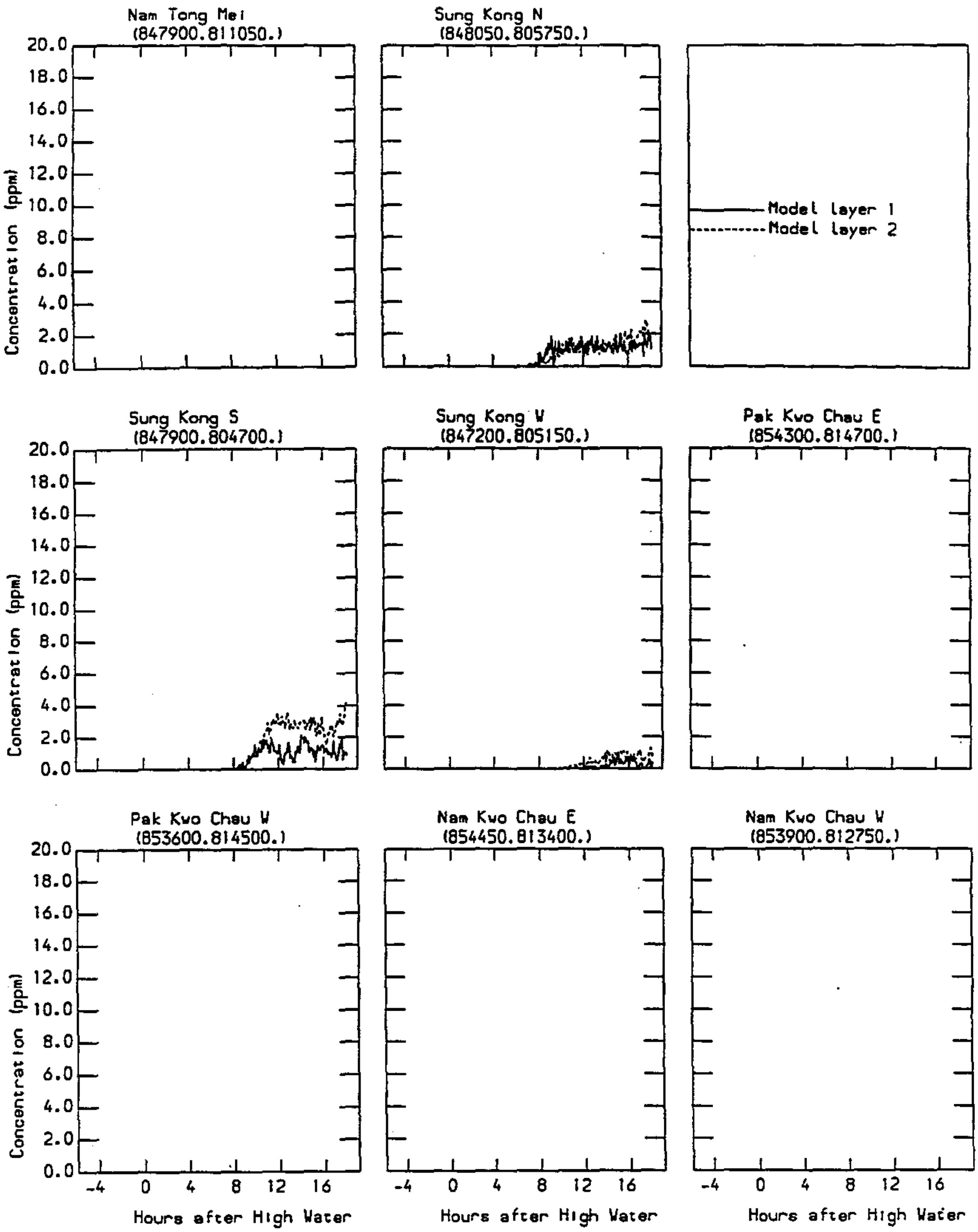


FIGURE D24 - SCENARIO 8: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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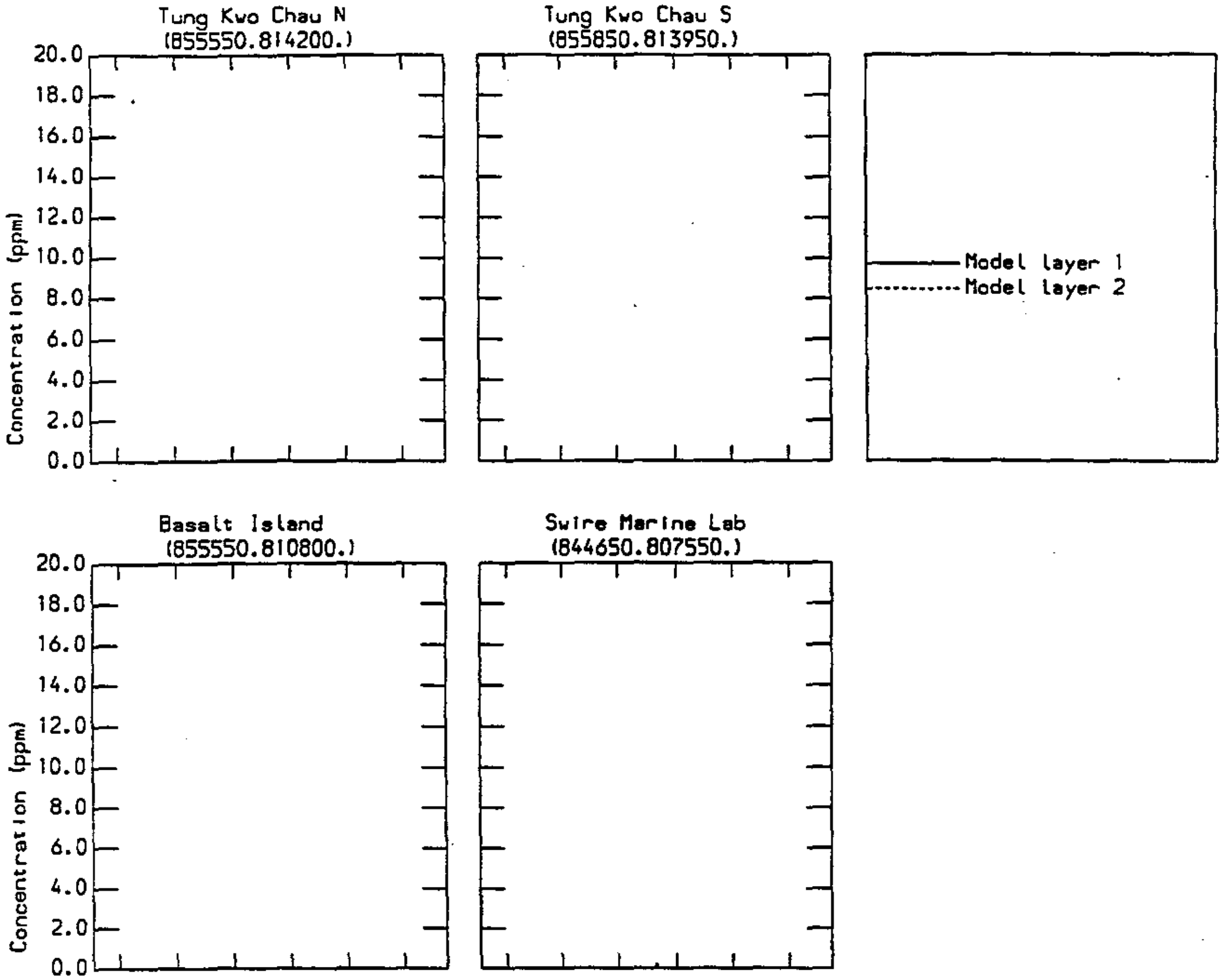

FIGURE D25 - SCENARIO 8: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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Hong Kong

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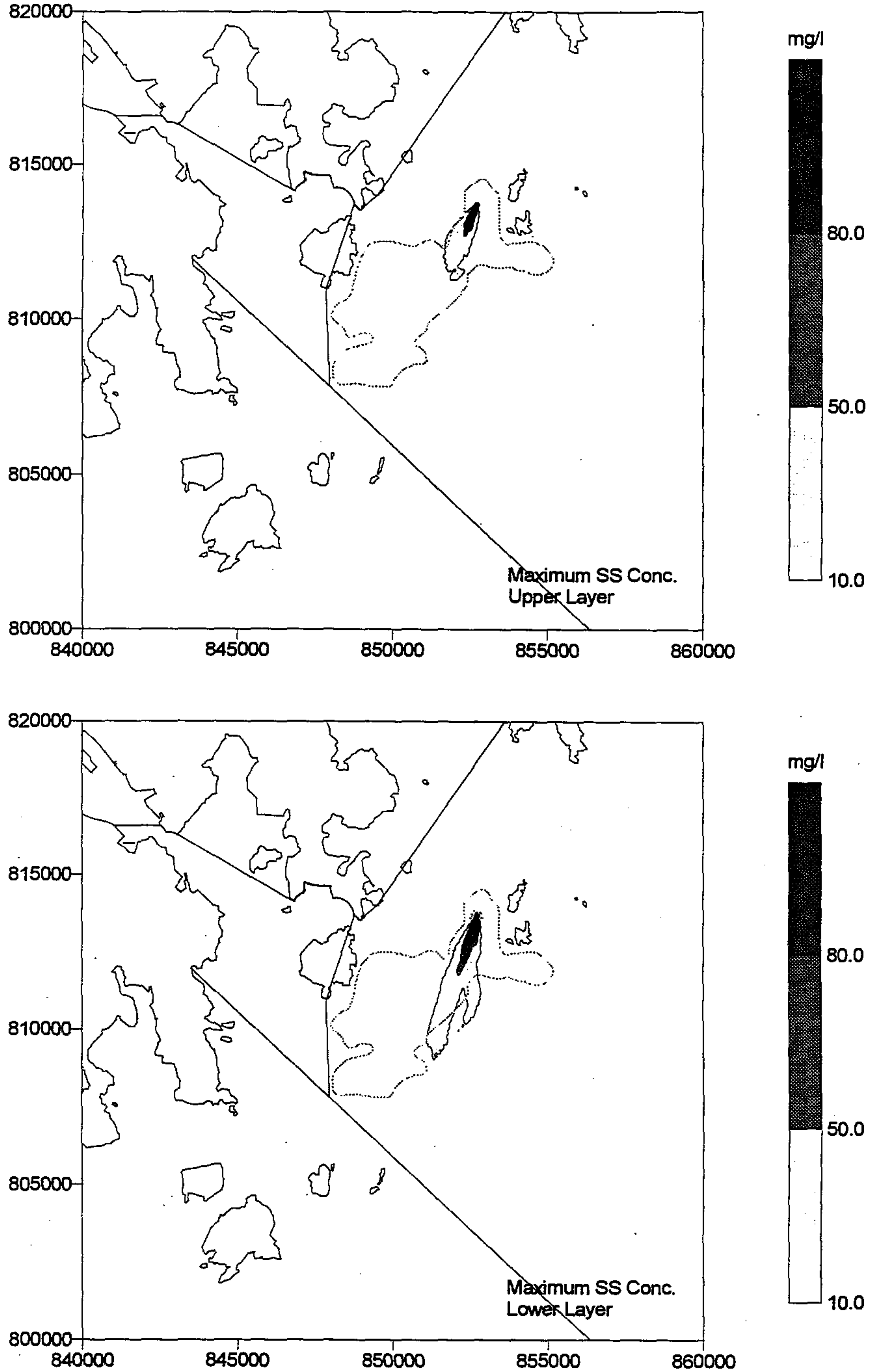
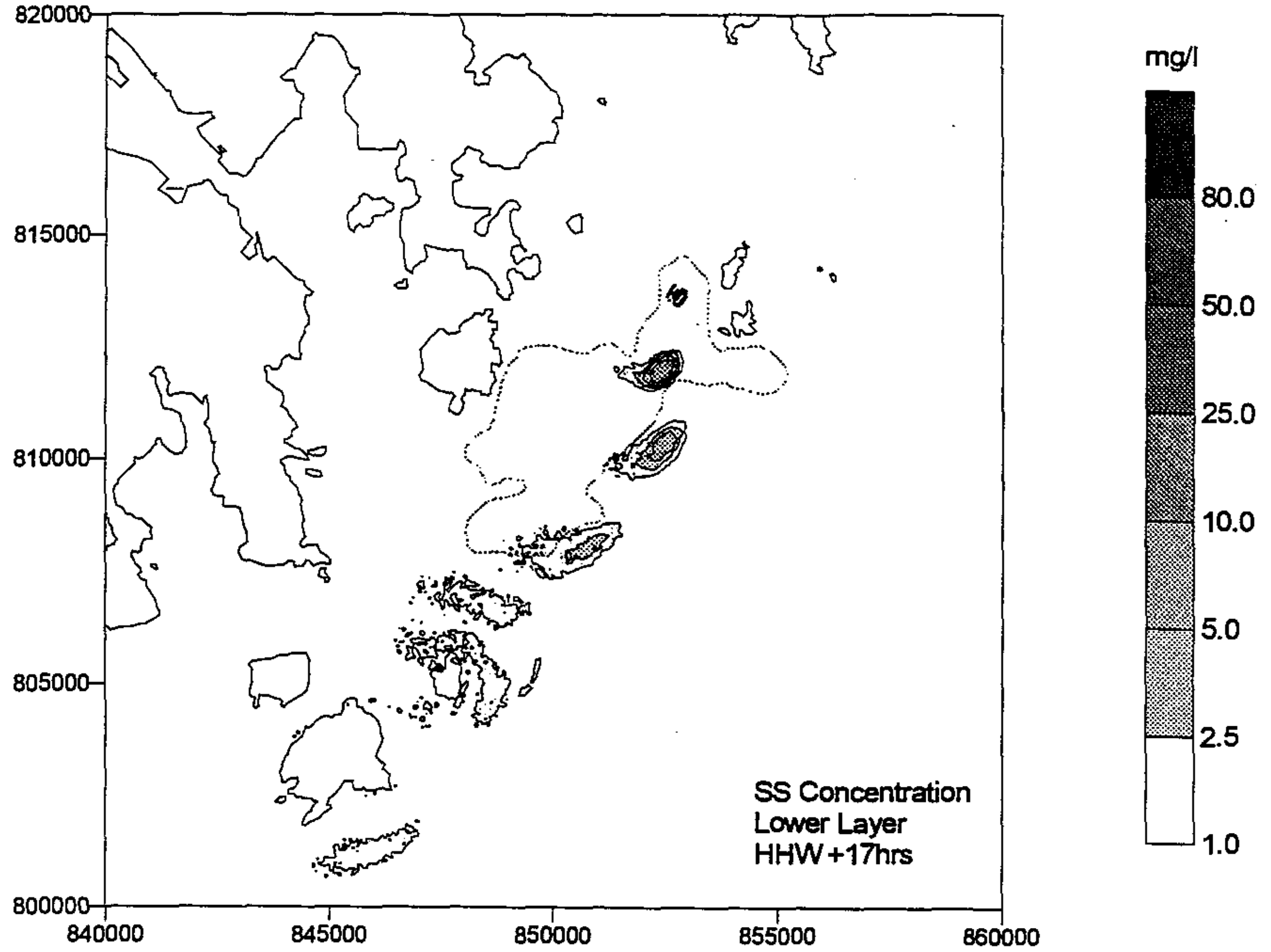


FIGURE D26 - SCENARIO 9 MAXIMUM PREDICTED SUSPENDED SEDIMENT CONCENTRATION



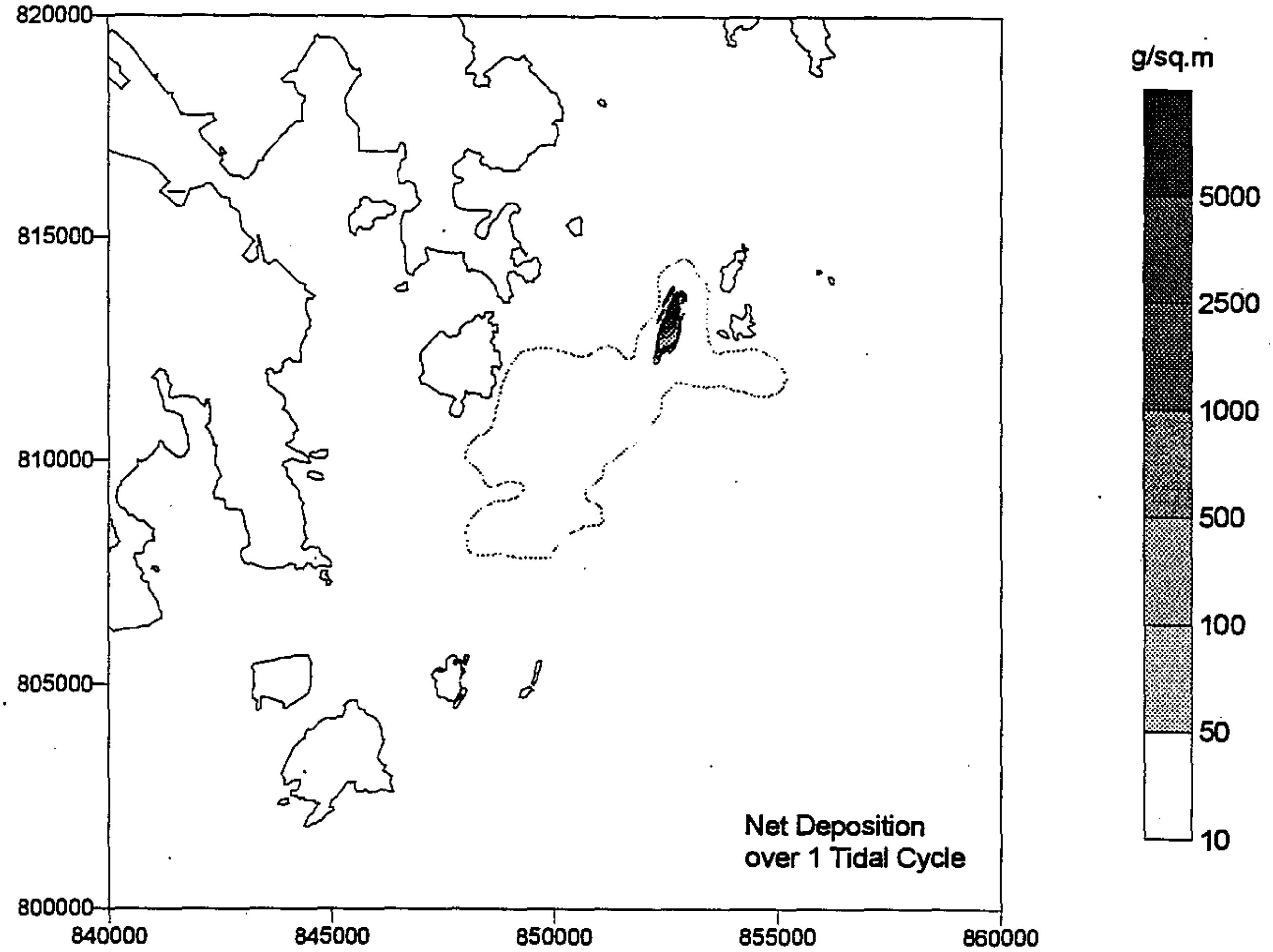
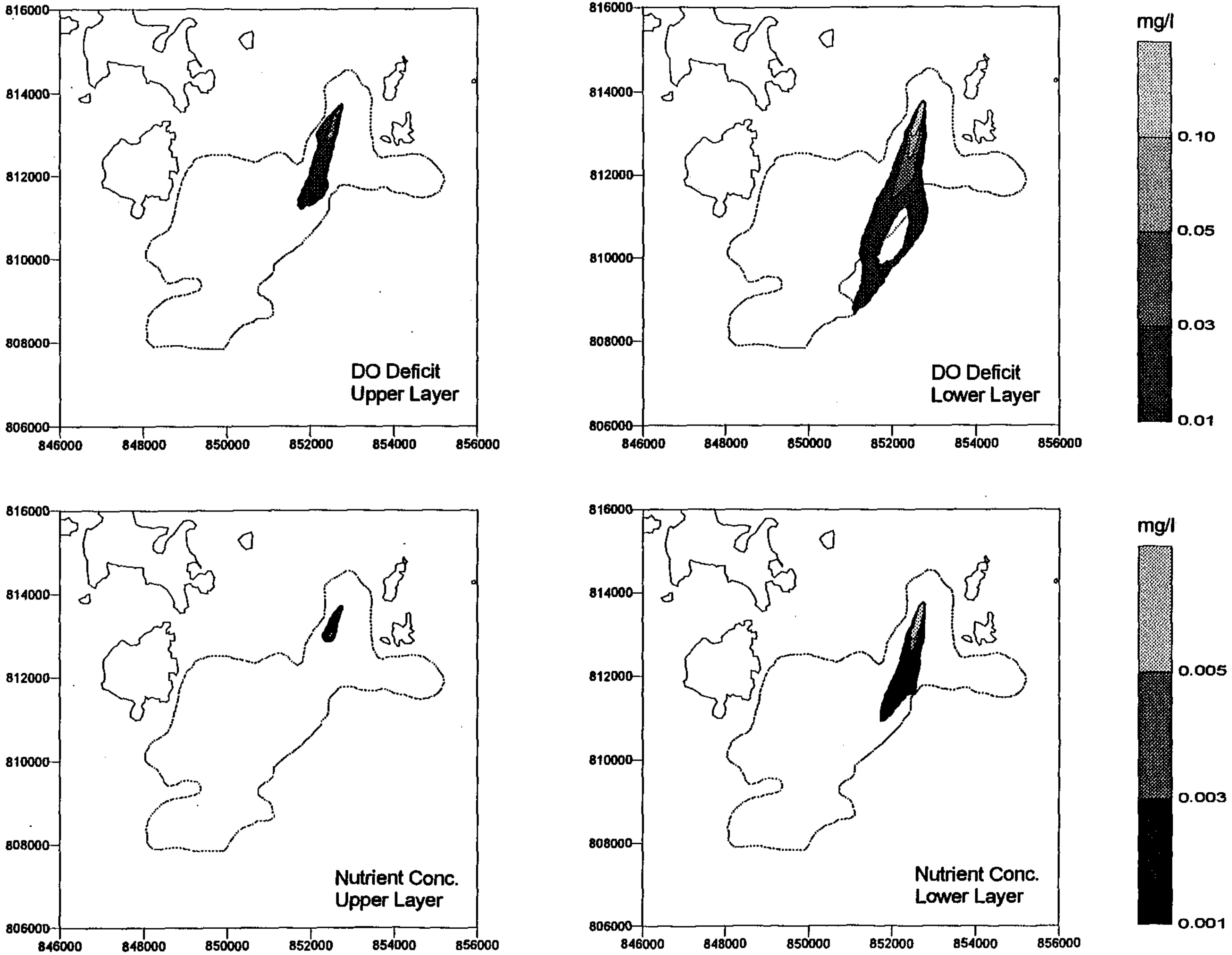


FIGURE D27 - SCENARIO 9: PREDICTED SEDIMENT TRANSPORT AND DEPOSITION

FIGURE D28 - SCENARIO 9: PREDICTED DO DEPLETION AND NUTRIENT ELEVATION



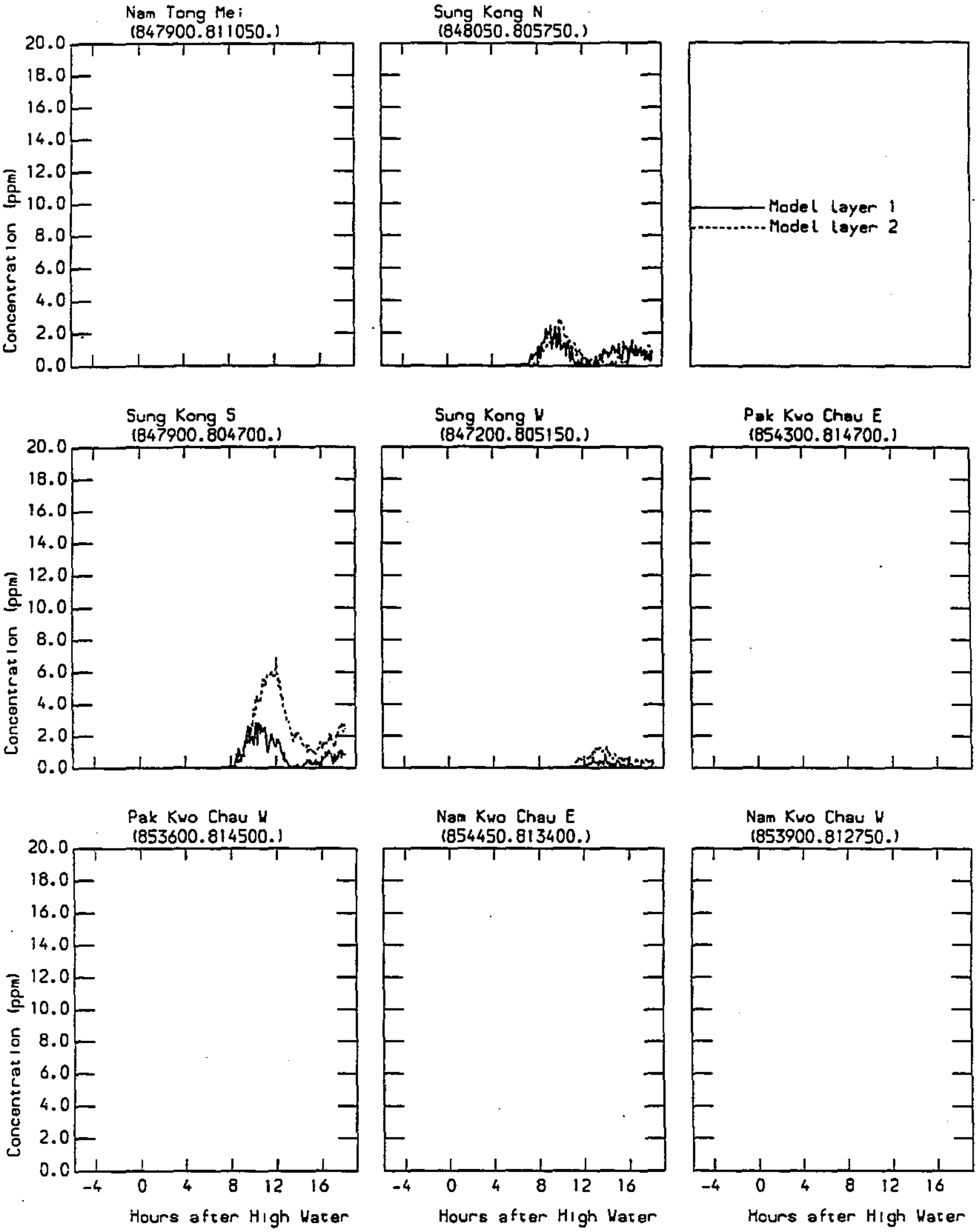


FIGURE D29 -SCENARIO 9: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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Hong Kong

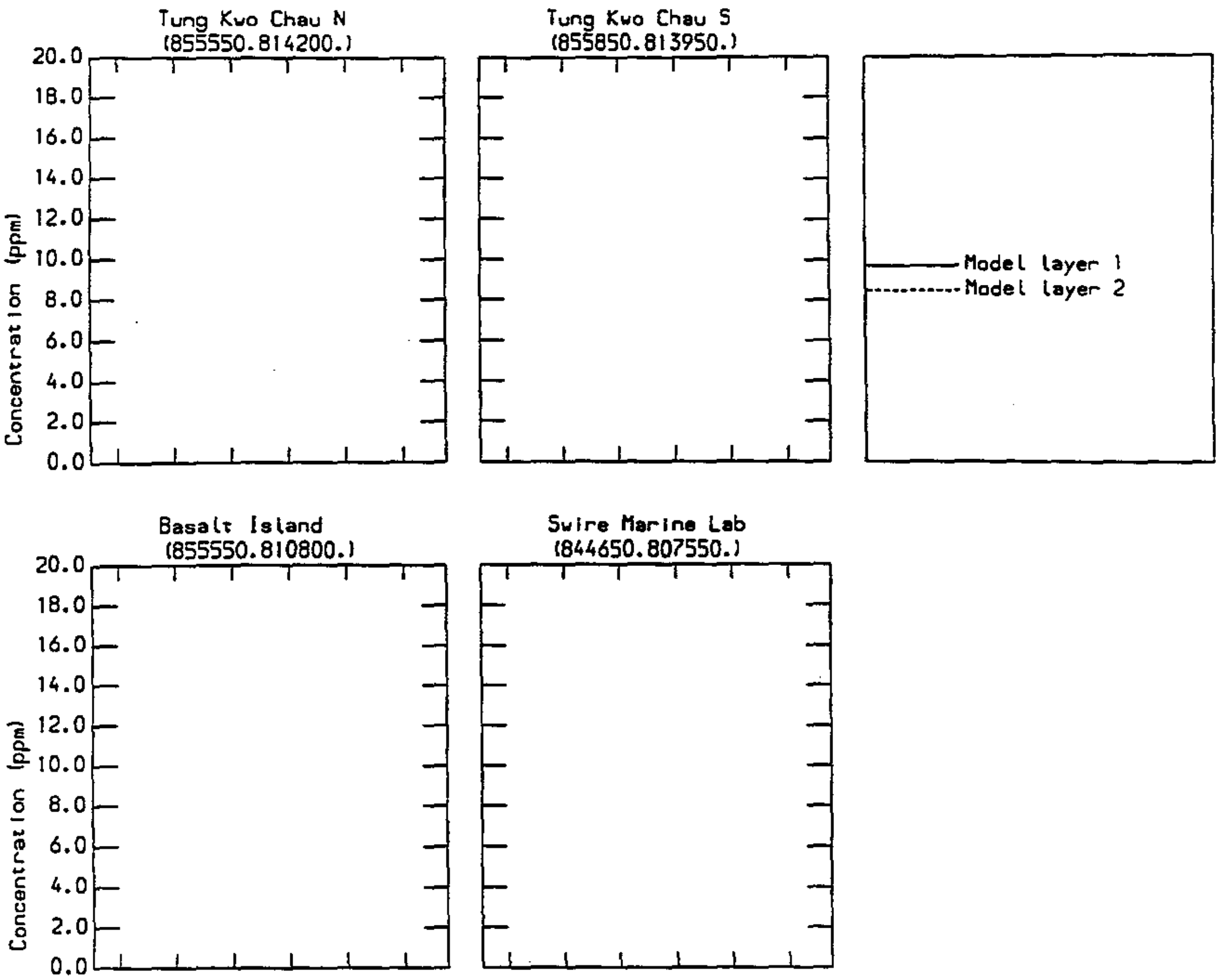

FIGURE D30 -SCENARIO 9: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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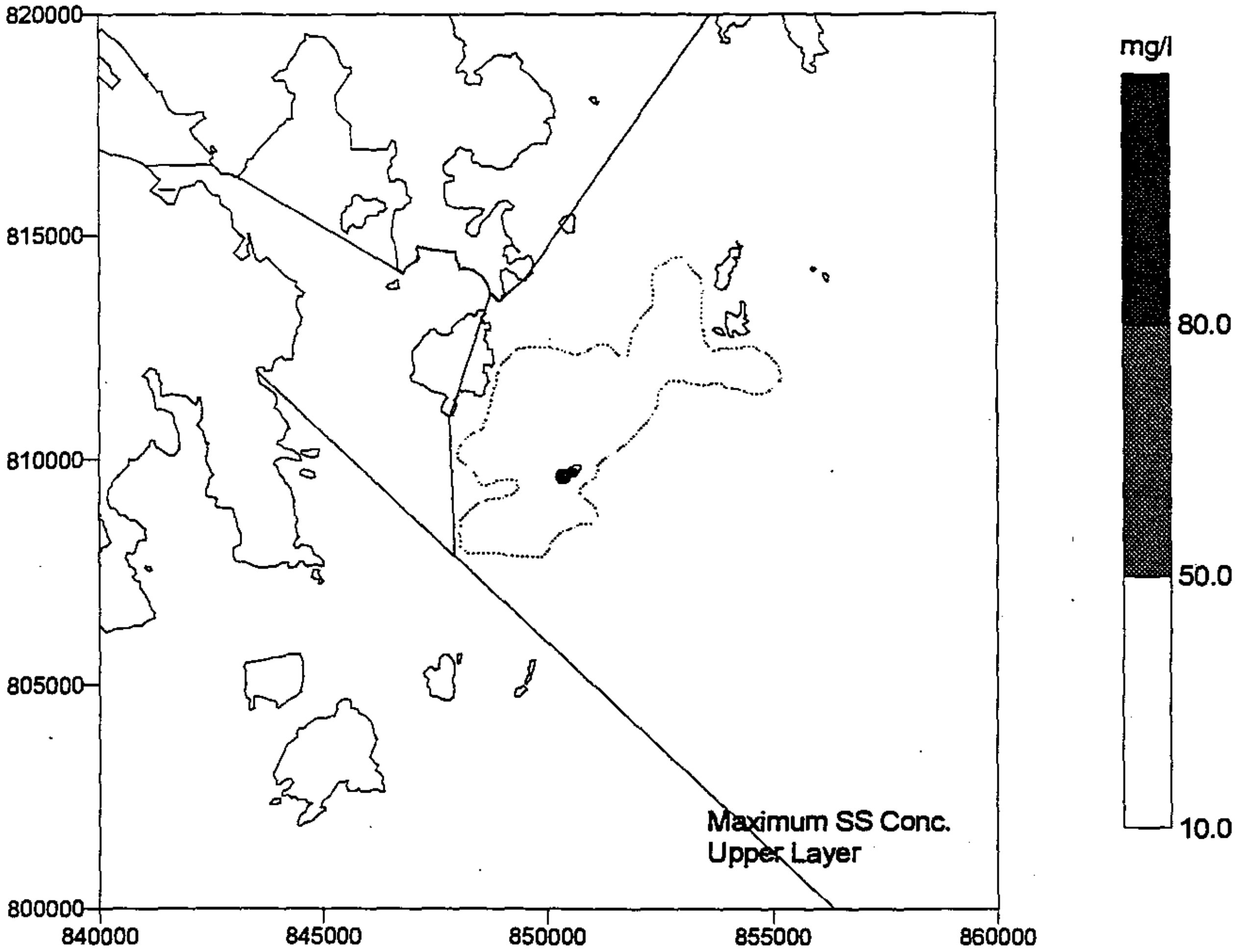
Annex E

Wet Season Water Quality Modelling Results



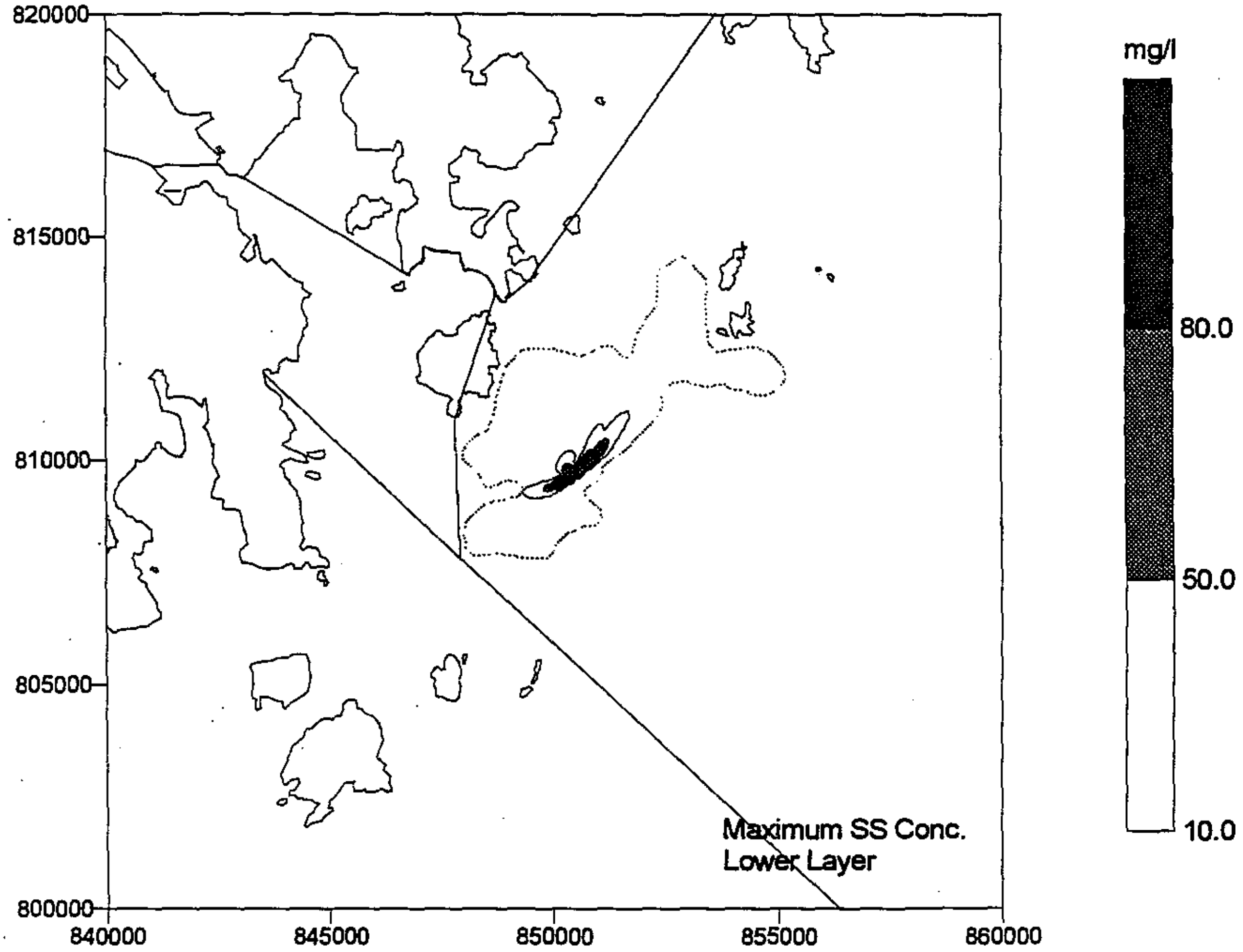
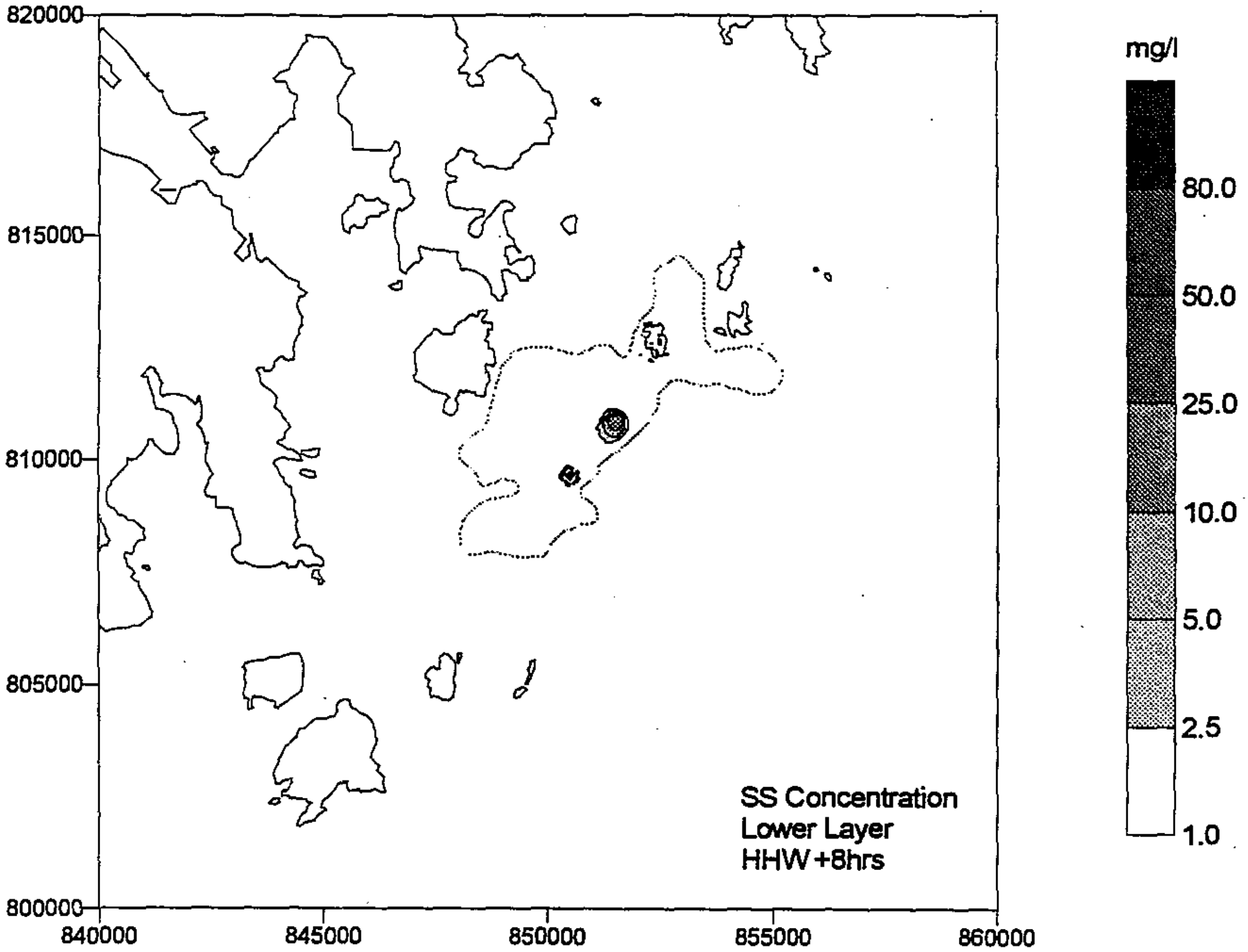


FIGURE E1 - SCENARIO 7: PREDICTED MAXIMUM SUSPENDED SEDIMENT CONCENTRATION



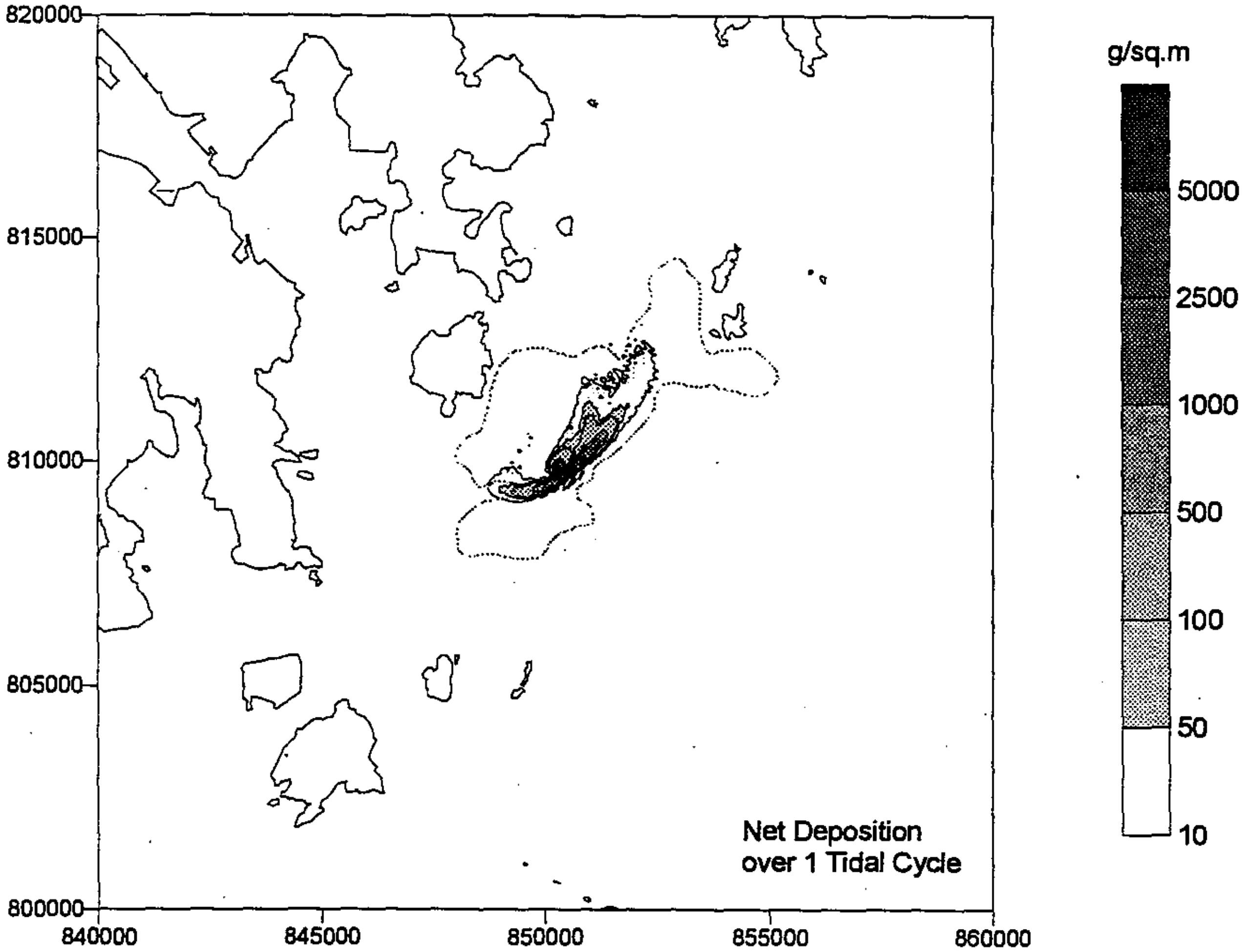


FIGURE E2 - SCENARIO 7: PREDICTED SEDIMENT TRANSPORT AND DEPOSITION

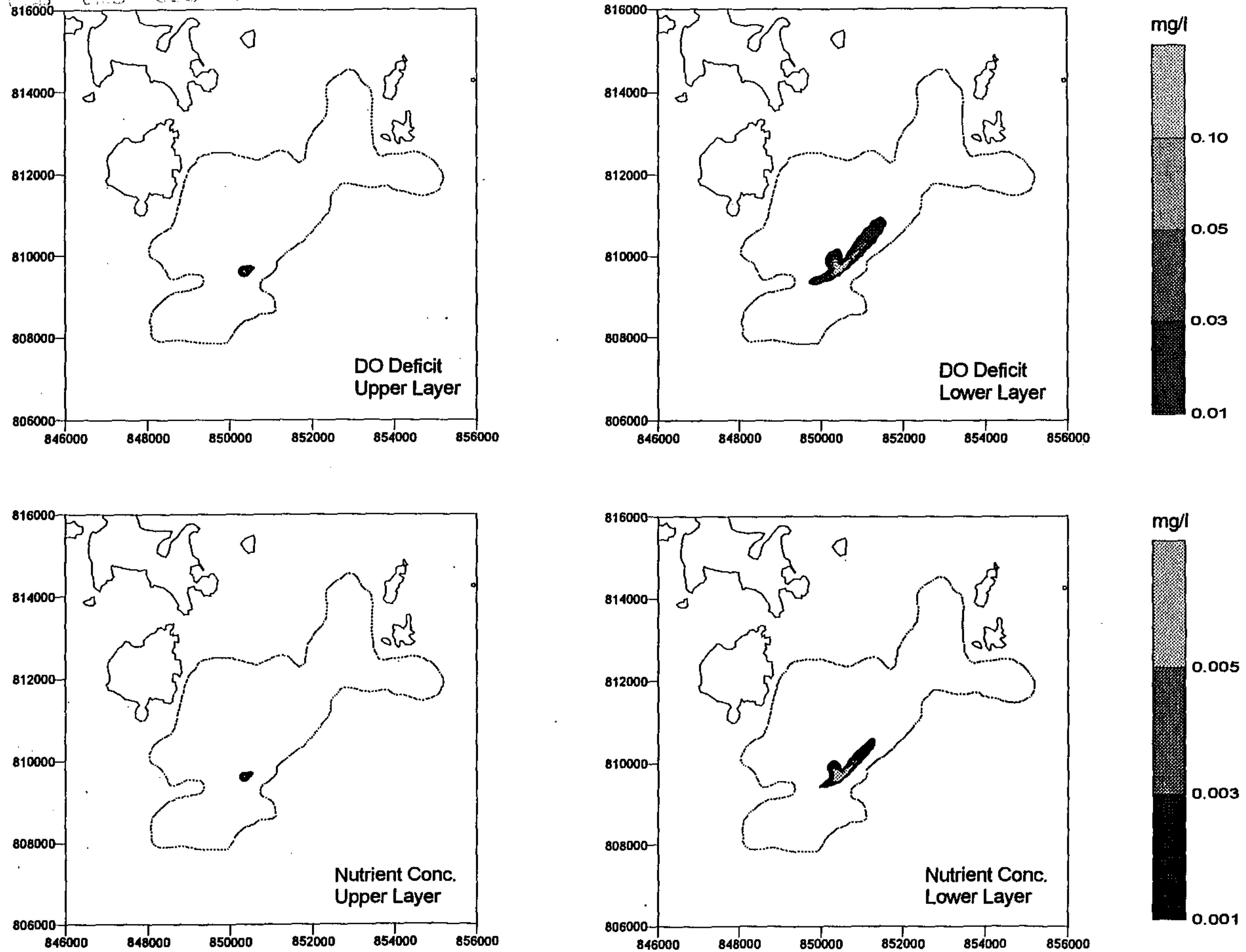


FIGURE E3 - SCENARIO 7: PREDICTED DO DEPLETION AND NUTRIENT ELEVATION

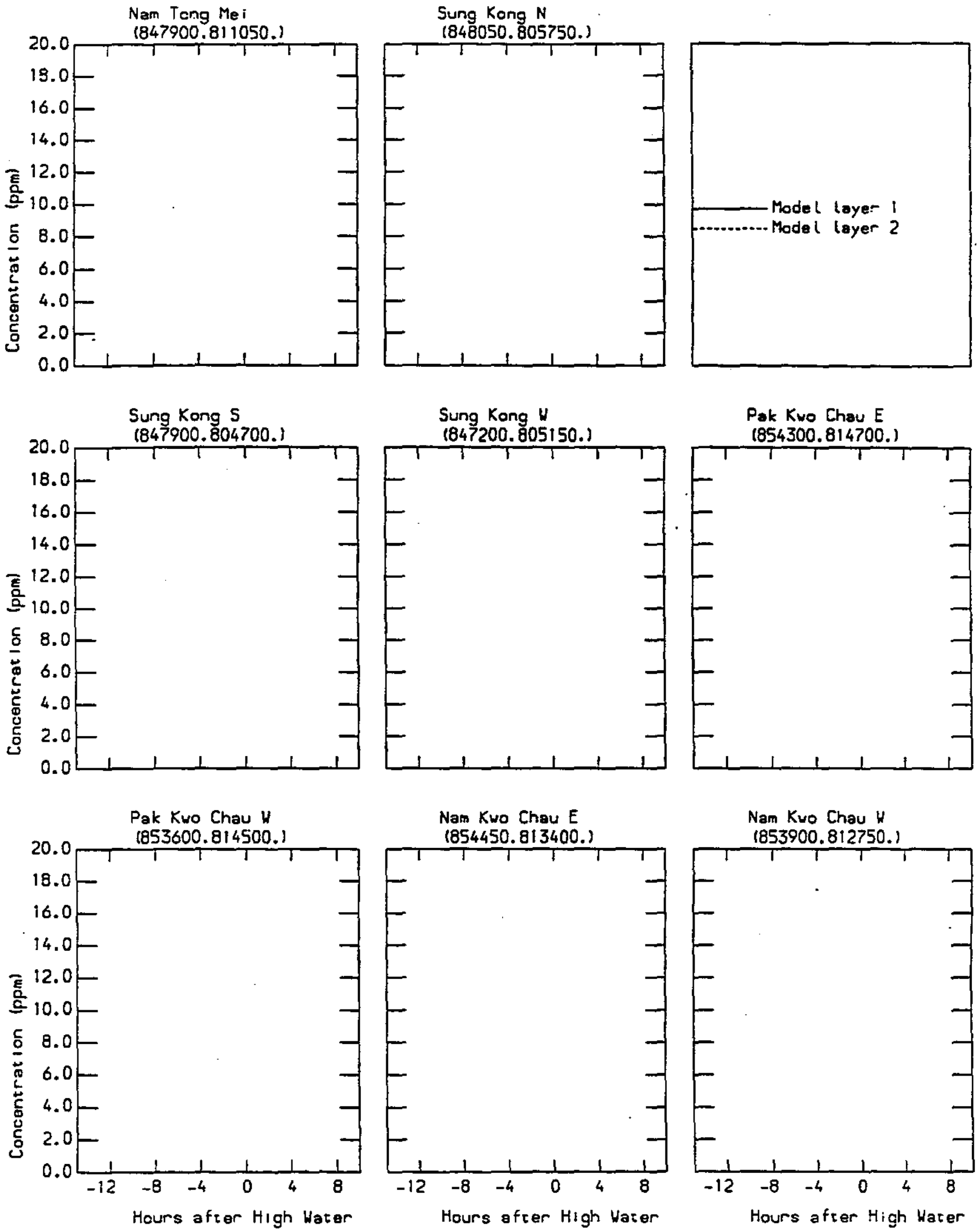


FIGURE E4 - SCENARIO 7: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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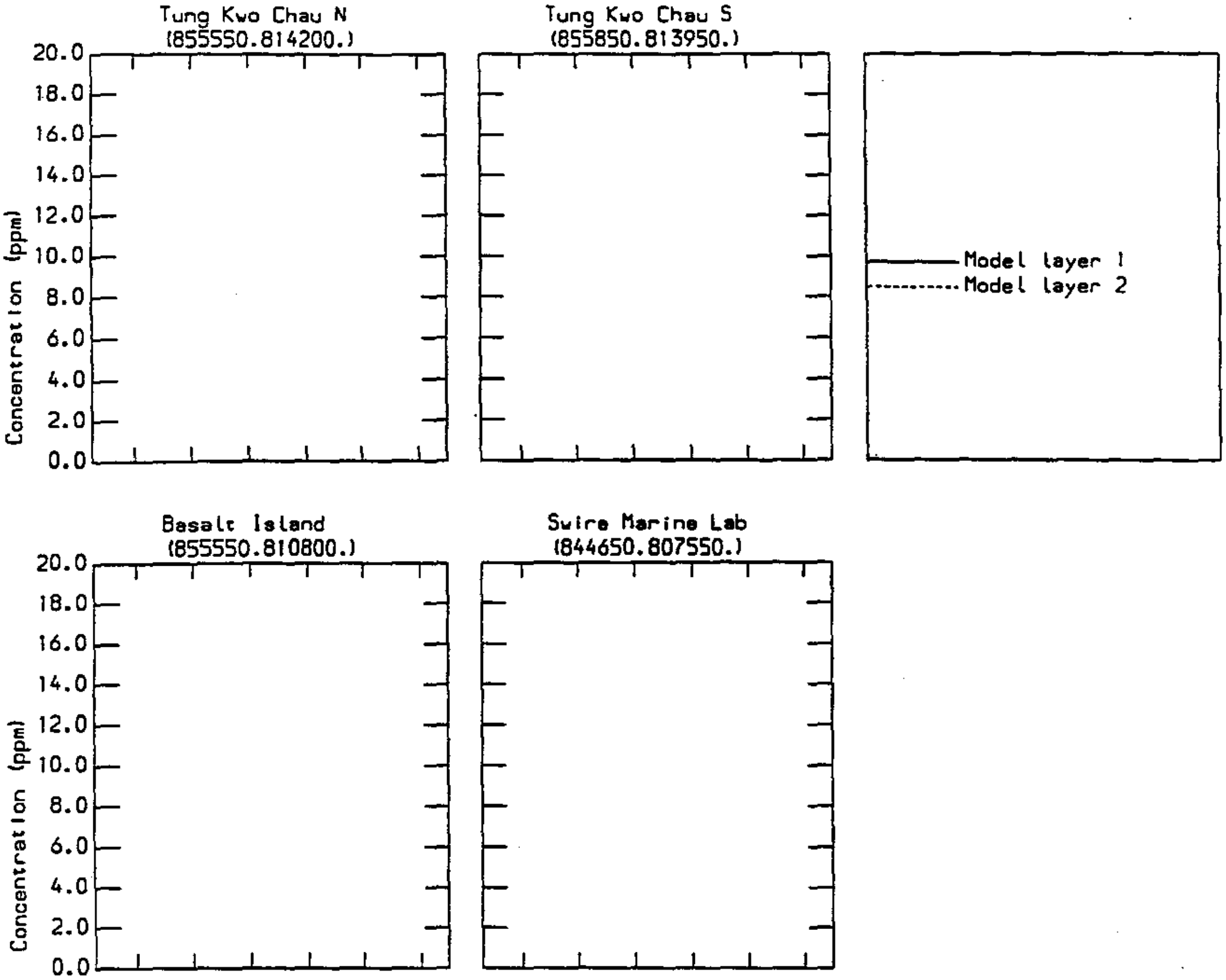

FIGURE E5 - SCENARIO 7: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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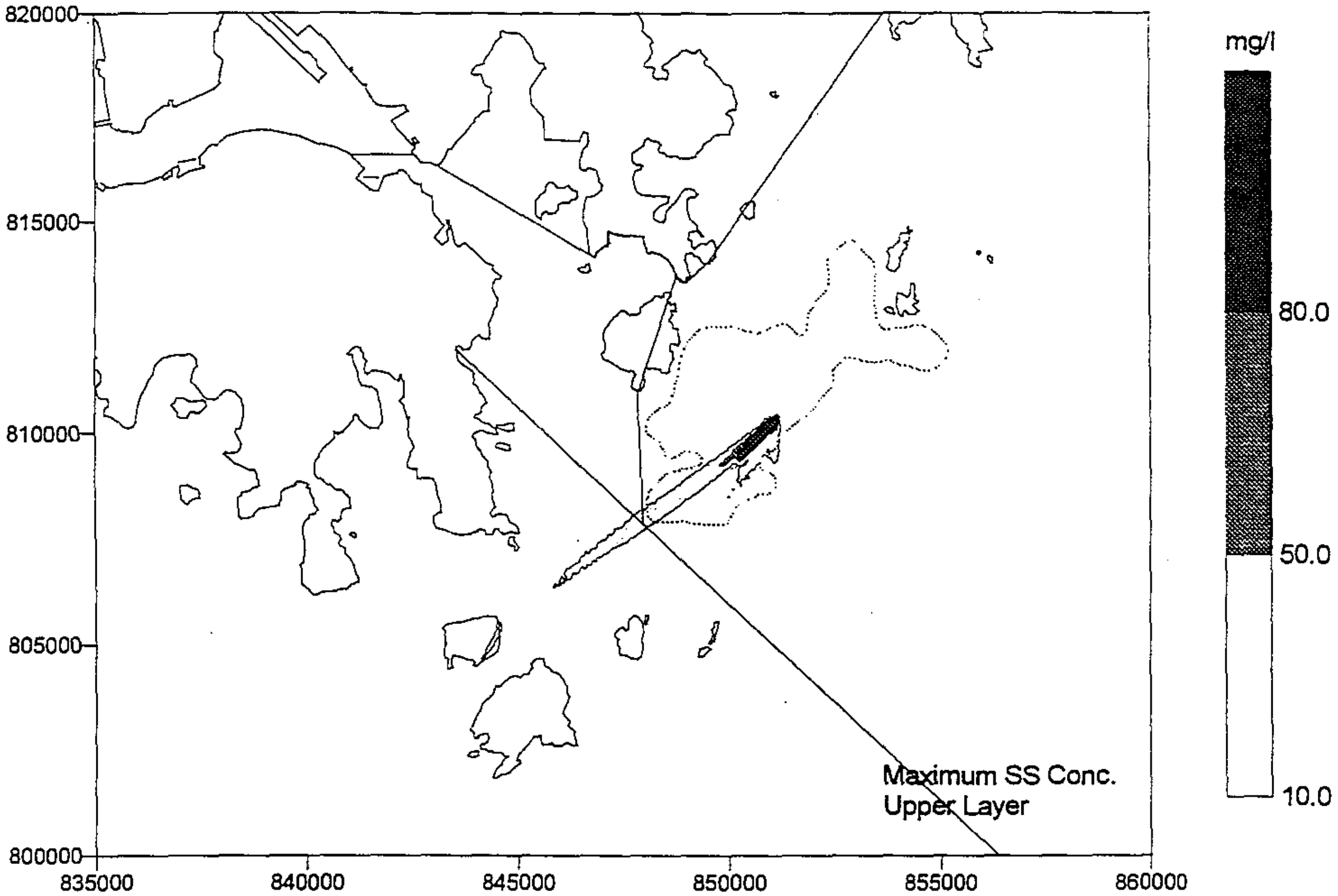
Annex F

Transitional Season Water Quality Modelling Results



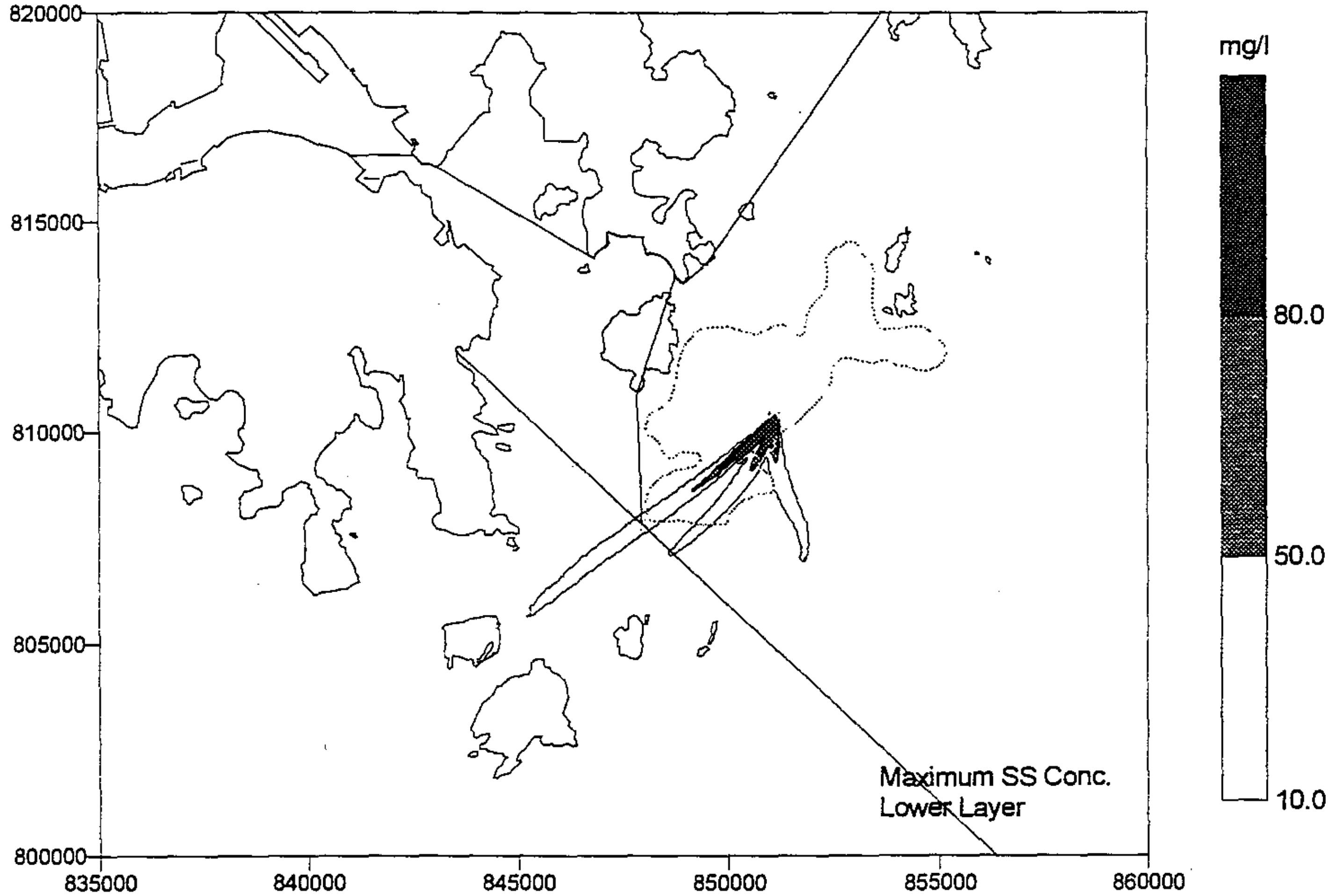
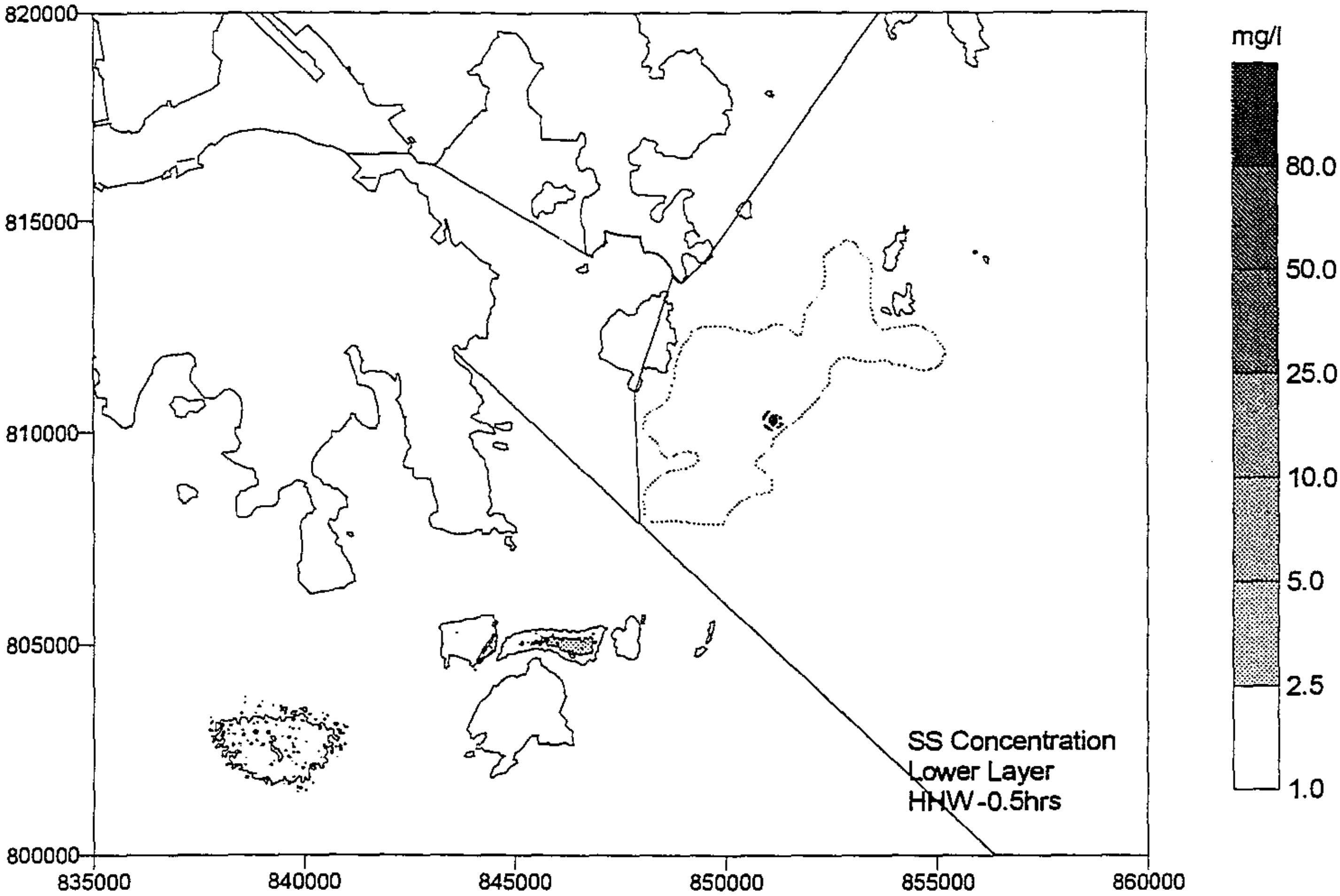


FIGURE F1 - SCENARIO 5: PREDICTED MAXIMUM SUSPENDED SEDIMENT CONCENTRATION



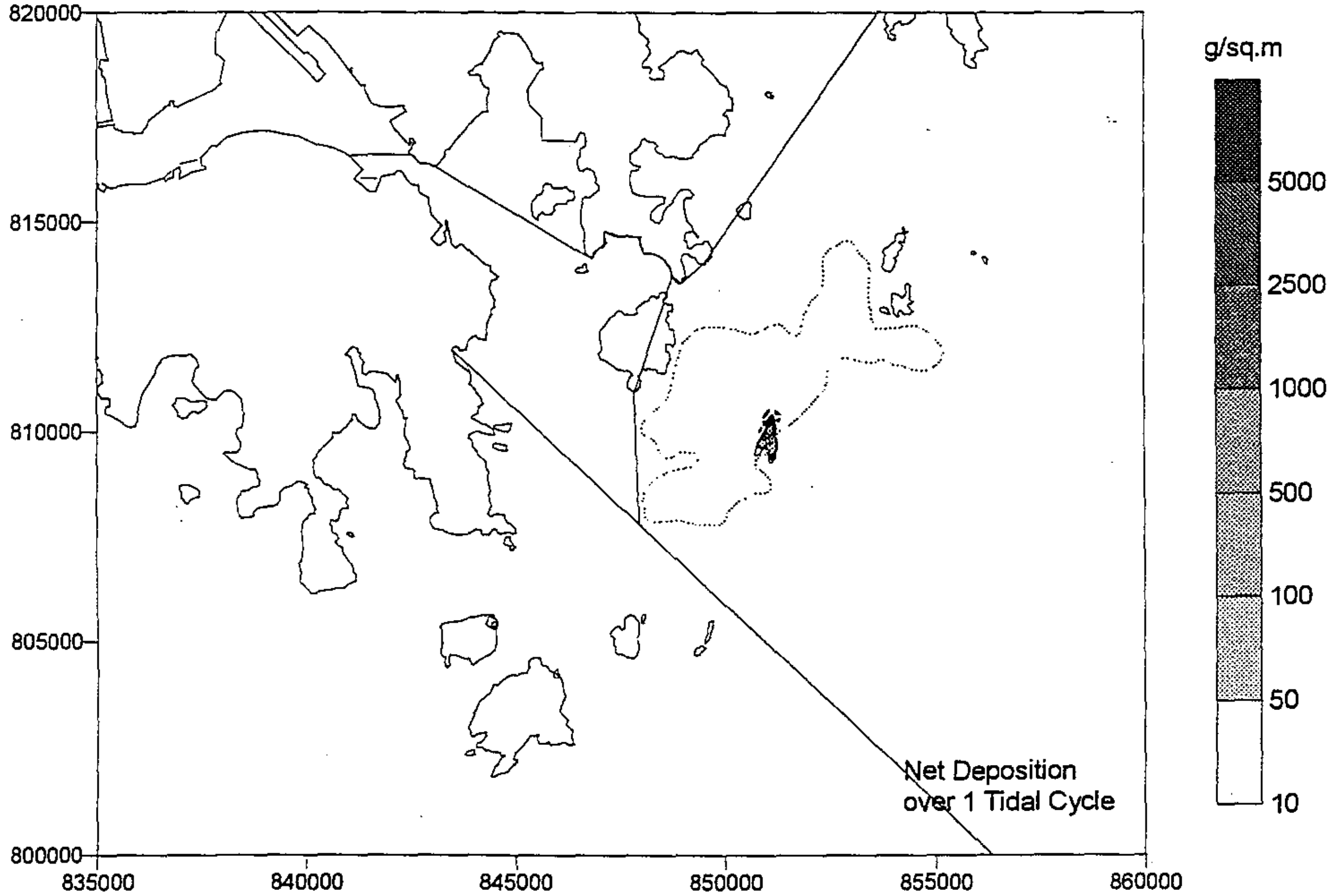


FIGURE F2 - SCENARIO 5: PREDICTED SEDIMENT TRANSPORT AND DEPOSITION

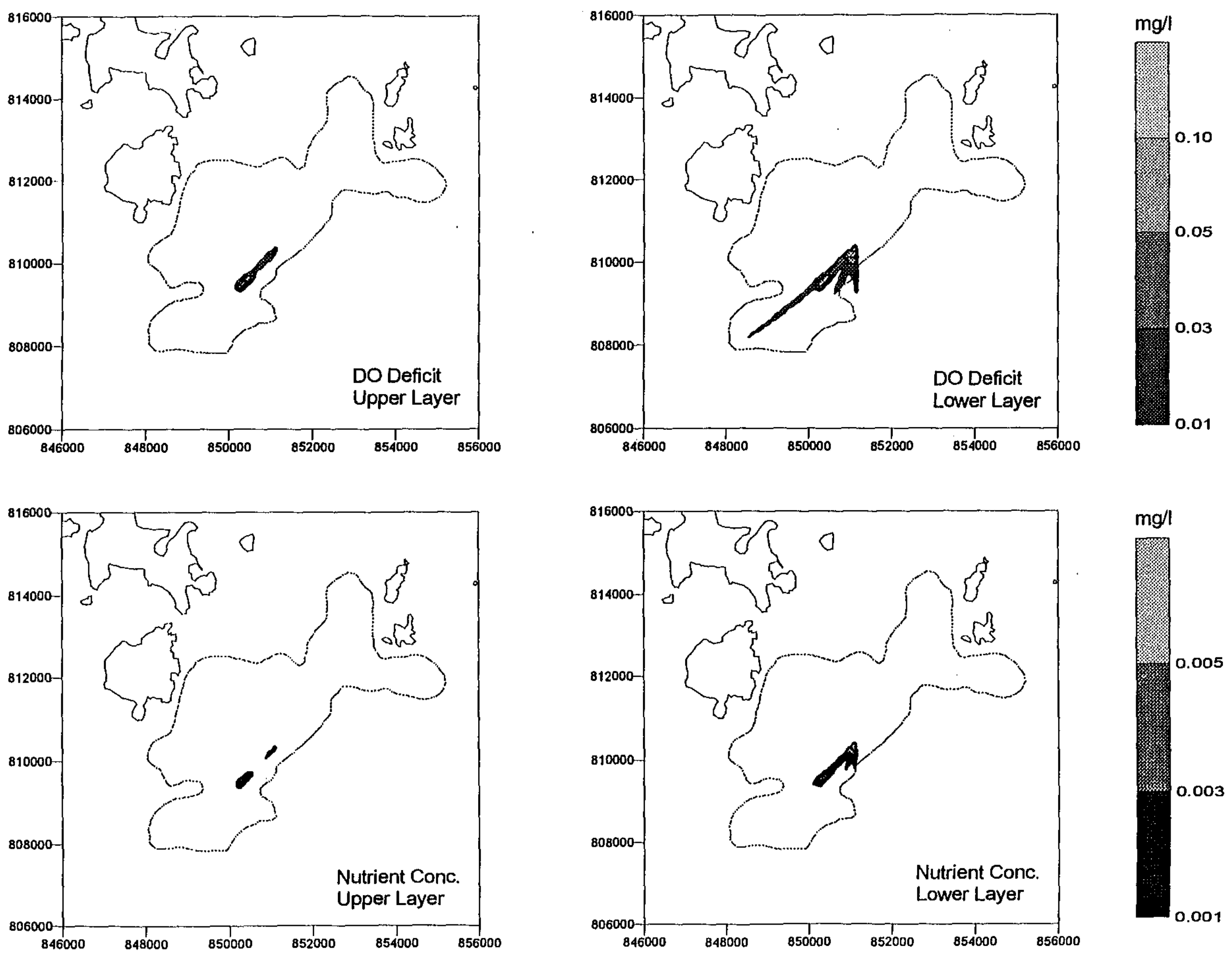


FIGURE F3 - SCENARIO 5: PREDICTED DO DEPLETION AND NUTRIENT ELEVATION

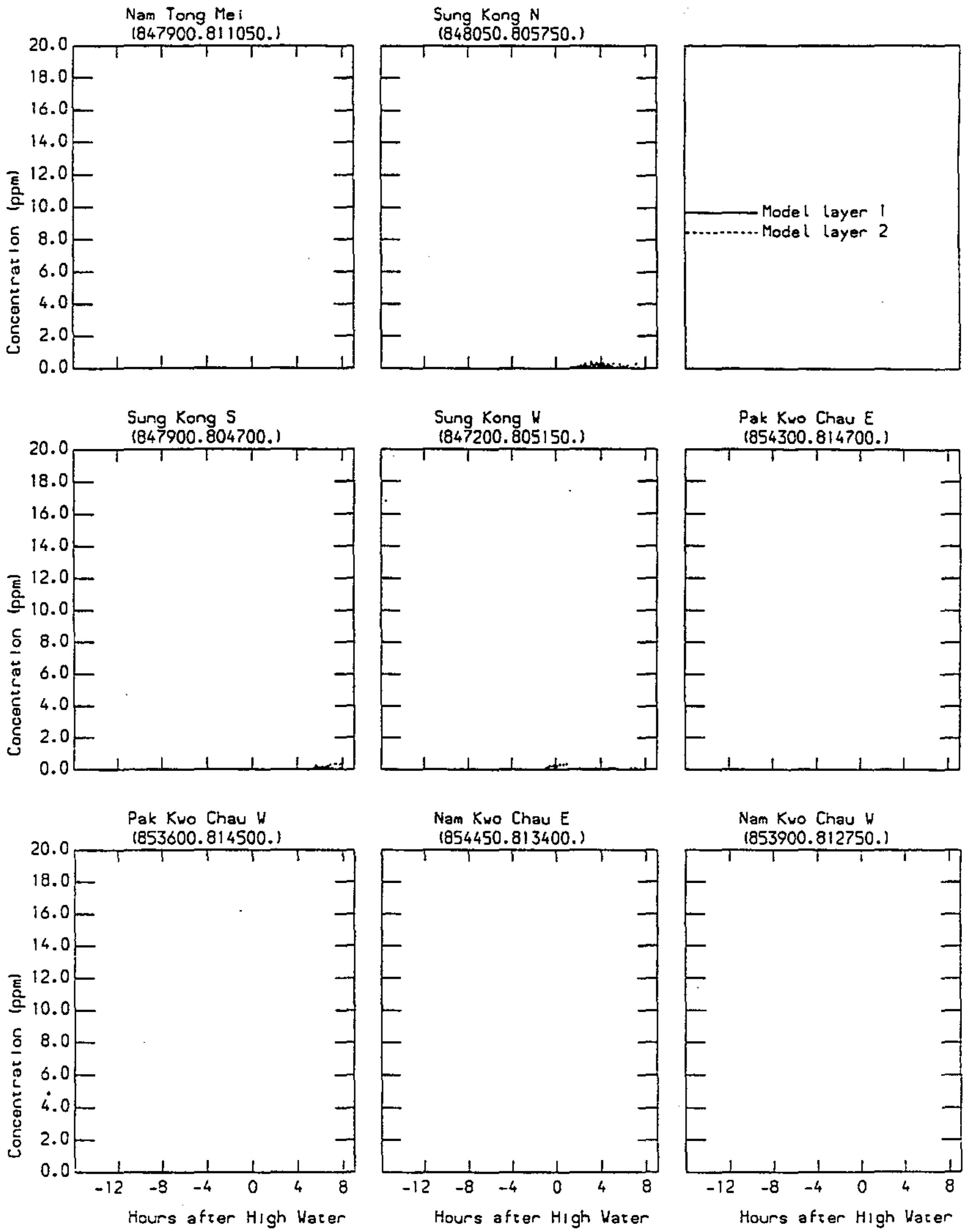


FIGURE F4 - SCENARIO 5: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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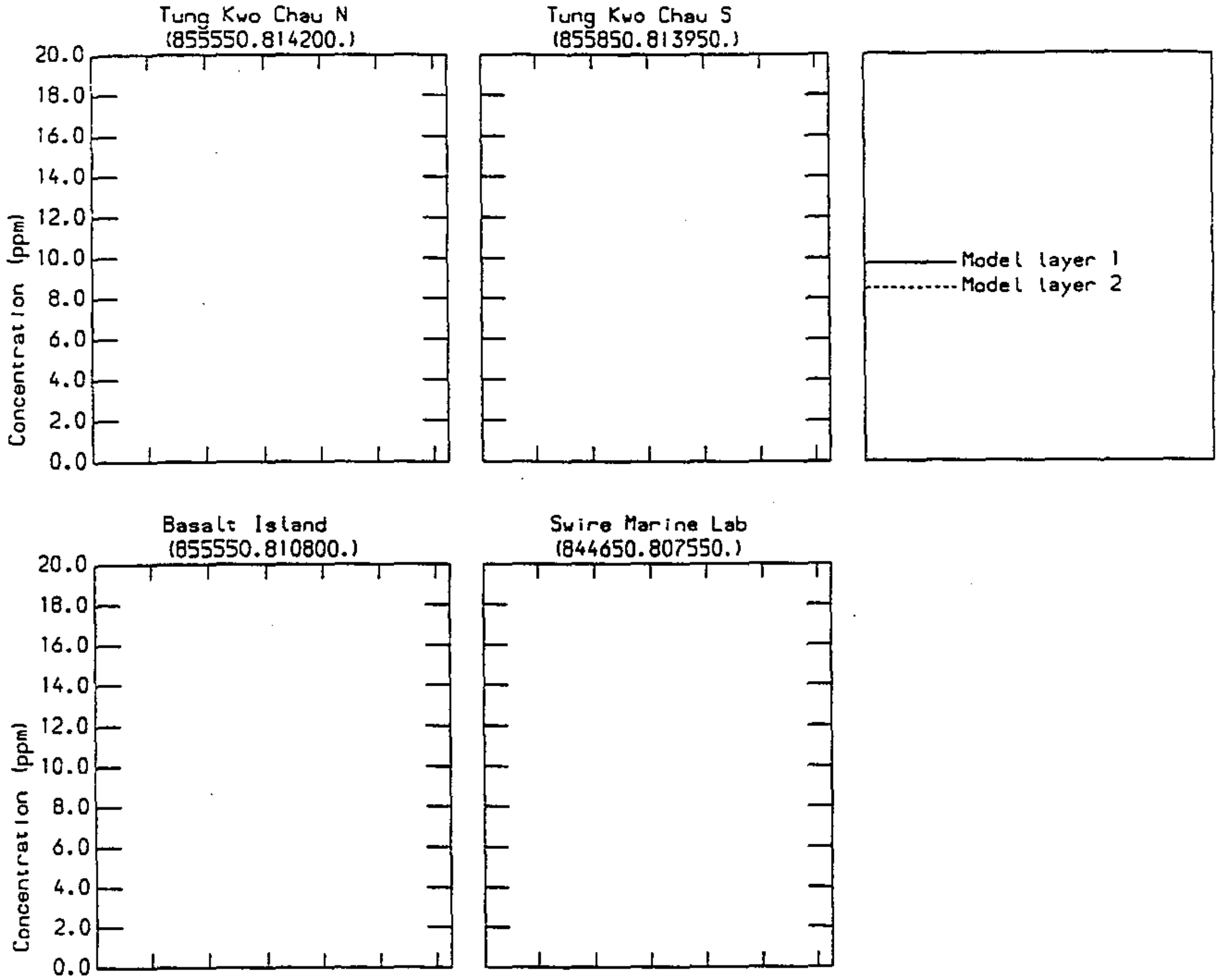

FIGURE F5 - SCENARIO 5: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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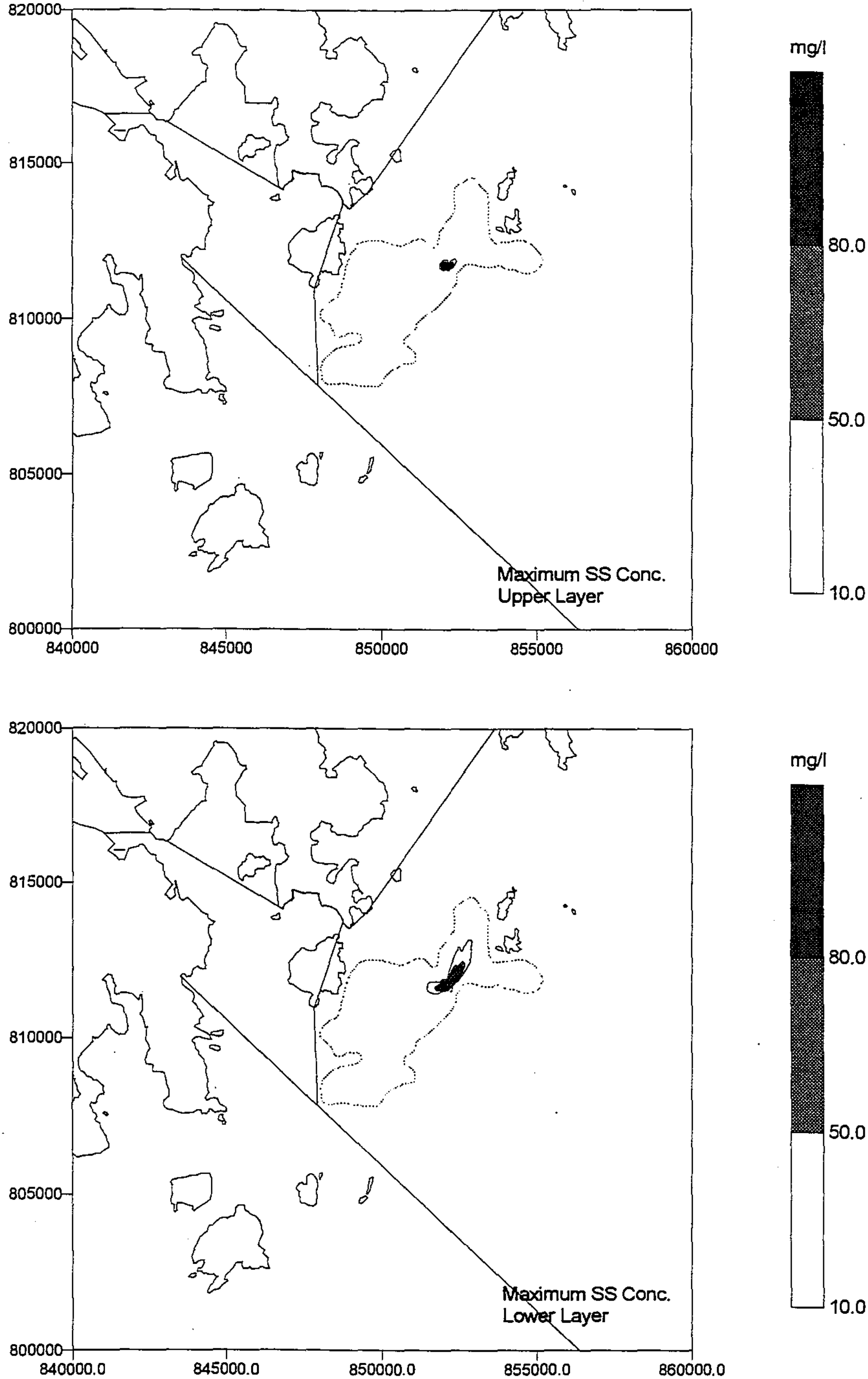

FIGURE F6 - SCENARIO 6: PREDICTED MAXIMUM SUSPENDED SEDIMENT CONCENTRATION

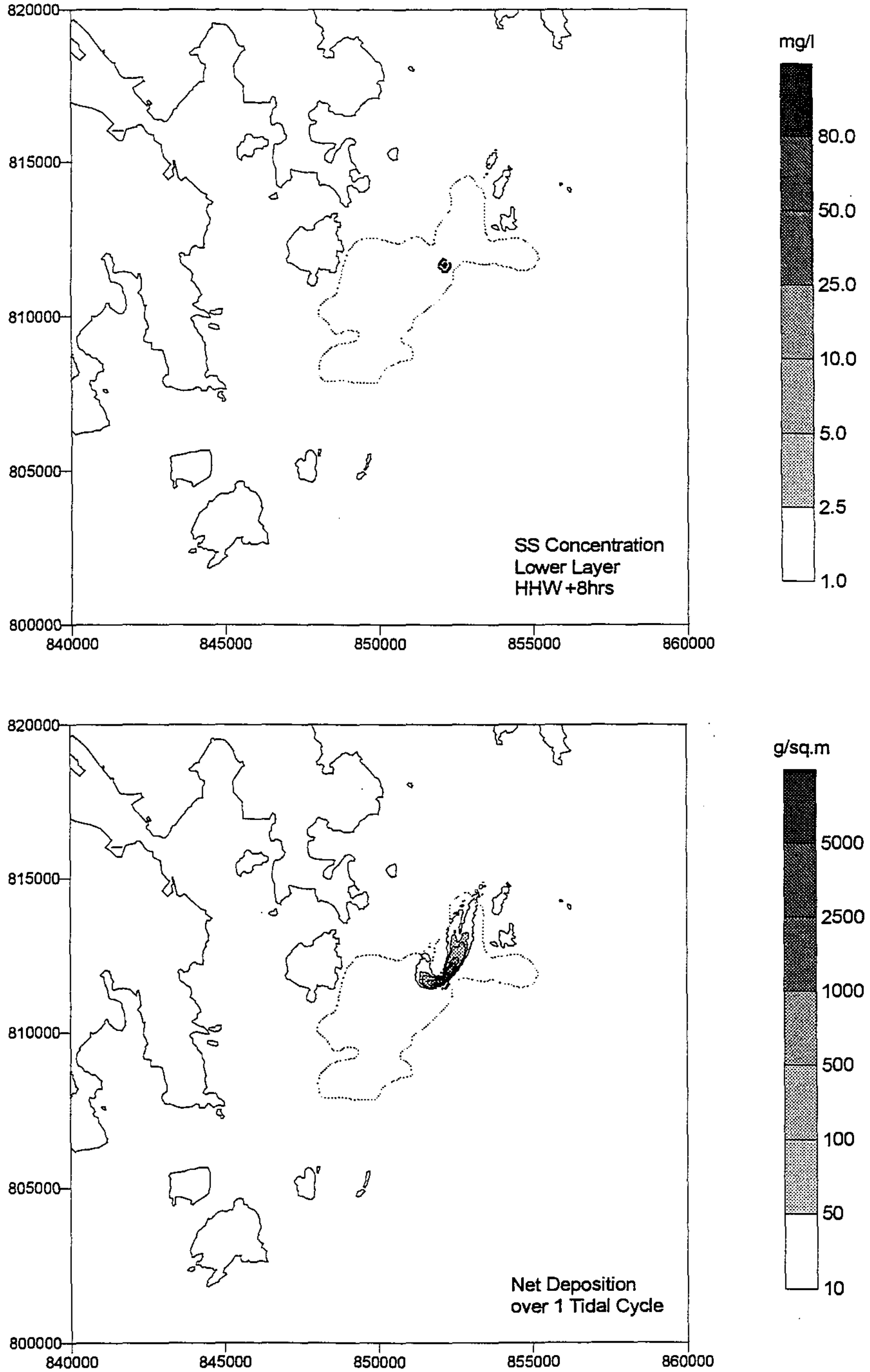

FIGURE F7 - SCENARIO 6: PREDICTED SEDIMENT TRANSPORT AND DEPOSITION

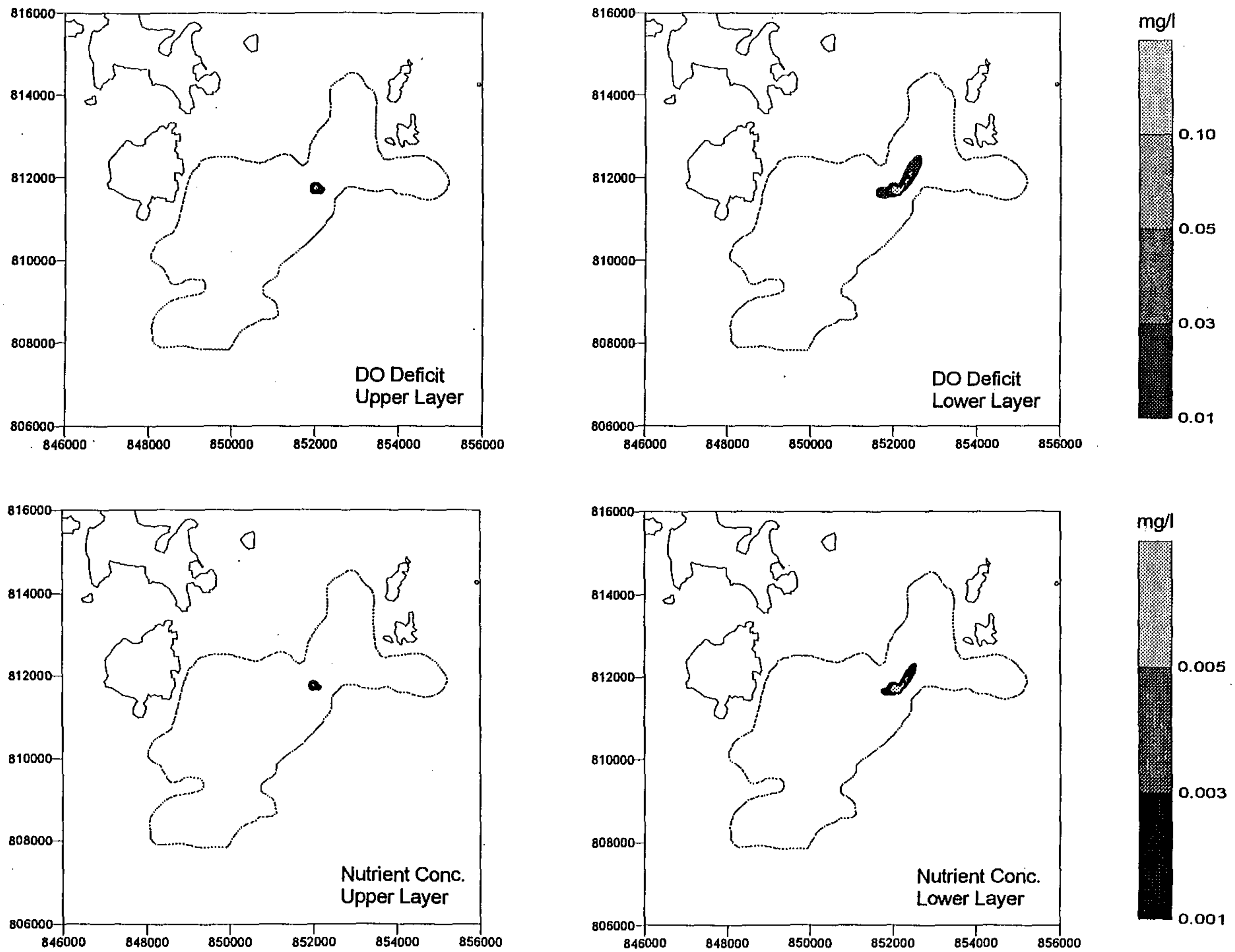

FIGURE F8 - SCENARIO 6: PREDICTED DO DEPLETION AND NUTRIENT ELEVATION

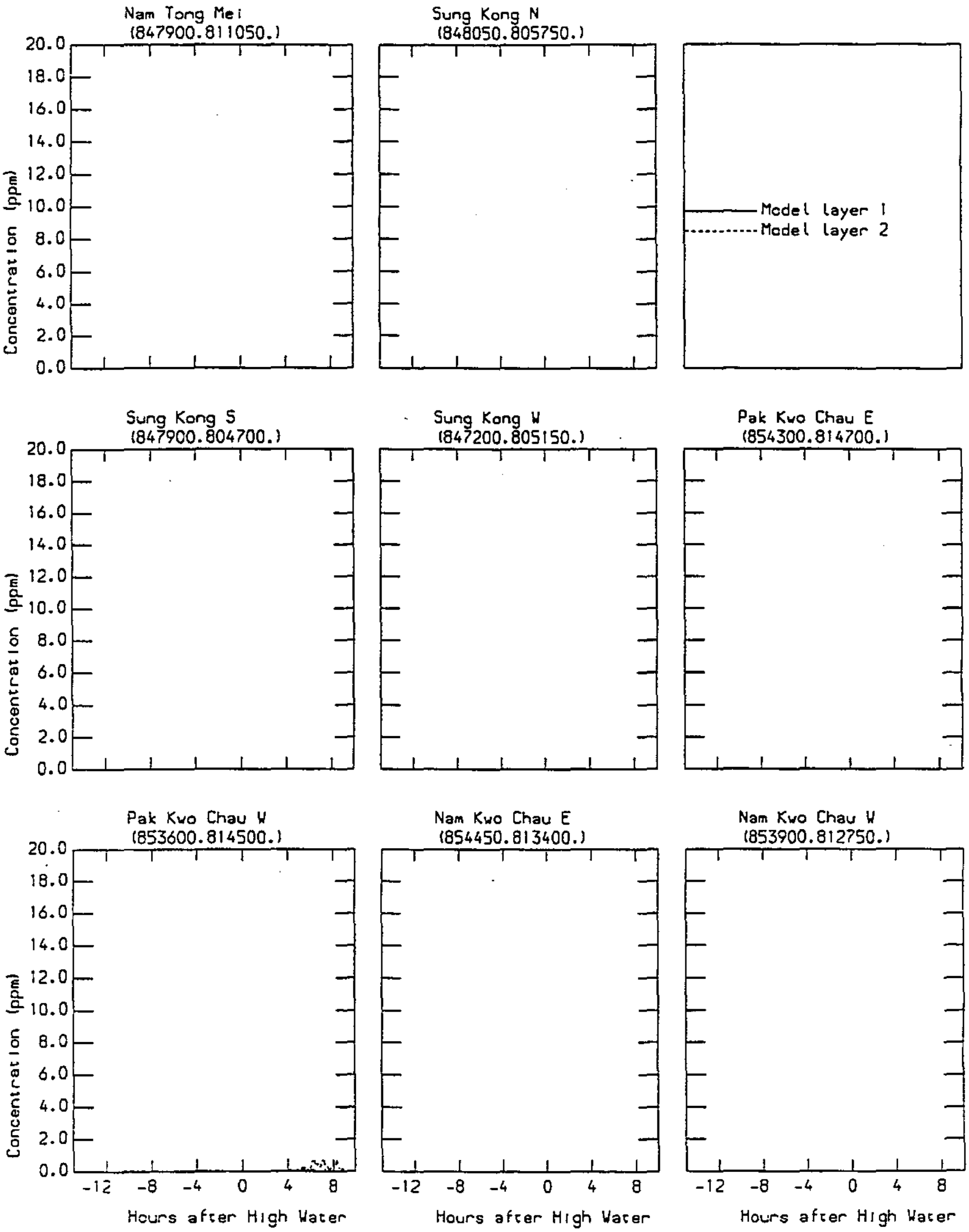

FIGURE F9 - SCENARIO 6: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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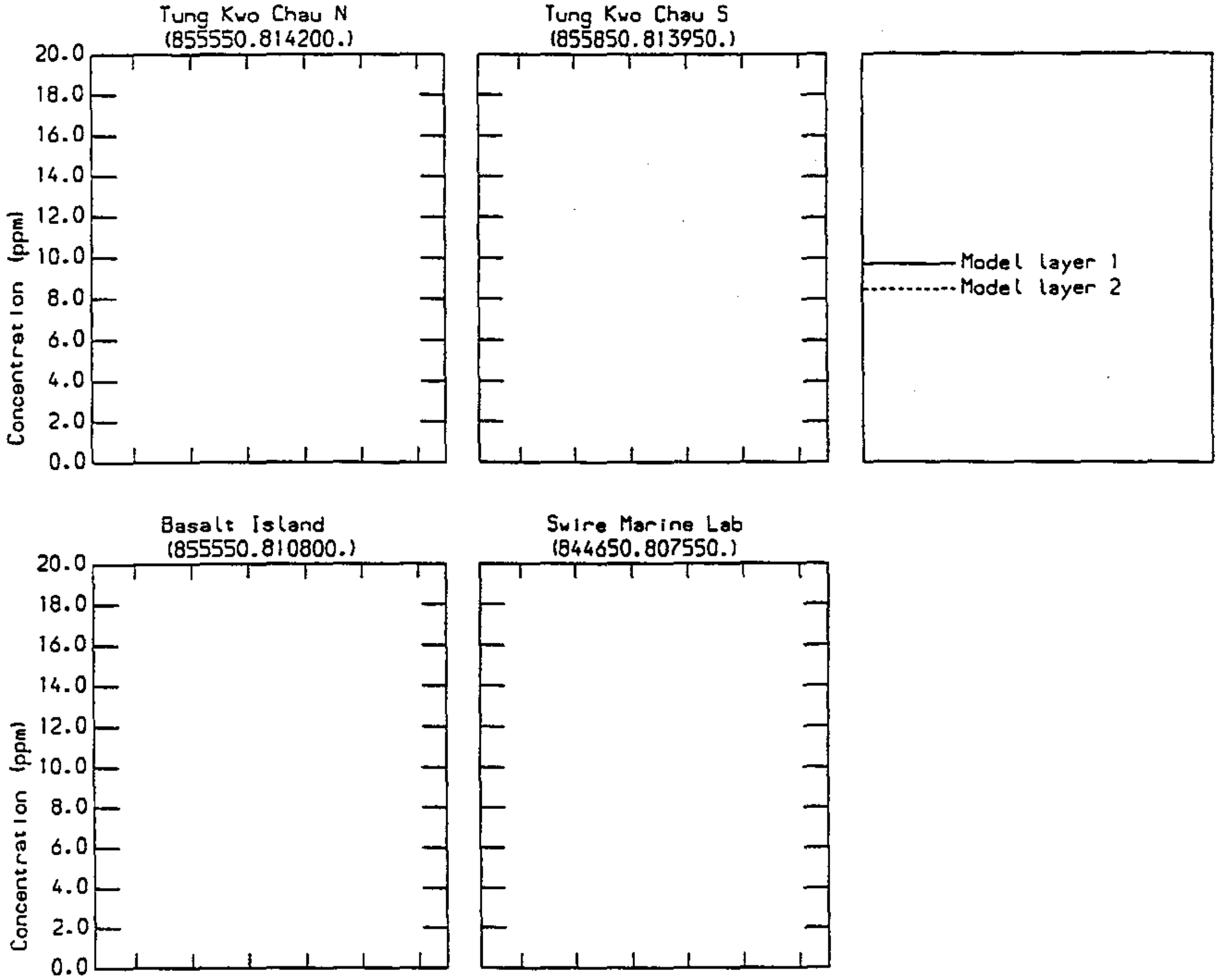

FIGURE F10 - SCENARIO 6: PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS THROUGHOUT THE TIDAL CYCLE AT SENSITIVE RECEIVERS

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Annex G

Additional Calculations on Dissolved Oxygen Depletion

G1 INTRODUCTION

This *Annex* presents additional information on the calculation of absolute DO depletion within individual plumes. This is the second of the two methodologies used to predict DO depletions resulting from the backfilling of the ETLC MBAs. The first method predicts the tidally averaged DO depletion which is the average amount by which DO is depleted over 24 hours at a single point in space.

G2 METHODOLOGY

The DO depletion associated with individual plumes resulting from trailer dumps was calculated as follows:

- A snap shot (*Figure G2a*) of the plumes resulting from trailer disposal events was used to estimate how suspended sediment concentrations associated with a plume change with the age of that plume. *Figure G2a* shows predicted suspended sediment concentrations in the upper and lower layers of the model. The disposal interval for the scenario shown was 3.84 hours. The ages of each of the plumes marked are therefore 0, 3.84, 7.68, 11.52, 15.36 and 19.2 hours.

- Trailer disposals were simulated because they result in greater losses of sediment to suspension than barges. Predictions of DO depletions from trailer plumes should therefore be greater than for barges.

- The average concentration of a plume between the consecutive ages shown in *Figure G2a* was calculated by averaging the maximum concentrations of the consecutive plumes. This is conservative because the averages are calculated from maximum predicted values not average values across the plume.

- The DO depletion exerted in the time between consecutive plumes was calculated using the equation presented in *Section 5.6.2*.

- Re-aeration was ignored which is a further conservative assumption.

- The overall DO depletion within a plume was calculated by summing the DO depletion between each of the consecutive plumes. This is conservative because it assumes that the volume of water within which the sediment exerts its oxygen demand is the same throughout the life of the plume. In practice this is not the case as the plume expands as it gets older.

G3 RESULTS

The results of the calculations described in *Section G2* are presented in *Tables G3a* and *G3b*.

Table G3a *Oxygen Depletion in the Upper Layer of the Plume*

Position	*Time (hrs after dump)*	*Maximum SS Concentration ($mg\ l^{-1}$)*	*Average SS Concentration ($mg\ l^{-1}$)*	*DO Reduction ($mg\ l^{-1}$)*
0	0	461.5		
			257.315	0.05
1a	0.5	53.14		
			40.355	0.06
1b	1	27.57		
			17.135	0.08
1	3.84	6.7		
			4.865	0.08
2	7.68	3.03		
			2.485	0.08
3	11.52	1.94		
			1.76	0.09
4	15.36	1.58		
			1.505	0.09
5	19.2	1.43		

Notes Re-aeration was ignored. This is a conservative assumption
The plumes at position 1a and position 1b are not shown in *Figure G2a*. Maximum concentrations for these positions were extracted from model output files.

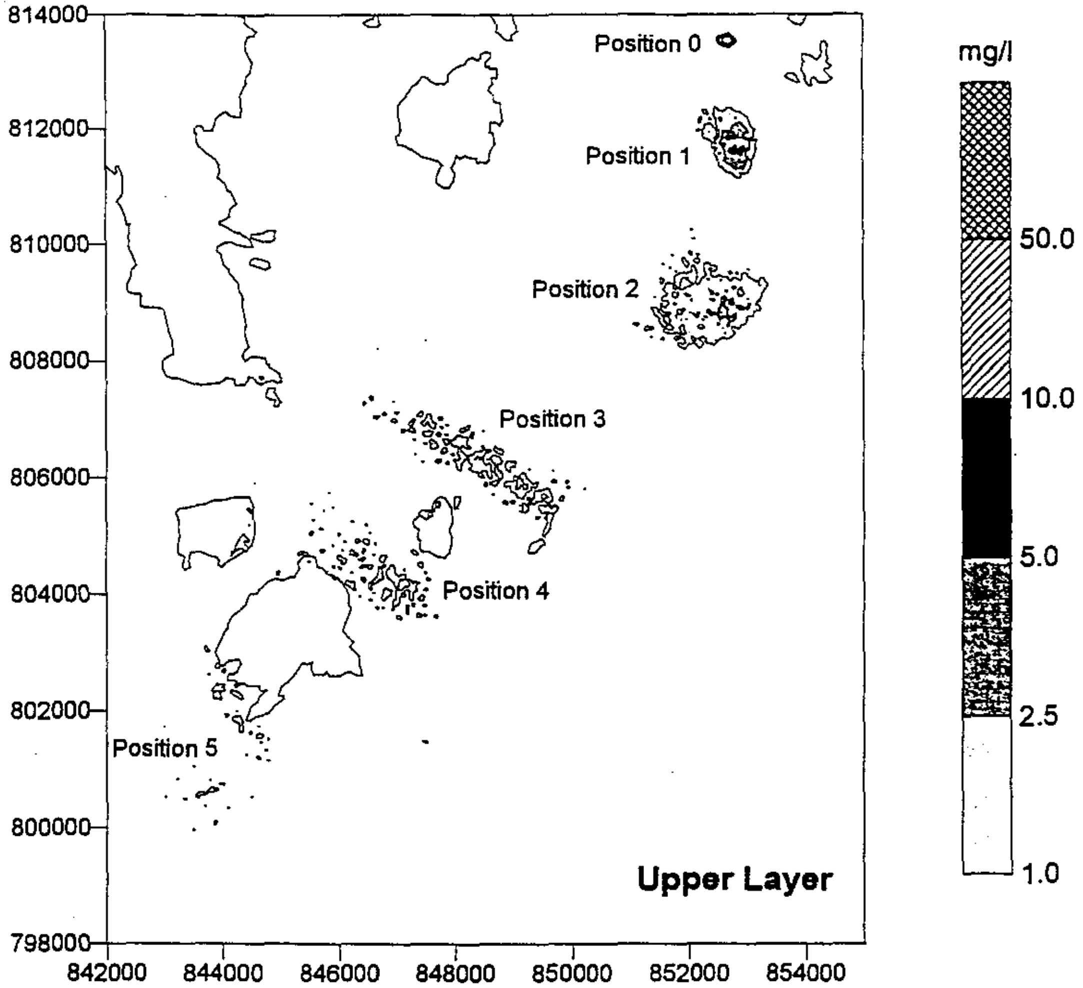
Table G3b *Oxygen Depletion in the Lower Layer of the Plume*

Position	*Time (hrs after dump)*	*Maximum SS Concentration ($mg\ l^{-1}$)*	*Average SS Concentration ($mg\ l^{-1}$)*	*DO Reduction ($mg\ l^{-1}$)*
0	0	1024.4		0
1a	0.5	349.83	687.115	0.13
1b	1	127.36	238.595	0.18
1	3.84	20.03	73.695	0.26
2	7.68	8.58	14.305	0.28
3	11.52	2.32	5.45	0.29
4	15.36	1.81	2.065	0.29
5	19.2	1.66	1.735	0.29

Notes Re-aeration was ignored. This is a conservative assumption
The plumes at position 1a and position 1b are not shown in *Figure G2a*. Maximum concentrations for these positions were extracted from model output files.

By comparing the values in Table G3a with the values in G3b it can be seen that less DO depletion is predicted in the upper layer than in the lower. This reflects higher suspended sediment concentration predictions in the lower layer.

Depletion in the upper layer of is predicted to be less than 0.1 mg l^{-1}. The majority of this depletion occurs within the first four hours of the life of the plume as can be seen by comparing the DO reduction that has occurred by the plume reaches position 1, which is approximately 3.84 hours after dumping, with the DO reduction that has occurred by the plume reaches subsequent positions. Depletion in the lower layer is predicted to be less than 0.3 mg l^{-1}. As is the case in the upper layer, the majority of the depletion occurs within the first four hours.



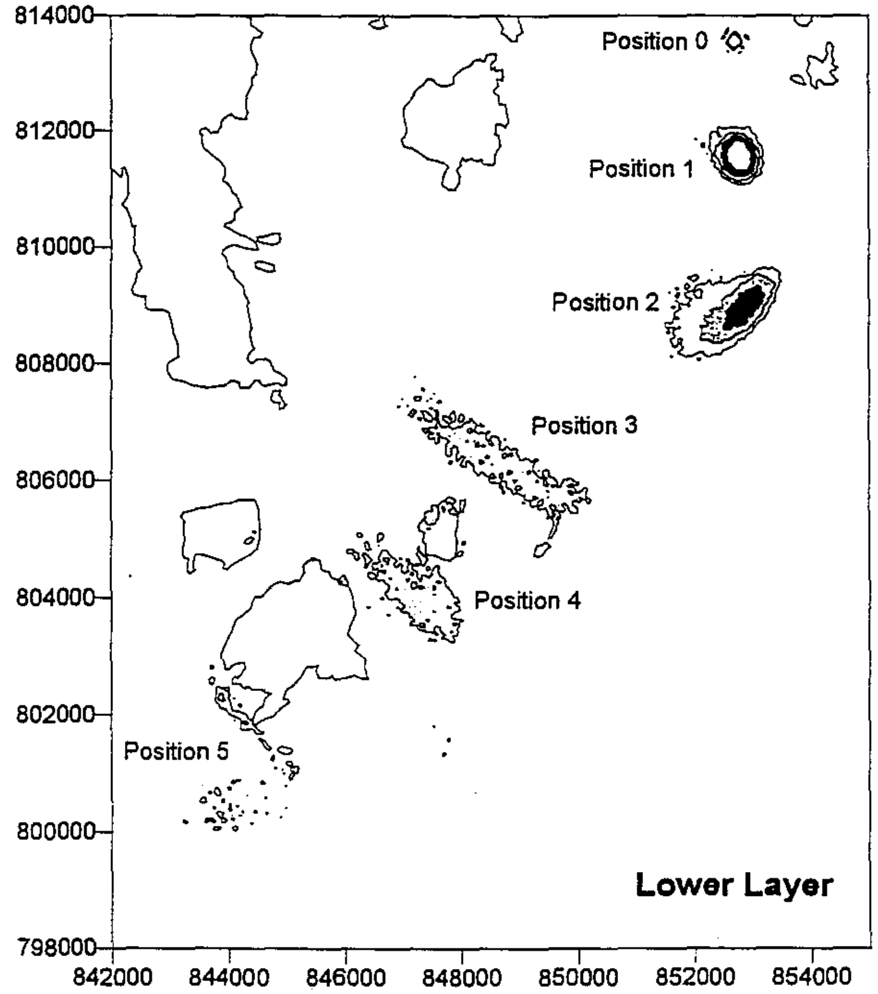


FIGURE G2a SNAP SHOT OF PLUMES FROM TRAILER DISPOSAL

Annex H

Background to Stability Analyses to Determine Backfill Level

H1 INTRODUCTION

This *Annex* presents additional information on calculations performed to evaluate the stability of the backfilled pit presented in *Section 3.9*. Information is presented on:

- tidal and seasonal current predictions;
- waves height predictions including the model used, and wave induced currents;
- the stability analyses used including background theory.

H2 PREDICTION OF TIDAL AND SEASONAL CURRENTS

Tidal and seasonal currents were predicted using the WAHMO 2 layer model. Further details of the model are provided in *Section 3* of this report because the WAHMO model was also used for hydrodynamic predictions for the SEDPLUME sediment transport model. The model simulations were conducted using the bathymetry for the ETLC MBAs prior to sand extraction taking place which is conservative because it results in higher predicted current speeds. Upper and lower level tidal current velocities were output from the model and the maximum values from the spring tides are presented in *Table H1a.* The upper level represents the top 3 m of the water column and the lower level the remaining depth.

Table H2a *Current Speeds Predicted by WAHMO in the ETLC MBAs*

Location	Season	Model Layer	Speed ($m s^{-1}$)	Direction (°N)
RP1	Wet	Upper	0.36	38
		Lower	0.21	13
	Dry	Upper	0.49	217
		Lower	0.37	200
RP2	Wet	Upper	0.40	52
		Lower	0.18	28
	Dry	Upper	0.43	223
		Lower	0.34	215
RP3	Wet	Upper	0.52	60
		Lower	0.20	50
	Dry	Upper	0.49	230
		Lower	0.41	229

Shear stresses resulting from tidal and seasonal currents were calculated from peak spring tide values. These are greater than the equivalent neap tide values and consequently the bed shear stresses during neap tides will be less than those quoted.

H3 *PREDICTION OF WAVE INDUCED CURRENTS*

The location of the Tung Lung Chau Borrow Pits is such that the most significant component of wave energy at the site will be waves approaching from southerly directions from the South China Sea. Offshore waves will be modified by the processes of depth refraction and shoaling as they propagate inshore towards the Tung Lung Chau Borrow Pits. In this Study Voluntary Ship Observations (VOS)[1] of waves in the area were used to derive extreme offshore wave conditions. The HR Wallingford wave refraction model OUTRAY was then used to represent the effects of refraction and shoaling on these waves as they propagate inshore.

The VOS data obtained for the Victoria Harbour study covers a sea area defined by 18.8° to 21.8°N, 112.0° to 115.0°E, and contains approximately 24,000 observations made between 1949 and 1985. The data is divided into eight 30° sectors centred on 60°N through south to 270°N. For this study extreme wave heights for return periods of 0.1, 1, 10, and 100 years were derived for each sector by fitting a three-parameter Weibull distribution to the data. Extreme offshore wave conditions are presented in *Tables H2b, H2c and H2d.* These Tables also show the results of OUTRAY modelling discussed in the following Section. Data in *Table H2d* shows the largest offshore waves approach the area of interest from the 60°N sector for all return periods. For the shorter return periods the 60°N and 90°N sector wave heights are noticeably the largest.

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[1] HR Wallingford (1988) Hydraulic and Water Quality Studies for Victoria Harbour Report EX 1703

Table H2b *Offshore Wave Data and Nearshore Wave Refraction Results at RP1*

Return Period (years)	Offshore Direction (°N)	H_s (m)	T_m (s)	Nearshore Direction (°N)	H_s (m)	T_m (s)
0.1	120	1.4	4.2	154	0.7	4.0
	150	1.6	4.4	163	1.0	4.2
	180	2.2	5.2	169	1.3	5.0
	210	2.2	5.2	173	1.0	5.1
	240	1.5	4.3	181	0.3	4.4
1	120	3.6	6.6	147	1.9	6.7
	150	3.9	6.9	164	2.4	6.8
	180	4.2	7.2	171	2.4	7.0
	210	4.1	7.1	174	1.8	6.9
	240	3.6	6.6	181	0.8	6.5
10	120	5.8	8.4	143	3.3	9.0
	150	6.3	8.8	164	4.1	9.1
	180	6.1	8.6	171	3.6	8.7
	210	5.9	8.5	175	2.6	8.5
	240	5.5	8.2	182	1.2	8.3
100	120	8.0	9.9	142	5.0	10.9
	150	8.8	10.4	164	6.1	11.1
	180	8.0	9.9	172	5.0	10.3
	210	7.6	9.7	176	3.5	9.9
	240	7.3	9.5	184	1.7	9.8

Table H2c *Offshore Wave Data and Nearshore Wave Refraction Results at RP2*

Return Period (years)	Offshore Direction (°N)	H_s (m)	T_m (s)	Nearshore Direction (°N)	H_s (m)	T_m (s)
0.1	90	3.1	6.2	114	2.4	6.0
	120	1.4	4.2	125	1.3	4.2
	150	1.6	4.4	141	1.4	4.4
	180	2.2	5.2	155	1.5	5.1
	210	2.2	5.2	167	1.0	5.2
	240	1.5	4.3	180	0.3	4.5
1	90	5.2	8.0	118	4.0	7.9
	120	3.6	6.6	129	3.2	6.5
	150	3.9	6.9	143	3.3	6.8
	180	4.2	7.2	156	2.9	7.1
	210	4.1	7.1	166	1.9	7.0
	240	3.6	6.6	177	0.8	6.8
10	90	7.1	9.3	121	5.6	9.4
	120	5.8	8.4	132	5.2	8.3
	150	6.3	8.8	144	5.4	8.8
	180	6.1	8.6	156	4.3	8.7
	210	5.9	8.5	166	2.7	8.6
	240	5.5	8.2	176	1.3	8.5
100	90	8.8	10.4	122	7.1	10.6
	120	8.0	9.9	133	7.3	10.0
	150	8.8	10.4	145	7.8	10.6
	180	8.0	9.9	156	5.7	10.1
	210	7.6	9.7	166	3.6	9.8
	240	7.3	9.5	175	1.8	10.0

Table H2d *Offshore Wave Data and Nearshore Wave Refraction Results at RP3*

Return Period (years)	Offshore Direction (°N)	H_s (m)	T_m (s)	Nearshore Direction (°N)	H_s (m)	T_m (s)
0.1	60	4.6	7.5	107	2.8	7.7
	90	3.1	6.2	115	2.6	6.1
	120	1.4	4.2	126	1.3	4.2
	150	1.6	4.4	140	1.4	4.4
	180	2.2	5.2	152	1.5	5.1
	210	2.2	5.2	163	0.9	5.2
	240	1.5	4.3	175	0.3	4.8
1	60	6.7	9.1	109	4.4	4.4
	90	5.2	8.0	117	4.4	8.1
	120	3.6	6.6	127	3.3	6.5
	150	3.9	6.9	139	3.3	6.7
	180	4.2	7.2	151	2.7	6.9
	210	4.1	7.1	162	1.6	6.8
	240	3.6	6.6	174	0.7	6.7
10	60	8.5	10.2	110	5.9	11.0
	90	7.1	9.3	118	6.2	9.7
	120	5.8	8.4	128	5.4	8.4
	150	6.3	8.8	140	5.3	8.7
	180	6.1	8.6	151	3.8	8.4
	210	5.9	8.5	162	2.2	8.2
	240	5.5	8.2	173	1.0	8.0
100	60	10.2	11.2	111	7.3	12.2
	90	8.8	10.4	118	7.9	10.9
	120	8.0	9.9	129	7.6	10.1
	150	8.8	10.4	140	7.5	10.4
	180	8.0	9.9	151	5.1	9.8
	210	7.6	9.7	161	2.9	9.4
	240	7.3	9.5	171	1.3	9.2

H3.1 DESCRIPTION OF THE OUTRAY WAVE REFRACTION MODEL

The HR Wallingford OUTRAY wave refraction model predicts wave activity at coastal sites given a spectral description of offshore wave conditions. The model uses the concept of wave rays, which are lines perpendicular to wave crests. These rays are tracked seawards from a selected inshore point to the offshore edge of the model grid system, using Snell's Law to calculate changes in ray paths due to refraction effects. Because the ray paths are reversible, each ray then gives information on how energy travels between the seaward edge of the grid system and the inshore point of interest.

Computations in the OUTRAY model can be split into two parts. The first stage involves consideration of many ray paths, representing a wide range of offshore wave periods and directions, to generate a set of matrices known as transfer functions. These transfer functions describe the transformation of wave energy between the edge of the refraction grid and the inshore point of interest. The second stage uses these transfer functions to modify each of the offshore spectra into a corresponding inshore spectrum at the specified inshore point.

OUTRAY represents the effects of wave refraction, shoaling and energy dissipation due to seabed friction. The effects of wave breaking in shallow water in the nearshore zone are accounted for using empirical methods.

H3.2 APPLICATION OF OUTRAY TO THIS STUDY

An OUTRAY refraction grid for Hong Kong was set up by HR Wallingford during earlier studies in the Study Area [2][3] and was most recently applied to a study of the proposed Eastern Waters Borrow Pits[4]. For the this Study the same grid was recommissioned and extended to include the area near the Tung Lung Chau Borrow Pits. The additional bathymetric data required was obtained from Admiralty Chart 937 and from recent bathymetric surveys of the East Tung Lung Chau area. The model was set up and run for conditions prior to extraction of the sand which are representative of the bathymetry following the completion of backfilling.

Using OUTRAY the offshore wave conditions described were transformed to the three Points RP1, RP2 and RP3, shown in *Figure 3.9a*. Point RP1 lies towards the northerly end of the borrow area at approximately 852925 mE 813950 mN. As this point is sheltered by the Ninepins Group of islands, offshore direction sectors in the range 120°N through south to 240°N were considered. Point RP2 lies in the middle of the borrow area at approximately 851475 mE 811650 mN. RP2 is also sheltered by the Ninepins Group, although to a lesser extent than RP1, and hence offshore sectors in the range 90°N through south to 240°N were

[2] HR Wallingford (1988) Hydraulic and Water Quality Studies for Victoria Harbour Report EX 1703

[3] HR Wallingford (1991) Analysis of Wave Conditions and Water Levels at Black Point, Hong Kong Report EX 2300

[4] Hyder Environmental (1996) Sand Dredging and Backfilling of Borrow Pits in the Potential Eastern Waters Borrow Area

considered. Point RP3 lies at the southerly end of the area at approximately 849750 mE 808900 mN. RP3 is less sheltered by the Ninepins Group than the other two points, hence offshore sectors from 60°N through south to 240°N were considered. All the model runs were carried out using a water level of +2.0 mPD, corresponding to Mean High High Water at Waglan Island in the Po Toi Island Group.

H3.3 *DISCUSSION OF RESULTS OF OUTRAY MODELLING*

The wave conditions predicted at the refraction points are given in *Tables H2b, H2c* and *H2d* for points RP1, RP2 and RP3 respectively. Each table also shows the extreme offshore waves which propagate from the South China Sea.

Wave conditions predicted at Point RP1 are presented in *Table H2b*. RP1 is the most sheltered of the three points, lying to the west of the Ninepins group of islands. The largest predicted waves approach RP1 from 164°N with a significant wave height of 6.1 m for the 100 year return period. The largest waves approach RP1 from directions in the range 164°N to 170°N for all return periods, which is consistent with the combination of the exposure of RP1 to southerly directions, the bathymetry of the area and the larger offshore wave conditions from the 150°N and 180°N direction sectors.

Point RP2 lies in the middle of the borrow area and is less sheltered than RP1. Predicted wave conditions for this refraction point are presented in *Table H2c*. Comparison with *Table H2b* for Point RP1 shows the more exposed nature of RP2 in the overall increase of the predicted inshore significant wave heights. At Point RP2 the largest predicted significant wave height is 7.8 m, which approaches from 145°N for the 100 year return period. For the shorter return periods of 0.1 and 1 year the largest waves approach from directions between 114°N and 118°N, reflecting the larger offshore wave conditions from the 90° direction sector for these return periods.

The predicted wave conditions for RP3 are given in Table 3. Point RP3 is the most southerly of the refraction points considered. It is more exposed than RP1, and similar to RP2, but receives more shelter from the Po Toi Island Group than either of the other two, as can be seen by comparison of *Table H2d* with *Tables H2c* and *H2d*. The largest waves approach RP3 from 118°N with a significant wave height of 7.9 m for the 100 year return period. The largest waves approach RP3 from directions in the range 107°N to 118°N for all return periods, consistent with the exposure of this point, the local bathymetry and the larger offshore wave conditions from the 60°N and 90°N directions sectors.

H3.3.1 *Typhoons*

For typhoon conditions, in accordance with practice in previous borrow pit studies, it has been assumed that wind and surge induced current speeds result in a doubling of the current induced bed shear stress. Wave conditions associated with the typhoon have been assumed to correspond to the 1 in 100 year return period wave. Typhoons only occur only during the wet season and so the bed shear stress induced by the wet season peak spring tide flows was doubled to provide the predicted representative typhoon tidal / oceanic conditions.

H4 *BACKGROUND THEORY FOR BACKFILL STABILITY ANALYSES*

The following sections giving background theory relevant to this Study are derived from the HR Estuarine Muds Manual[5], the HR Manual of Marine Sands[6] and previous borrow pit stability studies.

H4.1 *FLOW INDUCED BED SHEAR STRESS*

The shear stress generated at the bed by currents can be obtained from direct field measurement or estimated by a knowledge of the bed roughness, flow depth and the flow characteristics. Estimates can be made either from the average flow velocities throughout the depth or from a measured through depth flow profile.

H4.1.1 *Flow Averaged Through Depth*

For a given depth averaged velocity, u(ms^{-1}), the flow induced bed shear stress, τ_b (Nm^{-2}), is calculated using:

$$\tau_b = \rho_w C_D u^2$$

where ρ_w is the density of the fluid (kgm^{-3}) and C_D is the drag coefficient calculated from:

$$C_D = \left[\frac{0.40}{\ln\left(\frac{h_0}{z_0}\right) - 1} \right]^2$$

where h_0 is the total water depth (m) and z_0 is the bed roughness length. The bed roughness length, z_0, can be estimated from the Nikuradse roughness, k_s, by

$$z_0 = \frac{k_s}{30} \qquad (1)$$

Previously, values for k_s of 1.0 mm and 0.1 mm have been used. For this study,

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[5] HR Wallingford (1992) Estuarine Muds Manual
[6] HR Wallingford (1994) Manual of Marine Sands

1.0 mm was used in order to give an upper estimate for the bed shear stresses.

H4.1.2 *Variable Flow Through Depth*

In situations, such as those occurring in the borrow pits, where considerable variations in the bathymetry exist, the through depth flow profiles cannot be well approximated by a logarithmic curve. In cases such as this, it is the lower part of the flow velocity profile that has the greatest impact on the bed shear stresses. It is therefore proposed that for this study only the lower part of the velocity profile is approximated by a logarithmic profile, given by:

$$u(z) = \frac{u_*}{\kappa} \ln\left(\frac{z}{z_0}\right) \tag{2}$$

where z is the height above the bed (m), u(z) is the corresponding velocity (ms^{-1}), u_* is the frictional shear velocity, κ=0.40 is von Karman's constant and z_0 is the bed roughness length.

For these calculations, equation (1) above is replace by a more complicated expression (1A) derived from experimental data.

$$z_0 = \frac{k_s}{30}\left[1 - \exp\left(\frac{-k_s u_*}{27\nu}\right)\right] + \frac{\nu}{9u_*} \tag{1A}$$

This equation gives z_0 in terms of u_*, and so the velocity profile can be approximated by use of equations (1A) and (2) using u_* as a free variable. Once an estimate of u_* has been obtained in this manner, the bed shear stress, τ_b, is obtained from:

$$\tau_b = \rho_w u_*^2$$

H4.2 *Wave Induced Bed Shear Stress*

The shear stress generated at the bed by waves can be obtained by direct field measurement or estimated from a knowledge of the bed roughness, flow depth, wave height and period. For given values of wave height and period, and depth of water, the maximum bottom orbital velocity can be calculated using first order linear wave theory from the relationship

$$U_m = \frac{\pi H}{T\sinh\left(2\pi\frac{d}{L}\right)}$$

where: U_m = maximum bottom orbital velocity (ms^{-1})
H = wave height (m)

T = wave period (s)
d = water depth (m)
L = wave length (m)

The magnitude of the wave length can be determined iteratively, using

$$\omega^2 = gk \tanh(kd)$$

where: $\omega = 2\pi/T$ (s^{-1})
g = acceleration due to gravity (ms^{-2})
$k = 2\pi/L$ (m^{-1})

However, an explicit algebraic expression has been developed at HR which relates the root mean square bottom orbital velocity U_{rms} to significant wave height, H, zero crossing period, T_z, water depth, d and gravitational acceleration, g.

$$U_{rms} = \frac{0.25\ H}{T_n\ \left(1 + At^2\right)^3}$$

where the natural wave period, T_n, is defined by

$$T_n = \sqrt{d/g}$$

and

$$A = \left[6500 + (0.56 + 15.54\ t)^6\right]^{1/6}$$

and

$$t = \frac{T_n}{T_z} = 1/T_z\sqrt{d/g}$$

The maximum bottom orbital velocity, U_m, is then calculated using the relationship

$$U_m = \sqrt{2}U_{rms}$$

The peak bed shear stress under a wave, τ_m, can be calculated from

$$\tau_m = \frac{1}{2}\rho_w f_w U_m^2$$

where f_w is the bed friction factor calculated from

either $f_w = 0.3$

if $A/k_s \leq 1.57$

or

$$f_w = 0.00251 \exp\left[5.21\left(\frac{A}{k_s}\right)^{-0.19}\right]$$

if $A/k_s \geq 1.57$

where $A+U_mT/2pi$ is the semi-orbital excursion length.

H4.3 *COMBINED FLOW AND WAVE INDUCED BED SHEAR STRESSES*

In this study, three methods are used to calculate the combined wave and flow induced bed shear stress: linear addition and the methods of Fredsøe[7] and Huynh-Tanh and Temperville[8]. In previous studies, these methods have produced similar results, but they are all included for completeness.

Using similar methodologies to those outlined in the previous two sections, the wave and flow induced bed shear stresses due to waves alone, τ_w, and due to currents alone, τ_c, are calculated.

For the Fredsøe[9] and Huynh-Tanh and Temperville[10] methods, the relative importance of the two stresses is given by

$$x = \frac{\tau_c}{\tau_c + \tau_w}$$

It is now possible to calculate the coefficients

$$Y = 1 + ax^m(1-x)^n$$

and

$$y = x\left[1 + bx^p(1-x)^q\right]$$

knowing that a, m and n are obtained by equations of the form

$$a = a_1 + a_2|\cos\phi|^I + \left(a_3 + a_4|\cos\phi|^I\right)\log\left(\frac{f_w}{C_D}\right)$$

and that b, p and q come from equations of the form

[7] Fredsoe (1984) *Op Cit*
[8] Huynh-Thanh and Temperville (1991) *Op Cit*
[9] Fredsoe (1984) *Op Cit*
[10] Huynh-Thanh and Temperville (1991) *Op Cit*

$$b = b_1 + b_2|\cos\phi|^J + \left(b_3 + b_4|\cos\phi|^J\right)\log\left(\frac{f_w}{C_D}\right)$$

where ϕ is the angle between the wave direction and the current direction.

The values for $a_1..a_4$, $b_1..b_4$, $m_1..m_4$, $n_1..n_4$, $p_1..p_4$, $q_1..q_4$, I and J are given for each of the Fredsoe[11] and Temperville[12] models.

Finally the coefficients Y and y are used for calculating the maximum and mean bed shear stresses τ_{max} and τ_m.

$$\tau_{max} = Y\left(\tau_c + \tau_w\right)$$

$$\tau_m = y\left(\tau_c + \tau_w\right)$$

H4.4 *CONSOLIDATION*

Naturally formed or deposited beds of cohesive material will consolidate under their own self weight. This process comprises the expulsion of the pore water with accompanying large strains. The excess pore pressures within the cohesive bed will dissipate with time and the interparticle stress σ_v' will increase. The floc matrix will compress to form a structure of higher density, ρ_d, with a correspondingly lower permeability k.

If there is an instantaneous increase in the total stress such as that which would be caused by placement of a hopper load of mud, the pore pressure is seen, by experiment, to rise immediately. With time the pore pressure returns to its original value as water drains from the pore spaces. The load is therefore gradually transferred to the particle framework. With this increasing effective stress the particle framework strains and this is accompanied by a decrease in porosity and an increase in density. When consolidation is complete the pore water pressure is at its equilibrium value and the effective stress is equal to the total stress.

The consolidation process for a cohesive bed will generally result in a density profile which increases with depth below the surface and with time. The density at any point and time within a cohesive sediment bed will depend to a large degree on the time history of the deposition to the bed and the physical characteristics of the cohesive sediment.

Two empirical relationships have been derived from laboratory tests in consolidation columns on cohesive sediments. The vertical effective stress, σ_v', is the interparticle stress and is given by the difference between the total stress and the pore water pressure. The effective stress can be expressed as a function of dry density, ρ_d, by

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[11] Fredsoe (1984) *Op Cit*
[12] Huynh-Thanh and Temperville (1991) *Op Cit*

$$\sigma_v' = C_1 + C_2\rho_d + C_3\rho_d^2$$

The permeability k of the cohesive sediment can also be expressed as a function of dry density by

$$\log(k) = C_4 + C_5\rho_d$$

where C_1 ... C_5 are laboratory derived constants.

The consolidation process cannot be normalised in terms of density alone. This is because the absolute bed thickness affects the rate of dissipation of pore water. Hence, for two beds of equal density but different thicknesses the thinner bed would be expected to consolidate more quickly.

H4.5 EROSION OF COHESIVE MATERIAL

The flocs on the surface of a cohesive sediment bed are bound together by interparticle attractive forces. To remove a floc by flowing water requires a shear stress sufficient to overcome the attractive forces. The erosion shear strength of a cohesive sediment surface is defined as the shear stress required to be exerted by the flowing water to cause erosion of flocs. The erosion shear strength, τ_e, of a cohesive sediment bed has been shown by laboratory studies[13] to be related to the dry density ρ_d by the following empirical equation

$$\tau_e = E_1\rho_d^{E2} \qquad (1)$$

The rate of erosion of cohesive sediment has been studied in laboratory flume experiments at HR. It has been found that the rate of erosion, dm/dt, is related to the magnitude of the excess shear stress, $(\tau_b - \tau_e)$, by the constant m_e. This can be expressed by the empirical equation.

$$\frac{dm}{dt} = m_e\ (\tau_b - \tau_e) \qquad (2)$$

There is considerable variation in the erosion properties of cohesive sediments from different sites. Tests on mud from Hong Kong have lead to the choice of empirical values;

$$E_1 = 0.0014,\ E_2 = 1.2 \text{ and } m_e=0.0007$$

It should be noted that the laboratory experiments were carried out for dry densities less than about 200 kgm^{-3} (bulk density $\approx$1,150 kgm^{-3}) and that extrapolation for the higher densities is a best estimate based on the results of other laboratory experiments at HR[14].

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[13] HR Wallingford (1992) *Op Cit*
[14] HR Wallingford (1992) *Op Cit*

Annex I

Species Lists and Abundance Data from Previous Reports

Table I1 *Invertebrate species captured during trawls in the Ninepins area* [1]

	Species
Phylum Arthropoda	*Arcania heptacantha*
Subphylum Crustacea	*Charybdis cruciata*
Class Malacostraca	*Charybdis gracilimanus*
Order Decapoda	*Charybdis hongkongensis*
(Crabs)	*Charybdis feriatus*
	Charybdis truncata
	Charybdis vadorum
	Charybdis variegata
	Charybdis sp
	Dorippe granulata
	Eucrate crenata
	Eucrate sp
	Myra fugax
	Portunus haanii
	Portunus hastatoides
	Portunus sanguinolentus
	Pugettia sp
	Unidentified sp
(Shrimps)	*Acetus* sp
	Alpheus sp
	Heterocarpus sp
	Metapenaeus affinis
	Metapenaeus barbata
	Metapenaeus ensis
	Metapenaeus sp
	Penaeus sp
	Parapenaeopsis hardwickii
	Unidentified sp
Order Stomatopoda	*Oratosquilla oratoria*
(Mantis Shrimps)	*Squilla* sp
Phylum Mollusca	*Anadara subcrenata*
Class Bivalve	*Anomalocardia squamos*
	Bassina calophylla
	Corbulla crassa
	Dosinia sp
	Laternula anatina
	Paphia sp
Class Gastropoda	*Apollon* sp
	Armina japonica

(1) Binnie Consultant Ltd (1994a) Marine Ecoloogy of the Ninepin Islands

	Species
	Babylonia lotusa
	Babylonia sp
	Bedevina birileffi
	Bufonaria rana
	Distorsio reticulata
	Fusinus sp
	Fusolatirus sp
	Hemifusus ternatana
	Niotha variegata
	Oliva perviana
	Polinices sp
	Rapana sp
	Sipholonia sp
	Turitella sp
	Zeuxis squinijoreusus
	Unidentified sp
Class Cephalopoda	Unidentified sp
Phylum Chorodata	*Styela plicata*
Subphylum Urochordata	
Class Ascidiacea	
Phylum Echiura	*Thalassema sabinum*
Phylum Echinodermata	
Class Holothuroidea	Unidentified sp
Phylum Cnidaria	
Class Anthozoa	
Order Actiniaria	*Carcinactis ichikawai*
Order Pennatulacea	*Cavernlaria obesa*
	Pteroeides sparmanni

Table I2 ***Fish and Invertebrate Species and Abundance Captured at Ninepins and Po Toi by different Fishing Methods*** [2]

Site	Fishing Method	Type	Family	Species	Abundance of Eggs	Abundance of Larvae	Abundance of Adults	Notes
Ninepins	Trawling	Fish	Apogonidae	*Apogon ellioti*			1	
				Apogon kiensis			1	
			Arripididae	*Argyrosomus aneus*			1	
			Carangidae	*Caranx kalla*			6	
				Parastromateus niger *			1	
			Clupeidae	*Amblygaster sirm*			4	* Possible
			Engraulididae	*Thryssa hamiltonii*			602	
				Thryssa setirostris			918	
			Leiognathidae	*Leiognathus berbis*			3	
				Leiognathus bindus			3	
				Leiognathus ruconius			6497	
			Minoiae	*Minous pusillus*			1	
			Mullidae	*Upeneus moluccensis*			1	
			Myctophidae	*Benthosenma pterotum*			1	
			Nemipteridae	*Nemipterus virgatus*			2	
			Polynemidae	*Polynemus sextarius*			3	
			Sciaenidae	*Johnius belengeri*			18	
				Johnius sina			12	
				*Larimichthys crocea**			14	* Possible
				Larimichthys polyactis			3	
			Scombridae	*Scomberomorus guttatus*			1	
			Stromateidae	*Pampus argenteus*			47	
				Psenopsis anomala *			1	* Possible
			Synodontidae	*Harpodon microchir*			3	
			Tetradontidae	*Takifugu xanthopterus*			1	
			Triacanthidae	*Triacanthus biaculeatus*			2	
			Trichiuridae	*Trichiurus lepturus*			398	
			Triodontidae	*Lagocephalus gloveri*			2	
				Lagocephalus lunaris			3	
				Lagocephalus wheeleri			3	

(2) Binnie Consultants Ltd. (1995f) op cit

Site	Fishing Method	Type	Family	Species	Abundance of Eggs	Abundance of Larvae	Abundance of Adults	Notes
Ninepins	Gill Net	Fish	Acanthuridae	*Acanthurus olivaceus*			2	
			Balistidae	*Arotrolepis sulcatus*			1	
			Carcharhinidae	*Chaetodon wiebei*			2	
			Exocoetidae	*Exocoetidae**			1	* Possible
			Grammistidae	*Diploprion bifasciatum*			2	
			Kyphosiae	*Microcanthus strigatus*			3	
			Labridae	*Halichoeres dussumieri*			1	
				Pseudolabrus japonicus			1	
				Pteragogus flagellifera			2	
				Suezichthys gracilis			1	
				Stethojulis interruptus			3	
			Mullidae	*Parupeneus spilurus*			2	
			Nemipteridae	*Scolopsis vosmeri*			1	
			Ophichthidae	*Brachysomophis cirrhochilus*			1	
			Pentacerotidae	*Pentacerotidae**			1	
			Scorpaenidae	*Sebastiscus tertius*			3	
			Siganidae	*Siganus fuscescens*			2	
	Trawl		Tetraodontidae	*Chelonodon patoca*			2	
			Triodontidae	*Takifugu poecilonotus*			1	
		Invertebrates		*Loligo edulis*			23	** Not Specified in Source
				Sepia lycidas			10	
				Penaeus penicillatus			3	
	Plankton Trawl	Egg and Larvae	Callionymidae	*Metapenaeopsis palmensis*			3	
			Scorpaenidae	*Callionymus richardsoni*		1 ***		
			Sparidae	*Sebastiscus marmoratus*		76 ***		
				Sparus latus	7 ***			*** Abundance per m^3
Po Toi	Trawl	Fish	Apogonidae	*Apogon ellioti*			41	
				Apogon lineatus			9	
				Apogon semilineatus			2	
				Apogonichthys			15	
				Apogonichthys lineatus			51	
			Ariidae	*Arius maculatus*			1	
			Arripididae	*Argyrosomus aneus*			1	
			Carangidae	*Alepes*			2	
				Caranx kalla			26	
				Trachurus japonicus			1	
			Chaetodontidae	*Chaetodon modestus*			1	

Site	Fishing Method	Type	Family	Species	Abundance of Eggs	Abundance of Larvae	Abundance of Adults	Notes
Po Toi	Trawling	Fish	Clupeidae	*Ilisha elongata*			1	
				Sardinella lemuru			1	
				Sardinella sindensis			1	
			Cynoglossidae	*Cygnoglossus lida*			1	
			Engraulididae	*Setipinna taty*			5	
				Stolephorus insularus			6	
				Thryssa hamiltonii			301	
				Thryssa kammalensis			51	
				Thryssa setirostris			132	
				*Thryssa setirostris**			74	* Possible
				Thryssa thefuensis			75	
			Gobionellinae	*Oxyurichthys tentacularis*			1	
			Lactariidae	*Lactarius lactarius*			3	
			Leiognathidae	*Leiognathus berbis*			7	
				Leiognathus bindus			1	
				Secutro ruconius			190	
			Minoinae	*Minous pusillus*			19	
			Muraenesocidae	*Muraenesox bagio*			2	
			Myctophidae	*Benthosenma pterotum*			54	
			Nemipteridae	*Nemipterus japonicus*			1	
				Nemipterus virgatus			2	
			Ophichthidae	*Ophichthus cephalzona*			1	
				Pisodonphis cancrivorus			1	
			Percichthyidae	*Lateolabrax japonicus*			1	
			Polynemidae	*Polynemus sextarius*			11	
			Rhinogobiinae	*Parachaeturichthys polynema*			2	
			Sciaenidae	*Collichthys lucidus*			106	
				Johnius belengeri			70	
				Larimichthys polyactis			1	
				*Sciaenidae**			2	* Possible
			Siganidae	*Siganus fuscescens*			3	
			Stromateidae	*Pampus argenteus*			18	
			Synodontidae	*Harpadon microchir*			5	
			Tetraadontidae	*Legocephalus lunaris*			1	
			Trichiuridae	*Trichiurus lepturus*			320	
			Triodontidae	*Lagocephalus lunaris**			2	* Possible

Site	Fishing Method	Type	Family	Species	Abundance of Eggs	Abundance of Larvae	Abundance of Adults	Notes
Po Toi	Trawling	Invertebrates	**	*Solenocera sinensis*			88	** Not Cited in Source
				*Sepia lycidas**			71	* Possible
				Squilla spp.			32	
				Loligo edulis			17	
				Metapenaeus ensis			10	
				Peaeus penicillatus			1	
				Portunus sanguinolentus			1	
				Atypopenaeus compressipes			18	
				Pandalidae			17	
				Charybdis feriata			12	
				Parapenaeopsis tenella			10	
				Charybdis spp.			8	
				Charybdis variegata			4	
				Charybdis truncata			14	
				Trachypenaeus fulvus			1	

Site	Fishing Method	Type	Family	Species	Abundance of Eggs	Abundance of Larvae	Abundance of Adults	Notes
Poi Toi	Gill Netting	Fish	Albulidae	*Albula glossodonta*			1	
			Bothidae	*Pseudorhombus oligodon*			1	
			Carcharhinidae	*Chaetodon wiebeli*			1	
			Cynoglossidae	*Cynogolssus sinicus*			1	
				Paraplagusia japonica			8	
			Elopidae	*Elops machnata*			2	
			Ephipidae	*Drepane punctata*			1	
			Epinephelinae	*Epinephelus awoara*			1	
			Gerreidae	*Gerres filamentosus*			3	
			Grammistidae	*Diploprion bifasciatum*			10	
			Kyphosidae	*Pomadasys kaakan*			1	
			Labridae	*Stethojulis interruptus*			2	
			Lutjanidae	*Lutjanidae**			2	* Possible
			Monacanthidae	*Stephanolepis cirrhifer*			2	
			Mullidae	*Parupeneus spilurus*			2	
				Upeneus vittatus			1	
			Platycephalidae	*Platycephalus indicus*			6	
			Platyrhinidae	*Platyrhina sinensis*			3	
			Polynemidae	*Eleutheronema tetradactylus*		3	4	
			Sciaenidae	*Larimichthys polyactis*		369	1	
			Scorpaenidae	*Sebastiscus tertius*			1	
			Siganidae	*Siganus fucesens*			1	
			Sparidae	*Dentex tumifrons*			2	
			Synodontidae	*Synodus jaculum*			2	
				Trachinocephalus mypos			4	
			Tetraodontidae	*Chelonodon patoca*			1	
			Triodontidae	*Lagocephalus gloveri*			3	
Poi To	Plankton Trawl	Egg and Larvae	**	*Callionymidae richardsoni*			3	** Not Defined in Source
				Scorpaenidae marmoratus			1	

Table I3 *Coral Species Observed in Eastern Waters*[3]

Species	Site				
	South Ninepin	East Ninepin	One Foot Rock	Tung Lung Chau	Ching Chau
Dendronephthya gigantea	*		*	*	*
Dendronephthya spA		*			
Dendronephthya spB		*			
Balanophyllia sp			*	*	*
Psammocora sp		*	*		
Tubastrea aurea		*	*		
Tubastrea gracilis		*	*		
Cyphastrea serailia	*			*	*
Goniastrea aspera				*	
Pleiastrea versipora		*		*	*
Acropora candelabrum	*			*	*
Favia favus	*			*	*
Favites flexuosa					
Favites pentagona					
Goniopora sp					
Hydnophora exesa					*
Psammocora superficialis				*	*
Antipathes densa		*			
Echinogorgia sp		*			
Dendrophyllia gracilis		*			
Tubastrea coccinea		*	*		
Junceella juncea		*			
Gorgonian sp A			*		
Gorgonian sp B			*		
Gorgonian sp C			*		
Gorgonian sp D			*		
Gorgonian sp E			*		
Gorgonian sp			*		
Palysoa sp			*	*	
Coscinaraea columna				*	
Favites abdita				*	*
Goniopora columna				*	
Oulastrea crispata				*	*
Porites lobata				*	*
Cyphastrea microphthalma					*
Leptastrea purpurea					*
Montipora informis					*
Pavona varians					*
Platygyra pini					*

(3) Binnie Consultant Ltd. (1994a) *op cit*

Table I4 *Fish Species Abundance Observed at One Foot Rocks and Fury Rocks*[4]

Location	Common Name	Scientific Name
One Foot Rock	*Butterflyfish*	*Chaetodontidae spp.*
	Cardinal fish	*Apogonidae spp.*
	Damselfish	*Pomacentridae spp.*
	Grouper	*Epinephalus spp.*
	Rabbitfish	*Siganus spp.*
	Snapper	*Lutjanus spp.*
	Sweetlips	*Diagramma spp.*
	Wrasse	*Scaridae spp.*
Fury Rocks	*Anchovies*	*Not Specified*
	Barracuda	*Sphyraena barrauda*
	Goatfish	*Parupeneus spp.*
	Rockcods	*Epinephelus microdon*
	Scorpionfish	*Sebastipistes spp*
	Seaperch	*Lutjanus spp.*
	Surgeonfish	*Acanthurus spp.*
	Rabbitfish	*Siganus spp.*

(4) Binnie Consultants Ltd (1995F) *op cit*

Annex J

Species List and Abundance Data from Trawls in the Vicinity of the ETLC MBAs

Species and abundance data for Gastropods, Bivalves and Fish collected from Beam Trawl catches in and around the ETLC MBAs, data obtained from Leung & Morton 1997, and Leung 1997 (see Section 4 for full reference).

Table J1 *Gastropod species collected from close to or within the ETLC MBA:*

	Borrow Area				Edge of Borrow Area				
Species	33	34	41	46	29	30	43	45	Mean
Nassarius spp.	144	1365	256	603	1661	2505	2256	403	1149
Bursa rana	289	975	128	362	277	470	1611	0	514
Armina sp.	289	780	0	603	0	157	0	134	245
Cheungbeia spp.	289	195	128	0	0	0	322	0	117
Polinices melanostomus	0	780	0	0	0	0	0	134	114
Sinum spp.	0	390	0	0	138	157	161	0	106
Pleurobranchaea brockii	144	0	128	0	0	157	161	0	73.8
Rapana bezoar	0	195	0	0	0	0	322	0	64.6
Xenophora exuta	0	0	0	0	0	0	322	0	40.3
Murex trapa	0	0	0	0	277	0	0	0	34.6
Conus sulcatus	0	195	0	0	0	0	0	0	24.4
Philinopsis sp.	0	0	0	0	0	157	0	0	19.6
Gemmula deshayesi	144	0	0	0	0	0	0	0	18
Hemifusus ternatana	144	0	0	0	0	0	0	0	18
Lophiotoma leucotropis	144	0	0	0	0	0	0	0	18
Turricula nelliae spurius	144	0	0	0	0	0	0	0	18

Table J2 *Gastropod species collected from reference areas for the ETLC MBA:*

Species	31	32	40	Mean
Nassarius spp.	3009	1737	124	1623
Philine orientalis	1433	0	394	642.3
Lophiotoma leucotropis	143	695	0	279.3
Hemifusus ternatana	0	685	0	228.3
Ringicula doliaris	430	0	0	143.3
Turritella bacillum	3	347	0	115.7
Murex trapa	143	174	0	105.7
Polinices melanostomus	143	174	0	105.7
Turricula nelliae spurius	143	174	0	105.7
Philinopsis sp.	27	0	0	95.67
Funa jeffreysii	143	0	0	47.67
Bursa rana	0	0	124	41.33
Pleurobranchaea brockii	0	0	124	41.33

Table J3 *Bivalve species collected from close to or within the ETLC MBAs.*

Species	33	34	41	46	29	30	43	45	Mean
Corbula crassa	0	2145	0	0	138	157	2900	0	667.5
Placamen calophylla	1300	195	0	0	138	157	1289	0	384.9
Anadara ferruginea	866	0	0	121	277	313	806	0	297.9
Dosinia nanus	144	195	0	0	0	0	1772	0	263.9
Pteria breviata	0	0	0	724	0	0	0	0	90.5
Tellina sp.	0	390	128	0	0	0	161	0	84.88
Minivola pyxidatus	0	390	0	0	0	0	0	0	48.75
Limaria hirasei	0	195	0	0	0	0	0	0	24.38
Laternula anatina	0	0	0	0	0	0	161	0	20.13
Musculus sp.	0	0	0	0	138	0	0	0	17.25
Bucardium asiaticum	0	0	128	0	0	0	0	0	16
Mactrinula reevesii	0	0	0	121	0	0	0	0	15.13
Vepricardium sinense	0	0	0	121	0	0	0	0	15.13

Table J4 *Bivalve species collected from reference areas for the ETLC MBAs.*

Species	31	32	40	Mean
Placamen calophylla	573	2606	0	1060
Anadara ferruginea	430	1216	0	548.7
Corbula crassa	0	1564	0	521.3
Minivola pyxidatus	0	0	618	206
Gari lessoni	143	0	0	47.67
Theora fragilis	143	0	0	47.67
Circe scripta	0	0	124	41.33
Macoma candida	0	0	124	41.33

Table J5 *Commercial Fisheries Resources from around the ETLC MBAs*

Station	Area Type	Diversity H'	Abundance # 1,000 m^{-2}	Productivity g 1,000 m^{-2}	Rank out of the 51 stations sampled
31	Reference	1.45	38.55	112.92	15
32	Reference	1.66	5.39	56.46	24
40	Reference	2.34	22	129.04	10
29	Edge of MBA	2.19	no data	no data	no data
30	Edge of MBA	1.42	15.65	43.51	31
43	Edge of MBA	1.17	8.86	42.69	33
45	Edge of MBA	2.11	26.45	440.52	2
33	MBA	2.27	6.5	56.03	25
34	MBA	1.7	13.84	127.91	11
41	MBA	2.1	4.48	55.73	26
46	MBA	2.21	11.82	108.28	16