APPENDIX A

Water Quality Issues

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APPENDIX A1

Review of Lantau Port Studies

APPENDIX A1 REVIEW OF PREVIOUS STUDIES

1. Lantau Port and Western Harbour Development Studies (March 1993)

The LAPH studies investigated five scenarios using the WAHMO model suite :

- Baseline
- An 'Ultimate' development including Lamma Breakwater at the southern end of Western Harbour and a causeway between CT10/11 and CT12/13
- Same as the 'Ultimate' but with a bridge in place of the causeway
- Phase I and II (8 berths) ie CT10&11 plus a port breakwater
- Phase V including all terminals and causeway but no Lamma Breakwater

The scenarios included committed reclamations at West Kowloon, North Lantau and North Hong Kong Island. Pollutant inputs assumed future loads from Ma Wan (15,000 population), Peng Chau (8,000 pop.), Discovery Bay and Yi Pak (25,000 pop.). Existing discharge points were used except for Yi Pak which was assumed to discharge at the Discovery Bay outfall. Sewage treatment was restricted to screening and degritting. Sewage from Mong Kok, Sham Shui Po, Lai Chi Kok and Kwai Chung was assumed to discharge into Victoria Harbour southwest of Stonecutters Island. Pollutants from port-related activities were not included.

The LAPH study area for which model output was obtained is reproduced in Figure 4.1. It can be seen that only one station has local reference to near field impacts ie Station 6 located in Discovery Bay. At this station it was concluded that all scenarios produced a deterioration in water quality parameters (ammonia, inorganic nitrogen, *E.coli* and chlorophyll-a) but the presence of a bridge in place of a causeway reduced the impact. The chlorophyll-a concentrations ($8\text{-}11\mu g l^{-1}$) were considered indicative of an unstable system with potential for algal blooms. For the scenario including CT10&11 with the port breakwater, *E.coli* concentrations were predicted to increase five-fold to 500 per 100 ml. Dissolved oxygen exhibited opposite trends to all other parameters ie construction of the terminals resulted in an increase in dissolved oxygen within Discovery Bay waters. This was attributed to the change in circulation which drew water of high dissolved oxygen content from the south into the Bay, even though the flushing rate was reduced. It was this reduced flushing rate which permitted accumulation of contaminants within the Bay which in turn resulted in a higher Biochemical Oxygen Demand (BOD). Thus dissolved oxygen was shown to be independent of BOD.

Following the initial assessments, additional scenarios were run for wet season spring and neap tides to investigate the impact of different sewage options for the Discovery Bay area. These were :

- Discovery Bay, Yi Pak and Peng Chau to be treated to secondary standard and retaining the present outfalls

- Discovery Bay and Yi Pak to be diverted to Siu Ho Wan; Peng Chau treated to secondary standard but retaining the present outfall

Both scenarios resulted in a large improvement in water quality compared to previous scenarios but removal of sewage to Siu Ho Wan resulted in better water quality than for the baseline case.

The general conclusion was that a lower assimilative capacity of the embayed waters of

Discovery Bay would result from the construction of the Port reclamation, the implication being that all practicable measures should be considered to minimise pollutant loading from all sources.

Dredging and filling impacts were not addressed in detail and no reference was made to drained or fully dredged options. The assumption made was that certain parts of the area to be reclaimed would require dredging prior to the placement of fill and examples cited were some sea walls, the base of the proposed Lamma Breakwater and access channels. Obviously, specifics regarding detailed design were not available at the time of the study therefore these issues could not be addressed at that time.

2. LPD Stage I Container Terminals 10 & 11 Ancillary Works (Design) December 1994

This study was commissioned to carry out master planning for the container backup areas and serviced land for industrial development together with detailed engineering designs for the latter. An integral part of this work was to consider cumulative environmental impacts during :

- the construction phase for air, noise, water and Chinese White Dolphin (identified as a potential sensitive receiver in the LAPH study).
- the operation stage for air and noise.

The Brief did not include water pollution impacts during operation as these had been considered to have been assessed in sufficient detail in the LAPH study.

A review of existing water quality data showed that over a two year period, dissolved oxygen concentrations have decreased with a commensurate increase in turbidity, suspended solids and total nitrogen loadings in Discovery Bay. *E.coli* counts in the Bay were higher than in the Lamma Channel.

Contaminated mud was found in the area to be dredged for the Breakwater and EPD advised that the top 0.5 m of marine mud over the area to be dredged should be treated as contaminated (165,000m^3), thus requiring special conditions to be applied during dredging and disposal operations. Two stations sampled in the Contaminated Spoil Management Study (1993) were located in the present study area, one of which within the area to be reclaimed had a moderate concentration of mercury (Class 'B'). Vibrocoring within the Serviced Area indicated that sediments were Class 'A' with the exception of one station (VB1) where chromium concentration warranted Class 'B'. Further detailed vibrocore testing is presently being carried out to determine the extent of contaminated sediments in other areas requiring dredging. Uncontaminated mud (21.5Mm^3) were to be disposed of south of Cheung Chau.

Water quality impact assessments were performed using WAHMO models with regard to :

- construction of CT10&11, the Ancillary Works, the Breakwater and the Approach Channel. Scenarios investigated were Baseline, Interim (Baseline + Advanced Works) and completion of Stage I (CT10&11, back up areas, serviced land, breakwater, access channels, road links and utility services).
- the extent of sediment plume impacts from different dredging scenarios

- determine the potential for high levels of nutrients in Discovery Bay resulting from storm runoff from the port and Discovery Bay catchments and effluent discharges from Discovery Bay and Peng Chau.

- investigate the effect on water quality of removing pollution loads from Discovery Bay and Peng Chau (ie diversion to the proposed sewage treatment works at Siu Ho Wan).

The overall pattern deduced from the hydrodynamic studies (cumulative impact) was of a quiescent zone between the Breakwater and Approach Channel and a reduction in flow in and out of the Discovery Bay embayment with a concomitant decrease in flushing. The water quality implications of this were manifested in increased nitrogen and chlorophyll-a which together highlight potential problems of enhanced eutrophication and algal blooms, particularly in the wet season. Only a minor depletion in dissolved oxygen was forecast for the study area as a whole. These effects derive solely from changes in hydrodynamic regime and do not include additional loads derived from the Port Development itself.

Loads from the Port Development were incorporated into separate studies designed to investigate the influence of the following on water quality:

- Lantau Port as the only source of pollution ie stormwater
- as above plus stormwater from Penny's Bay
- as above plus stormwater from Discovery Bay and Peng Chau
- as above plus sewage from Discovery Bay and Peng Chau

Assumptions made for sewage inputs were as for the LAPH studies except that Peng Chau population was increased from 8,000 to 9,000.[1] Pollution load factors were taken from the Sewage Strategy Study (1989). Existing sources of stormwater in and around Discovery Bay were calculated as being greater than those for the Port Development by a factor of sixteen.

The greatest impact on water quality was the scenario including sewage from Discovery Bay and Peng Chau resulting in an order of magnitude decrease in water quality in the outer part of Discovery Bay and a 50% decrease forecast for the inner Bay. It was emphasized that there was a need to improve levels of sewage treatment or eliminate the discharges entirely, and to minimise the pollution load from Port operations.

Construction of the Port will have sediment impacts in short and long term perspectives:

- short term; from dredge and fill activities influencing water quality

- long term; by permanently influencing the hydrodynamics of the area sediment dynamics are also affected thus changing patterns of accretion and erosion and water quality.

Short Term

The short term impacts considered were pollution from sediment contamination, increases in suspended sediments, reductions in dissolved oxygen, increases in nutrients

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[1] The Explanatory Statement for Peng Chau North Layout Plan identifies a design population of 7,500 (DPO/L&I)

and the physical effects of sedimentation. Assessments for the Advanced Works were made on the basis of a fully dredged design. The remainder of the Ancillary Works was based on a drained design requiring minimal dredging. CT10&11 was also assumed to be a drained option.

Cumulative impacts for suspended sediment loads were assessed inclusive of the Ancillary Works, CT10&11, the Breakwater and the Approach Channel. Far field effects were limited to a maximum increase of 5 mg l^{-1} east of the Approach Channel and reduced to 1 mg l^{-1} in outer Discovery Bay and <1 mg l^{-1} east of Ma Wan and Tung Wan. Modelling of near field impacts indicated that increases in suspended sediments would be down to 50 mg l^{-1} within 150 m of dredging activity and approaching background values within 200 m.

Water quality impacts resulting from dredging were very small with respect to dissolved oxygen. For nutrients, a dredging rate of 40,000 m^3 per day was assumed with a loss of 5% of this to the water column. Based on these assumptions, nutrient increases were predicted to remain localised around the dredgers and to reduce to almost ambient within 100 m. In reality, existing inorganic nitrogen concentrations at 0.31 mgN l^{-1} already exceed the Water Quality Objective of 0.1 mgN l^{-1} but contributions from dredging will be less than 0.003 mgN l^{-1} within 200 m of dredging.

Long Term

Existing patterns of sedimentation in the wet and dry seasons was investigated using WAHMO. Existing deposition rates were of the order of 0.10 kg m^{-2} per tide in the dry season to 0.4kg m^{-2} per tide during the wet season. Far field sedimentation rates generally doubled from Baseline to the Interim scenario with localised areas exhibiting a five-fold increase for wet season spring tides, particularly to the north and west of Lamma, primarily as a result of the physical presence of the Breakwater reducing water current velocities.

Water quality impacts resulting from the change in hydrodynamics have been outlined above.

3. LPD Stage 1 Container Terminals 10 & 11 Preliminary Design (January 1995)

This study investigated the construction and operation of CT10&11 and the cumulative operational noise impact of CT10, 11, 12 and 13. With respect to water quality the following were assessed :

- dredging and fill placement (qualitative, as the Ancillary Works study modelled cumulative impacts)
- erosion of reclamation and runoff
- dredging of contaminated sediments
- sewage disposal (construction)
- temporary embayment of Penny's Bay
- operational stormwater discharges (qualitative)
- operational sewage disposal
- embayment of Discovery Bay

Unlike the LAPH report it was assumed that the Tsing Chau Tsai Mega Borrow Area would not be used as a source of fill. Instead, marine sand was evaluated as fill material based on a drained rather than fully dredged option. At this time the source of marine fill has not been specified but the assumption has been made that the fill will be clean sand. Assessment of water quality was based on information published in the LAPH studies, an updated review of EPD monitoring data and on-site measurements during December 1993 at the entrance to and within Penny's Bay.

Current speeds within Penny's Bay were low. The power station has a secondary sewage treatment facility and effluent discharges are under the control of the Water Pollution Control Ordinance and has a maximum daily flow rate of 345 m^3 per day to a 30/20 specification (suspended solids/BOD).

Water quality data for *E.coli*, ammonia and total inorganic nitrogen has shown a decreasing trend in quality from 1991 to 1993 but due to the small number of samples taken during this period, there was no statistical difference between data for the two years. The range of dissolved oxygen concentrations remained similar during the three years but there was a small but increasing trend in mean values of oxygen saturation from 87.7% to 90.6%. Penny's Bay exhibited lower dissolved oxygen than coastal waters.

Contaminated mud investigations found moderate copper contamination (Class B) at two stations and severe copper contamination at one station. Contamination was restricted to the top 100mm and it was assumed that dredging could be confined to the top 0.5m. Based on these assumptions the volume of contaminated mud arising from CT10&11 will be at least 30,000m^3. It was anticipated that at least 50% of mud from the Approach Channel will be classed as 'B' or 'C' subject to confirmation.

The source of marine fill for the terminals reclamation had not been identified at the time of the study so, for the purposes of assessing suspended sediment impacts, an average figure of 4.8% fines (<63µ) was used based on information published by GEO. The total estimated fill required for the reclamation was 80 Mm^3 which, based on 4.8% fines would generate 3.9 Mm^3 of material lost to the surrounding area. The settling time of the fines was calculated as just over one hour and therefore, given the low current velocities in the area, it was concluded that localised resettlement would occur. Attention was drawn to the naturally high background concentrations of inorganic nitrogen (approximately three times the Water Quality Objective) and as the source of fill was unknown, attention was drawn to the potential for increases in nutrients during filling operations.

There are no public sewers servicing the works area so temporary facilities will have to be provided. Space limitations preclude the use of septic tanks and soakaways therefore removal of sewage to a treatment facility capable of 20/30 performance (BOD/suspended solids) is proposed for the backup area. The outfall from the plant will have to comply with License conditions and should not discharge into areas of poor water circulation. During the operational phase, sewage will be collected and directed to the main sewer system thence to the new works at Siu Ho Wan.

Storm water generated within the terminals will drain to five outfalls along the southern edge structure. Drainage from the lorry parks and vehicle repair areas will pass through 3-stage petrol interceptors before entering the storm drains. At normal discharge rates the predicted water circulation within Discovery Bay would be expected to carry drainage waters southward into open waters. However, large quantities of runoff may stratify on the top of the marine waters and fan out into Discovery Bay against the normal circulation flow, and the low flushing rates would tend to contain any contaminants within the Bay.

4. Summary of Previously Identified Potential Impacts

The foregoing three studies have arrived at essentially similar conclusions, notwithstanding the different scenarios investigated. The primary impacts will be produced as a consequence of the physical presence of the reclamations for the terminals and breakwater and it is the fundamental location of CT10&11 in all scenarios that is responsible for the similarity of, in particular, near field impacts. These may be summarised as temporary or permanent.

Temporary Impacts

Modelled impacts of nutrients desorbed from suspended sediments during dredging are predicted to be small in comparison with the high background concentrations but this remains a key issue as any increase must be viewed with concern and measures should be taken to minimise these impacts as far as is practicable. Dissolved oxygen demand of suspended sediments will be small and within acceptable limits except in the immediate vicinity of dredgers. Bunds and settlement lagoons will reduce suspended sediment impacts during filling. The mariculture zone at Ma Wan should not be subject to elevated suspended solids concentrations as a result of the Port Development.

Permanent Impacts

Circulation rates within Discovery Bay will be changed as a result of the construction of CT10&11 and a quiescent zone will develop close to the Breakwater. Flows immediately outside Discovery Bay will reduce by up to approximately 20% and in the mouth of the Bay will reduce almost to zero. Sedimentation will increase in the vicinity of the Breakwater due to reduced water velocities. Far field changes in sediment deposition are greatest to the west of Lamma. Early implementation of diversion of sewage loads from Discovery Bay and Peng Chau to Siu Ho Wan will mitigate most effectively against eutrophication. If diversion is implemented, water quality in Discovery Bay should not deteriorate from that which exists at present and may actually improve. If sewage diversion is not implemented, water quality will deteriorate, particularly within Discovery Bay, with increased eutrophication and the possibility of algal blooms. Impacts from stormwater runoff should be within acceptable limits.

APPENDIX A2

Physicochemical Aspects of Contaminant Desorption from Resuspended Sediments

APPENDIX A2 PHYSICOCHEMICAL ASPECTS OF CONTAMINANT DESORPTION FROM RESUSPENDED SEDIMENTS

1. Introduction

It will be appreciated that the Lantau Port assessments rely to a large extent on the modelling assumptions made and limitations of the model itself. A common characteristic of modelling performed in all Lantau Port studies to date is that of conservatism. That is, scenarios adopted have tended, in the absence of detailed research or the known chemistry of the reactions involved, to assume worst case, and where multiple assumptions have been required, the resulting cumulative safety margins have probably been large with an over-prediction of impact.

In order to better appreciate the limitations of assessments of the above type and to explain why assumptions have needed to be made, the following section outlines the physicochemical aspects upon which contaminant desorption from resuspended sediments depends. The physicochemical factors, taken in context with normal dredging and filling practice and the behaviour of derived resuspended sediments, are essential to the present assessment. This is particularly pertinent regarding nutrient desorption which is of primary concern due to the inferred incipient eutrophication status of the study area and the large volumes of dredged and fill materials involved in reclamation of the Terminals.

2. General Approach to Assessments

Dredging practices and environmental implications were extensively reviewed in the Contaminated Spoil Management Study conducted for CED, parts of which are reproduced here for ease of reference. During the dredging process, sediments will be resuspended in the water column and the degree of resuspension depends on numerous factors, many of which are interactive and some of which are not directly related to the excavation process. These may be divided into four groups :

- The soil being dredged
- The method of dredging
- The hydrodynamic regime
- The existing water quality characteristics

Any assessment of the environmental effects of dredging operations must recognise the complexity and degree of synergistic interaction of these factors. It is evident from a study of available data that it is virtually impossible to predict the levels of suspended sediment around a working dredger satisfactorily and accurately. The normal approach therefore, is to describe in relative terms, the probable range of values within which suspended sediment concentrations are likely to fall. For modelling purposes, it is general practice to adopt the highest value only ie the worst case. Sediment resuspension can be quantified in two ways, each of which may have important environmental implications ie; in terms of sediment concentration in water and total quantity of sediment lost to the surrounding area.

While turbidity plumes from aquatic disposal operations may be highly visible, they usually contain suspended solids concentrations in the range of tens to hundreds of milligrams solids per litre, extend less than 1,000 to 2,000 m from the discharge point, and decrease to less than 100 mg l^{-1} within 300 m of the dredger. It should be borne in mind that the above plume measurements were typically made in areas experiencing tidal currents, unlike the Lantau Port area where flows are minimal and dispersion will be less.

For the purposes of dispersion predictions, the settling speed of the suspended sediments is often assumed as that equivalent to a certain size-fraction eg 63 µm for silt. However, the true settling speed may be much faster because cohesive sediments are not completely disaggregated during dredging and in addition, aggregation and flocculation may occur. Predictions based on the assumption that all fines will be released to the water column are therefore likely to be an overestimation. The WAHMO model allows for flocculation of dispersed particles by expressing the settling speed as a function of concentration and it is assumed that all particles less than 63 µm can flocculate and behave in the same way. The equations work well for natural concentrations greater than 100 mg l^{-1} but there is not much data for lower concentrations. The limitation that all fine particles are assumed to be dispersed still applies even in this situation.

Primary concerns relating to dredging and derived suspended solids are the potential release of metals and other contaminants such as nutrients (nitrogen and phosphorus compounds). It is in this context that the physicochemical properties of the sediment and water column become the controlling factors in controlling the availability of the contaminants. Chemicals may be associated with sediments in a number of ways. All the natural elements, including toxic heavy metals, may be associated with natural sediments as :

- Part of the mineralogical structures of the sediment particles,
- As complexes with reducible iron and manganese coatings on mineral particles,
- Associated with organic material or sulphides in the sediment,
- Ionically bound to the mineral particles, and
- Dissolved in the interstitial water.

The general pattern is that the environmental availability of metals associated with sediments increases in the order listed, but the amount of metal incorporated in these ways decreases in the same order. That is, most metals are largely bound in the mineral structure and reducible coatings on the particles or ionically bound to charged silicate clay surfaces, where they are relatively unavailable for environmental interactions.

3. Review of information

In harbours and sheltered areas receiving contaminant inputs the sediments below several millimetres depth are typically anoxic. Iron and manganese in the anoxic sediments are in a soluble form. However, on mixing with the overlying oxygenated waters during dredging, these metals are oxidised into insoluble forms. Iron, in particular, forms a floc onto which most of the other contaminants, particularly metals and phosphorus, adsorb ie they are 'scavenged' by the floc which coagulates and settles; this is a rapid process. Tests in the USA[1] have found that the only two compounds consistently released from sediments during laboratory studies were manganese and ammonia. All of the other chemicals studied generally showed little or no release. Generally, well-mixed laboratory systems allow considerably more sediment/water contact than occurs during most

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[1] "Fate and Effects of Sediment-Bound Chemicals in Aquatic Systems", Pergamon Books Inc 1987

dredging/disposal activities, especially hopper-dredge or mechanical dredging operations. It is generally accepted that sorption reactions are often the dominant reaction governing aqueous environmental chemistry. Lee and Jones[1] suggest that where turbidity is greater than 0.1 NTU (nephelometric turbidity units) then the sediment/water exchange reactions with the inorganic and/or organic particles in the water column will favour sorption reactions and scavenging of contaminants. For comparison, average turbidity readings vary in Hong Kong from approximately 1-3 NTU in Tai Tam Bay (clean seawater influence), to 5-10 NTU in Victoria Harbour and 20-60 NTU at East Sha Chau (Pearl River influence). Thus according to the foregoing authors, sorption reactions will be strongly predominant in Hong Kong waters. The inability to describe sorption reactions properly has been one of the most significant impediments to developing appropriate and predictive environmental chemistry-fate models. With respect to nutrients, deterministic eutrophication models of eutrophication load-response relationships have limited applicability as predictive tools for eutrophication management purposes.

The environmental assessment for the Lantau Port Advanced Works used elutriation tests in an attempt to estimate the potential for nutrient release from sediments in the study area. Elutriate tests were developed by the United States Corps of Engineers and the USEPA as an alternative to bulk sediment criteria for evaluating the potential hazard of contaminants associated with dredged sediments. The specification for conducting the elutriate tests was established to simulate the type and duration of sediment-water contact and mixing that would be expected to occur during hydraulic dredge disposal operations. The elutriate would be expected to simulate settled dredged-sediment slurry and therefore would not be representative of the situation in which sediment is resuspended during actual dredging. The former utilises a solids content of 20% by volume whereas during dredging, losses to the water column would be of the order of less than 5%. Thus the elutriation test may grossly overestimate the probable release of nutrient during dredging. Although elutriate tests predict the direction and approximate magnitude of release of contaminants from the dredged sediments, USA results have demonstrated that the bulk properties of a sediment cannot be used to quantify the release of contaminants from them. Elutriate tests are therefore restricted to predicting the *potential* for release of contaminants from aquatic sediments that are stirred into the water column. Estimations of nutrient impact therefore tend to assume that all nutrient present in all sediment lost to the water column is released. This is also likely to be a gross overestimate of the real situation.

Predictions of increased oxygen demand resulting from resuspension of sediments has been a specific requirement of a number of reclamation EIA's in Hong Kong. Oxygen demand associated with sediments has received considerable attention over the years and is a standard parameter included in many numerical models such as WAHMO. The main demand on oxygen is derived from the conversion of organic and inorganic matter released to the water column by bacteriological and chemical processes. In particular, oxidation of ammonia to nitrite-nitrate consumes considerable amounts of oxygen. It is important to note that the exchange reactions that govern the exertion of sediment oxygen demand are not atypical of those that would be expected to control the release of many, if not all, other contaminants. In most situations, the mass transport of sediment-associated contaminants to overlying waters is controlled by the physical mixing of the sediments and their interstitial waters, with the overlying waters. As a result, modelling efforts of sediment/water exchange reactions have limited validity and limited predictive capability in evaluating the impact of altered contaminant loads to a water body on the uptake and release of contaminants from the sediments. Estimates of near-field increased oxygen demand also tend to assume that there is no input of oxygen from external sources such as the atmosphere and tidal exchange ie a closed-cell approach has been adopted. Once again, simulations of the above processes will therefore tend towards worst case.

4. Summarising

To summarise, sediment-water exchange reactions are controlled in many cases by the hydrodynamics of the system rather than the concentrations of contaminant in the sediment. Therefore elutriation tests do not provide highly reliable or predictive results (Lee, G.F. 1970)[2] and at best provide only an indicative measure of potential impact. It is important to put dredging into proper perspective as a potential source of contaminants. Studies in the USA have concluded that there will be few situations, even where the sediments of a region contained substantial amounts of contaminants, that dredging or dredged-sediment disposal operations would have a significant effect on water quality. For Lantau Port, fill material will be clean sand therefore placing of fill will have even less impact.

It is important that potential impacts of large dredge and fill programmes such as Lantau Port are given detailed assessment. However, the constraints placed on the assessment arising from hydrodynamic and chemical processes are such that all simulations and estimates of impacts are undertaken as 'worst case'. The cumulative effect of this is that the results produced will overestimate the impacts, in some instances by considerable margins, and this should be borne in mind when reviewing the model results.

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[2] "Factors affecting the transfer of materials between water and sediments". Literature Review No.1, Eutrophication Information Program. University of Wisconsin, Madison.

APPENDIX A3

Approach to Modelling Studies

APPENDIX A3 APPROACH TO MODELLING

A complex suite of models is typically required to simulate the various water quality impacts derived from various sources or activities. In order to better appreciate the complexities and limitations in using these models, an outline description is provided below.

Five models of the WAHMO model suit were used to simulate the water quality impact due to the construction of CT10 and CT11; namely :

- TIDAL FLOW MODEL
- SEDIMENT TRANSPORT MODEL
- WATER QUALITY MODEL,
- BACTERIAL PLUME MODEL; and
- SEDIMENT PLUME MODEL.

All models were run using a 100 metre grid.

1. Tidal Flow

The TIDAL FLOW model is a two layer two dimensional hydrodynamic model to simulate the water flow pattern. Since Hong Kong lies in the estuary of the Pearl River, the pattern of water flow is greatly affected by the tidal condition (spring tide or neap tide) and also the pattern of fresh water discharge from the Pearl River (wet season or dry season). In the wet season, a two layer flow system is often observed in Hong Kong waters, with a layer of brackish water flowing on top of a layer of denser saline water. Water in the two layers has different properties and can flow in a different direction with a different velocity. Differences in salinity and temperature, hence density, of the two layers suppresses the vertical mixing between the layers. The two layer system usually disappears in the dry season. Use of the two layer two dimensional model can simulate the stratified system in Hong Kong waters, without imposing a heavy demand on computer capacity as required by a three dimensional model. The TIDAL FLOW model basically solves the governing equations (mass balance and momentum balance) of the system using a finite difference scheme.

The TIDAL FLOW model gives the water depth, speed and direction of each layer in the modelled area. These results are input to other models since all the water quality simulations depend on the flow field to a significant extent. All the other models used in the study adopt the same grid arrangement as that in the TIDAL FLOW model. When interpreting the model results, it should be kept in mind that in some cases, stratification does not exist and there will be no bottom layer in the model output at these locations.

2. Sediment Transport

The SEDIMENT TRANSPORT model is used to simulate the water quality impact due to dredging and filling activities. This model solves the governing convective diffusion equation to predict the fate of the sediment plumes resulting from dredging and filling. Settling of the fine cohesive sediments, deposition and erosion of the seabed are modelled. Distribution of the suspended solids and the mud deposition over tidal cycles are simulated. Since the dredged sediments contained nutrient and oxygen demand (BOD and COD), the depletion of dissolved oxygen in the water column due to the **suspended sediments only** and the release of nutrient into the water column through the dredged sediments can also be simulated using this model.

3. Water Quality

Besides the oxygen demand of the suspended sediments, there are other factors that affect the dissolved oxygen level. Major oxygen demand comes from the wastewater discharging from the local outfalls. The nutrient level in the water column affects the amount of algae in the water, which in turn influences the dissolved oxygen level through respiration and photosynthesis. These complex algal dynamics are modelled in the WATER QUALITY MODEL. This model solves an array of governing equations for various important parameters like dissolved oxygen, nutrient (in various forms), algae concentration, BOD etc to predict the long term behaviour of water quality subjected to specific pollution loading at the outfalls. Impact of stormwater discharge from the container terminal can also be simulated.

4. Bacterial Plume & Sediment Plume

Unlike the foregoing models which solve the set of governing equations numerically, the BACTERIAL PLUME and SEDIMENT PLUME models are random walk models that simulate the fate of pollutant/sediments over a shorter time scale and focused area. The BACTERIAL PLUME model simulates the transport of bacteria released from the outfalls to assess the impact, especially to the near shore beaches; a number of bacteria are released at the source, then advected by the prevailing current and dispersed statistically. Mortality rate (T_{90}) of bacteria changes depending on the time of day; this variation in mortality rate and the loading pattern are included in the model.

A simulation was also carried out to estimate the flushing capacity of the enclosed beaches of Discovery Bay and Yi Pak, making use of the SEDIMENT PLUME model. As stated previously, the model is also a random walk model used to predict the fate of pollutant/sediments over a short time scale. In the study, a finite number of pollutant particles was released in the enclosed area of Discovery Bay. These particles were then carried away and dispersed, assuming that the particles had neutral buoyancy (setting the settling velocity to zero). Concentrations of the pollutant at various times (12, 24, 36 and 48 hrs) after release were then compared to give a sense of the flushing capacity of the bay.

5. Assessment Rationale and Definitions

As the primary objective of this study has been to assess and compare a fully dredged option with a drained option, and there have been time constraints on modelling, the approach adopted has been, in the first instance, to look at the worst case situation for each stage of terminal construction for the fully dredged option. 'Worst case' in this context is taken here as meaning the cumulative maximum rate of dredging and filling activities. The rationale behind this approach was that in the event of compliance with Water Quality Objectives (WQO's) under worst case conditions, then the number of model runs could be minimised. In the event of noncompliance, similar conditions would be assessed for the drained option or possible mitigation measures examined.

The following definitions and assumptions for modelling have been used in this assessment :

The model covers an area of about 15 km by 18 km with :

- Northern Boundary - Coastline along Tai Lam Chung, Sham Tseng, Tsuen Wan and Kwai Chung

- Eastern Boundary - Victoria Harbour : from Sham Shui Po to Sai Ying Pun; East Lamma Channel : from Aberdeen to east Lamma Island

- Southern Boundary - from south Lamma Island to south of Cheung Chau to Shek Kwu Chau

- Western Boundary - North Lantau : from Tsing Chau Tsai Peninsula to Tai Lam Chung; Coastline along Tsing Chau Tsai (TCT) Peninsula, Penny Bay, Discovery Bay, Silvermine Bay, and Chi Ma Wan Peninsula; Water channel between Chi Ma Wan Peninsula and Shek Kwu Chau

Tidal Flow Model

Three situations were modelled by the Civil Engineering Department (CED) the model shapes are shown in Figures 3.1, 3.2 & 3.3 and are briefly described here :

Situation One - BASELINE

- simulates the condition before construction of the terminal.

- includes reclamation and dredging to be in place such as CT7, 8, and 9 , and the South Tsing Yi borrow pit (a 20 m deep pit approximately 2.5 km x 2.5 km).

Situation Two - CONSTRUCTION

- includes noise barriers for CT10 and 11, and the entrustment at the rear of CT11.

- Penny's Bay is not reclaimed, with a narrow water channel connecting the Bay to the coastal waters.

Situation Three - COMPLETED

- CT10 and 11 reclamations completed.

- port breakwater (about 2 km running in a northeast/southwest direction north of Siu Kau Yi Chau) in place, with a 600 m dredged fairway in front of CT10 and 11.

- Penny's Bay reclaimed.

Sediment Plume (suspended solids and derived nutrients)

Simulations were based on peak dredging and filling rates. For scenarios including both dredging and filling activities, the peak simultaneous rate was taken; this did not necessarily equate to the sum of individual peak rates, which may occur at different times.

Table No 3.1 : Sediment Plume Model Scenarios

Scenario	Description
I	Dredging Only for Fully Dredged Option
II	Dredging Only for Drained Sandfill Option
III	Filling and Dredging at the same time for Fully Dredged Option
IV	Filling and Dredging at the same time for Drained Sandfill Option
V	Filling and Dredging at the same time for Fully Dredged Option and noise bund in place

Assumptions :

- 24 hr dredging / filling operation
- Dredging - 5% fine material, all lost to suspension
- Filling - 3.7% fine material, all lost to suspension
- The following dredging / filling rates for different scenarios :

Scenario I :	Dredging	CT10 = 0.66 m^3/s
		CT11 = 0.66 m^3/s
Scenario II :	Dredging	CT10 = 0.196 m^3/s
		CT11 = 0.197 m^3/s
Scenario III, V :	Dredging	CT10 = 0.62 m^3/s
		CT11 = 0.66 m^3/s
	Filling	CT10 = 0.82 m^3/s
		CT11 = 0.61 m^3/s
Scenario IV :	Filling	CT10 = 0.95 m^3/s
		CT11 = 0.43 m^3/s

Water Quality (dissolved oxygen, nutrients)

Baseline	(a) Priority run :	Existing loading pattern. Flow data from Situation 1. Wet and dry season neap tides.
	(b) Secondary run :	As for (a) but spring tides.
Construction	Loading as for Baseline. Flow data from Situation 2. Wet and dry season neap tides.	
Completed	SSDS conditions apply. No loading from Discovery Bay or Peng Chau. Stormwater from Terminals and backup areas. Flow data from Situation 3. Wet and dry season neap tides.	

Bacterial Plume

Baseline	Existing loading pattern. Peng Chau and Discovery Bay outfalls included. Flow data from Situation 1. Wet and dry season neap tides.	
Construction	Peng Chau and Discovery Bay outfalls, loading as for Baseline for Peng Chau and reduced loading (*E.coli* 5000/100ml) for Discovery Bay due to chlorination of effluent. Flow data from Situation 2. Wet and dry season neap tides.	
Completed	(a) Priority run :	No loading from Discovery Bay or Peng Chau.

Stormwater from Terminals and Backup areas. Flow data from Situation 3. Wet and dry season neap tides.

(b) Secondary run : As for priority run but including Peng Chau future loading.

Stormwater flow modelling assumptions are provided in Table 3.2 and catchments/ outfall locations in Figures 3.4 and 3.5.

Nutrients

Using total nitrogen content as a measure of the nutrients associated with marine mud, EPD standard sampling data indicates typical total nitrogen content for marine mud in the harbour waters of 300-500 mg/kg of dry solids. For this study the upper value of 500 mg/kg has been chosen to give a conservative estimate of the nutrient levels. If it is assumed that the nutrients associated with the sediment are transported and diluted at the same rate as the sediment in suspension, then a suspended sediment concentration of 0.1 kg/m^3 would have an associated total nitrogen concentration of 0.05 mg l^{-1}. This value has been applied to both the cases of dredging marine mud from the reclamation site and to the fines portion of the reclamation fill material. As it has been necessary to assume that all nitrogen is available as 'nutrient', and is conservative in behaviour ie there is no 'decay' (loss or consumption) factor involved, this was considered as 'worst' case. However, EPD required that nutrient desorption be treated as fully conservative. It is therefore assumed that as the suspended sediment settles out with time, the 'nutrient' should be taken as remaining in solution ie all nutrient is desorbed instantaneously. This therefore represents an extreme worst case. Loss rate of sediment to the water column during dredging was taken as 5%.

Sewage

For inputs from sewer outfalls it was agreed with EPD that a per capita approach would be used for calculating loadings. Previous assessments used per capita figures obtained from the Sewage Master Plan for the year 2011 and nutrient loadings from the rapid assessment method from the Sewage Strategy Study (for 2006). Based on these figures, loadings are as follows :

• BOD	0.042 kg/cap/day
• COD	0.090 kg/cap/day
• Suspended Solids	0.040 kg/cap/day
• TKN	0.0077 kg/cap/day
• NH_4	0.0050 kg/cap/day

Current populations of 12,000 for Discovery Bay and 6,000 for Peng Chau were assumed and present daily flow rates of 3,768 m^3 for Discovery Bay and 1,400 m^3 for Peng Chau were derived from the Sewage Master Plan data. For assessment of future sewage input from Peng Chau the 2011 population forecast of 9,000 was adopted with a daily flow of 2,100 m^3. For *E.coli*, a count of 10^7/100 ml was assumed for untreated sewage and, on consultation with EPD, 5×10^3/100 ml for Discovery Bay after chlorination.

Flushing

Simulations of the flushing capacity of Discovery Bay under different conditions were performed. A short term event over a focused area was modelled by simulating 29 conservative 'pollutant' sources placed at 200 m intervals within the Bay. The 'pollutants' were subsequently mixed and diluted in the environment, and the concentration distribution of pollutants observed at 0.5, 12, 24, 36 and 48 hours after release.

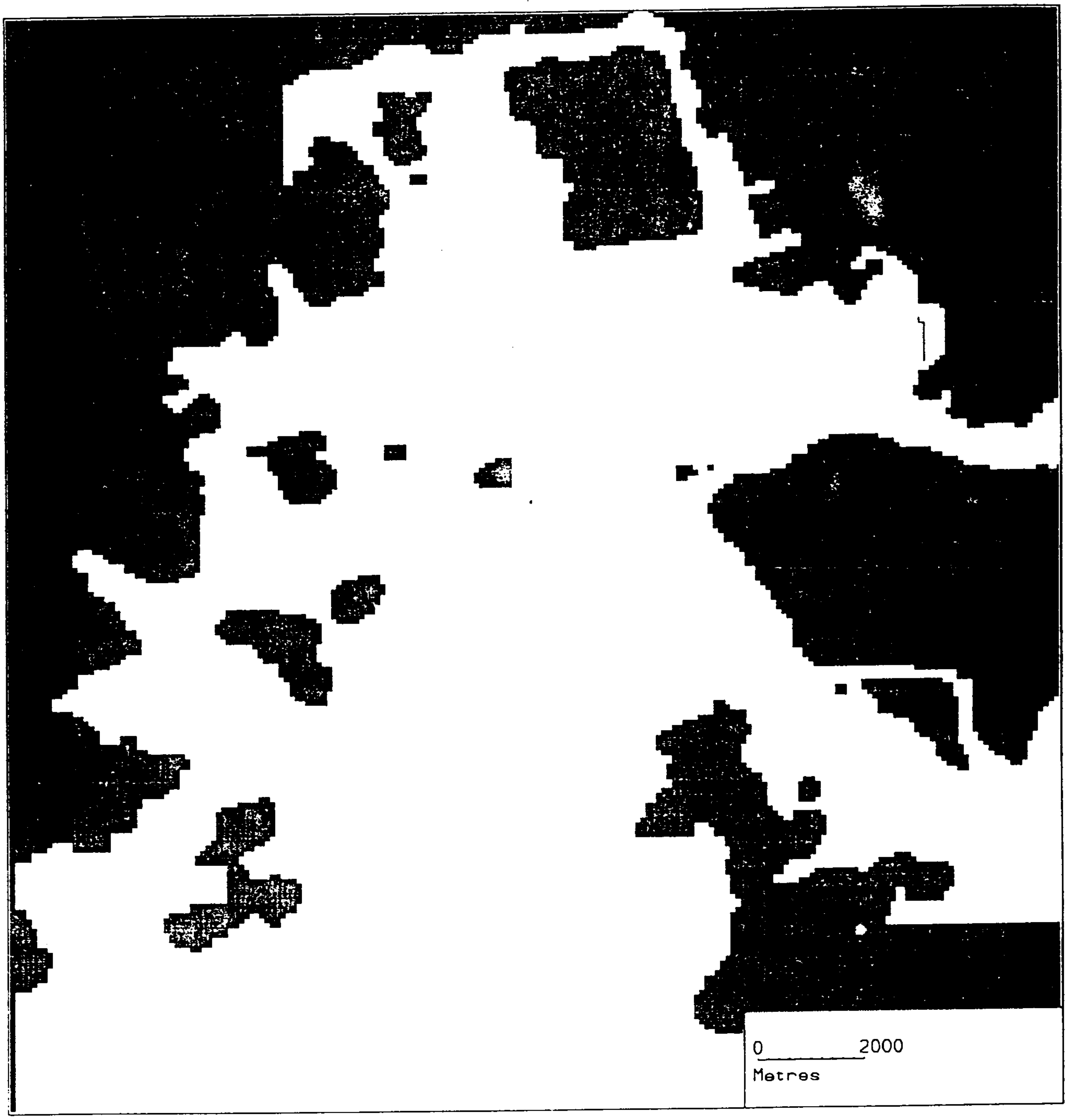
TABLE 3.2 CT10&11 DETAILED DESIGN - STORMWATER FLOW MODELLING ASSUMPTIONS

Catchment Area	Area (sq.m)	Surface Nature	Maximum Runoff (cu.m/s)	Time of Conc. (min.)	Vol (cu.m) Dur 24 hrs	Vol (cu.m) Dur 0.5 hr	Drainage System	Total Runoff (cu.m/s)	Total Vol (cu.m) Dur. 24 hrs.	Total Vol (cu.m) Dur. 0.5 hr.	Time of Discharged Dur. 24 hrs. (hrs.)	Time of Discharged Dur. 0.5 hr. (hr.)
A	818450	Natural Slope	45.47	29.09	509076	80208	4.8W x 3.0H Three Cells B.C.	73.07	795494	125335	24.5	1.0
B	450480	Paved Area	27.5	23.9	286419	45127						
C	1098880	Paved Area	56.47	37.22	683503	107690	4.8W x 2.5H Six Cells B.C.	116	1404028	221213	24.8	1.1
D	1158400	Natural Slope	59.53	37.18	720525	113523						
E1	514240	Natural Slope	38.29	22.37	319857	50396	4.8W x 2.0H Six Cells B.C.	66.48	641773	101115	24.4	1.1
F	517550	Paved Area	30.19	22.78	321916	50720						
E2	142080	Natural Slope	11.45	7.5	88374	13924	4.8W x 2.0H Twin Cells B.C.	45.49	374394	58988	24.1	0.8
G1	459840	Paved Area	37.04	7.5	286020	45064						
G2	300000	Paved Area	24.17	7.1	186600	29400	4.8W x 2.0H B.C.	24.17	186600	29400	24.1	0.8
11-1	229500	Paved Area	15.94	12.11	142748	22491	2100Ø	15.94	142749	22491	24.2	0.7
11-2	134400	Paved Area	9.33	12.11	83599	13171	2100Ø	9.33	83597	13171	24.2	0.7
11-3	134400	Paved Area	9.33	12.11	83599	13171	2100Ø	9.33	83597	13171	24.2	0.7
11-4	128000	Paved Area	8.89	12.11	79616	12544	2100Ø	9.89	79616	12544	24.2	0.7
11-5	202900	Paved Area	14.09	12.11	126204	19884	2100Ø	14.09	128204	19884	24.2	0.7
10-1	192200	Paved Area	13.61	11.89	119548	18835	2100Ø	13.61	119548	18835	24.2	0.7
10-2	124000	Paved Area	8.76	11.89	77128	12152	2100Ø	8.78	77128	12152	24.2	0.7
10-3	130200	Paved Area	9.22	11.89	80984	12760	2100Ø	9.22	80984	12759	24.2	0.7
10-4	130200	Paved Area	9.22	11.89	80984	12760	2100Ø	9.22	80984	12759	24.2	0.7
10-5	227000	Paved Area	15.08	11.89	141194	22246	2100Ø	18.08	141194	22246	24.2	0.7

REMARKS:

1. THE RETURN PERIOD FOR THE STORM IS 1 IN 200 YRS.
2. THE DURATION OF THE STORM IS 24 HRS. FOR THE LONG TERM EVENT.
3. THE DURATION OF THE STORM IS 0.5 HRS FOR THE SHORT TERM EVENT.

Data source: MCAL
Catchment Areas shown in Figure 3.5



CT 10 & 11 DETAILED DESIGN

TIDAL FLOW MODEL : BASELINE LAYOUT

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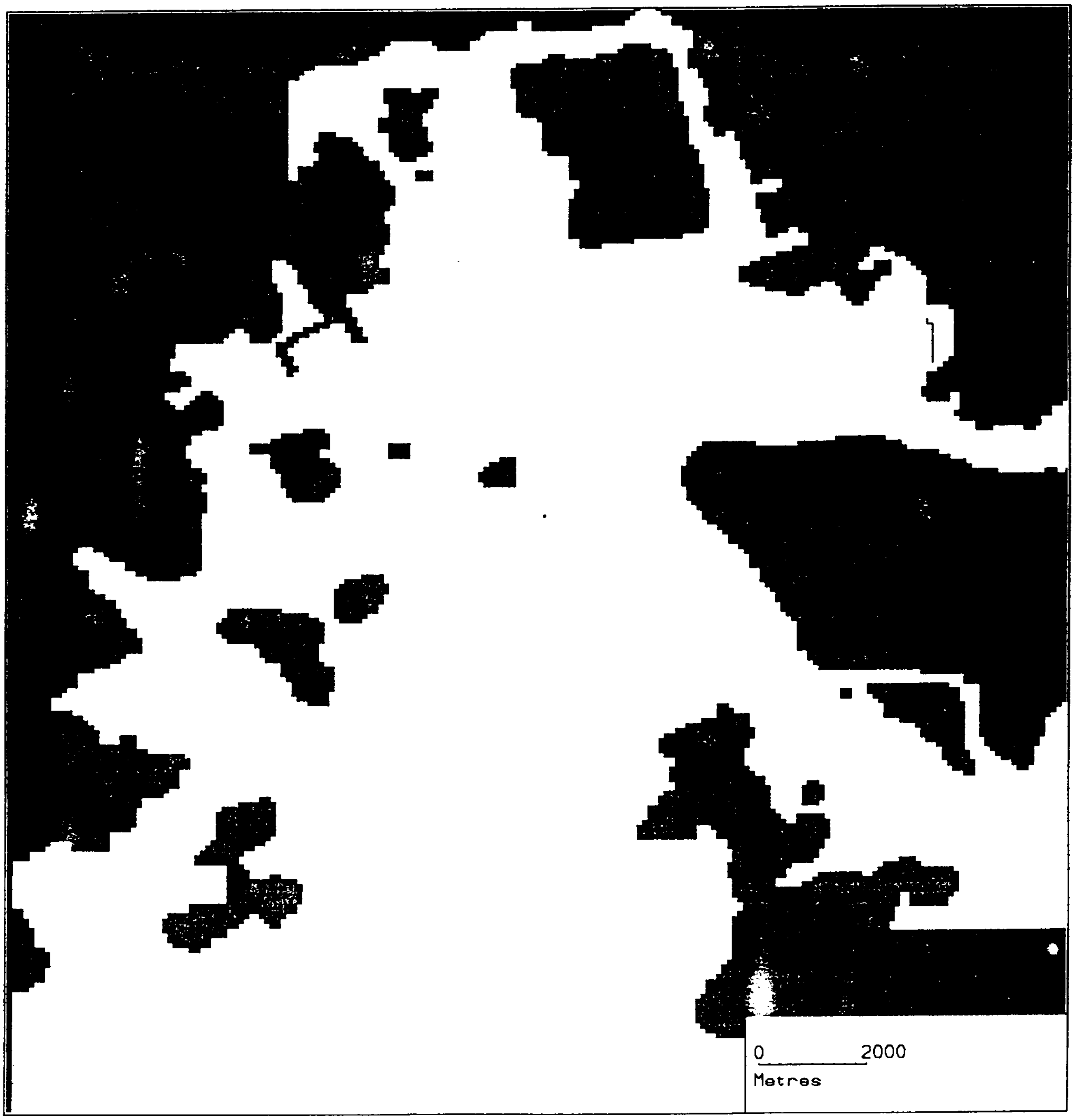

CT 10 & 11 DETAILED DESIGN

TIDAL FLOW MODEL : CONSTRUCTION LAYOUT

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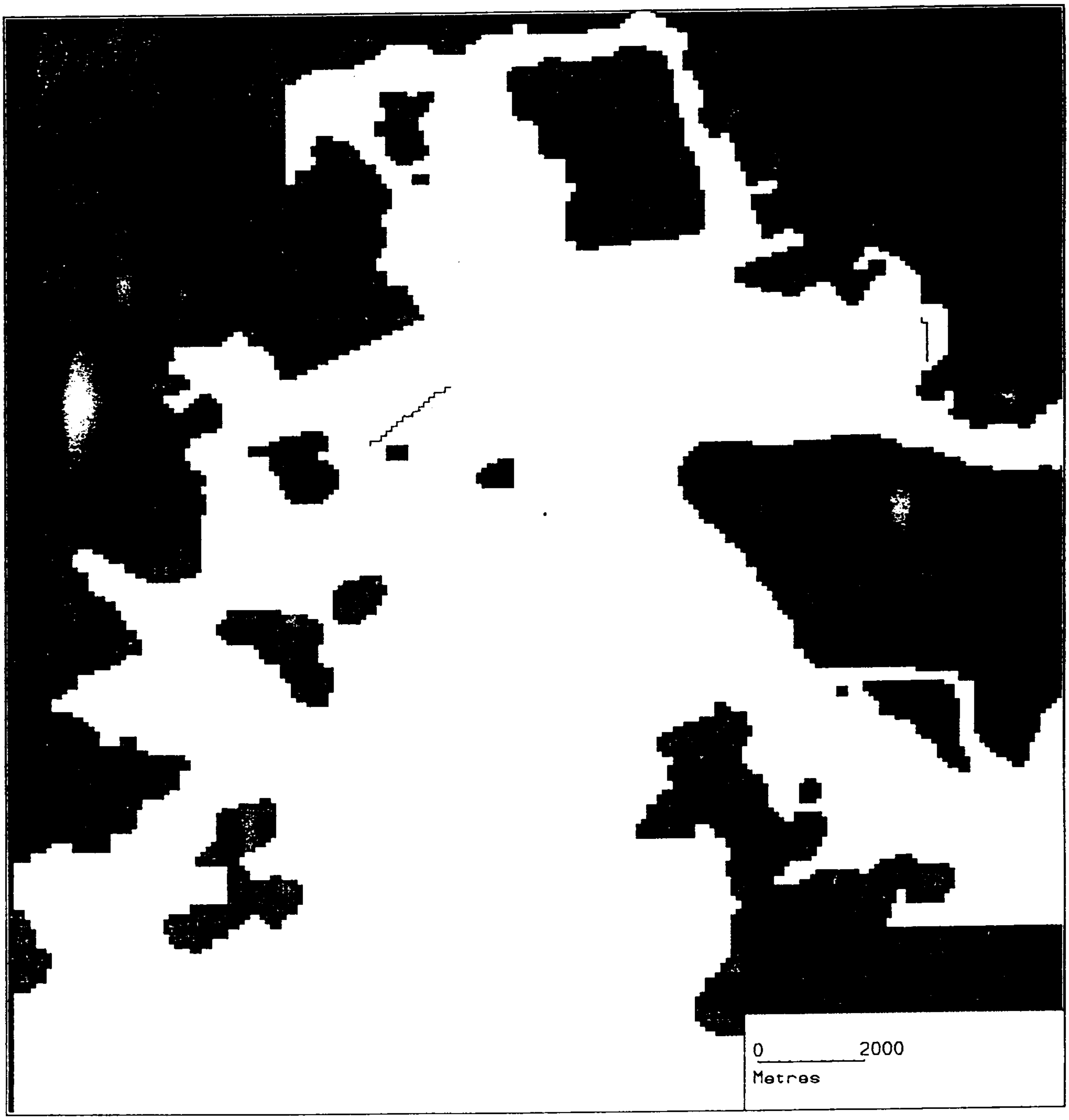

CT 10 & 11 DETAILED DESIGN TIDAL FLOW MODEL : COMPLETED LAYOUT	Fig. No. A 3.3	Page No.	CONSULTANTS IN ENVIRONMENTAL SCIENCES (ASIA) LTD
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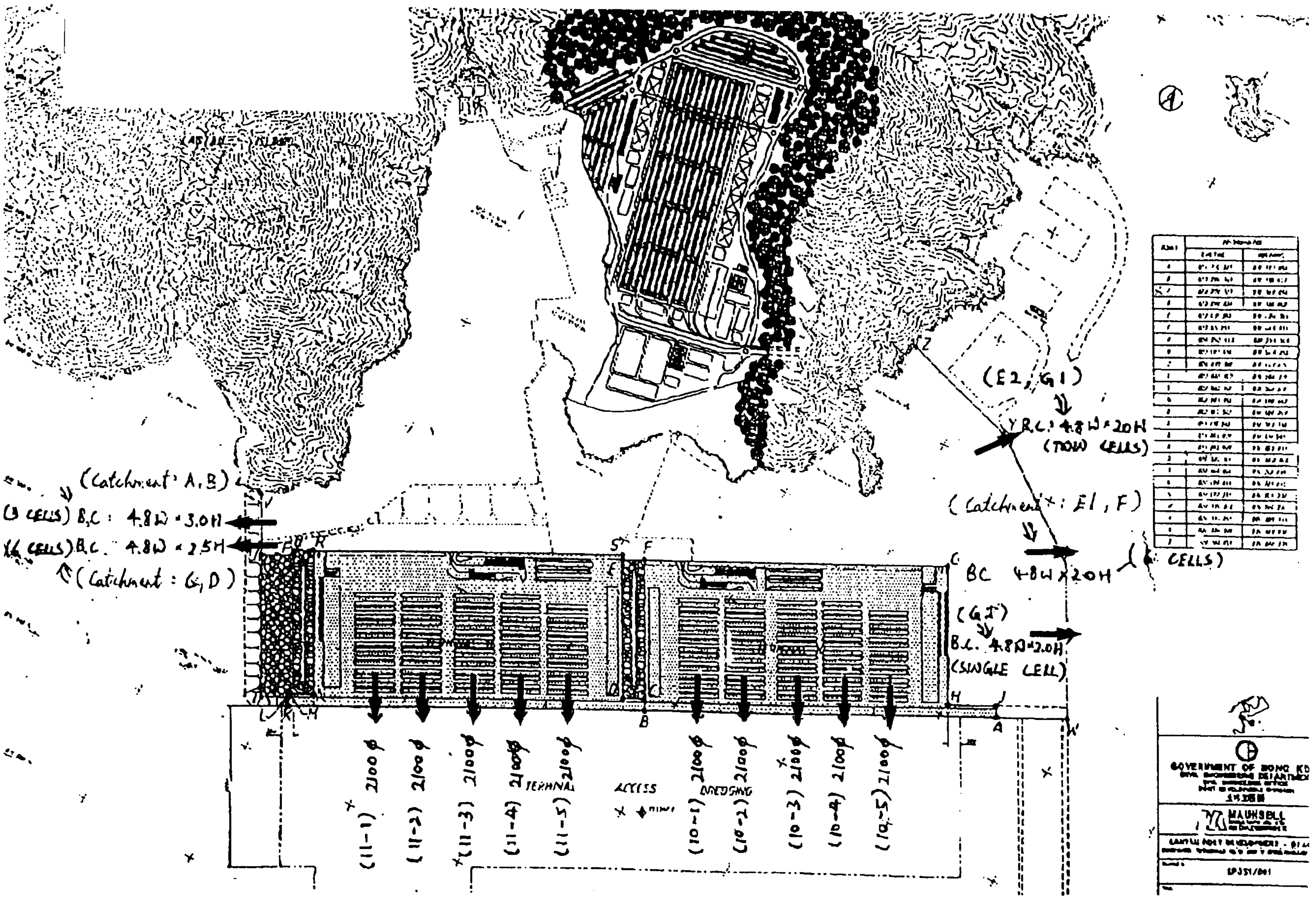

CT 10 & 11 DETAILED DESIGN

PROPOSED LOCATIONS OF STORMWATER OUTFALLS

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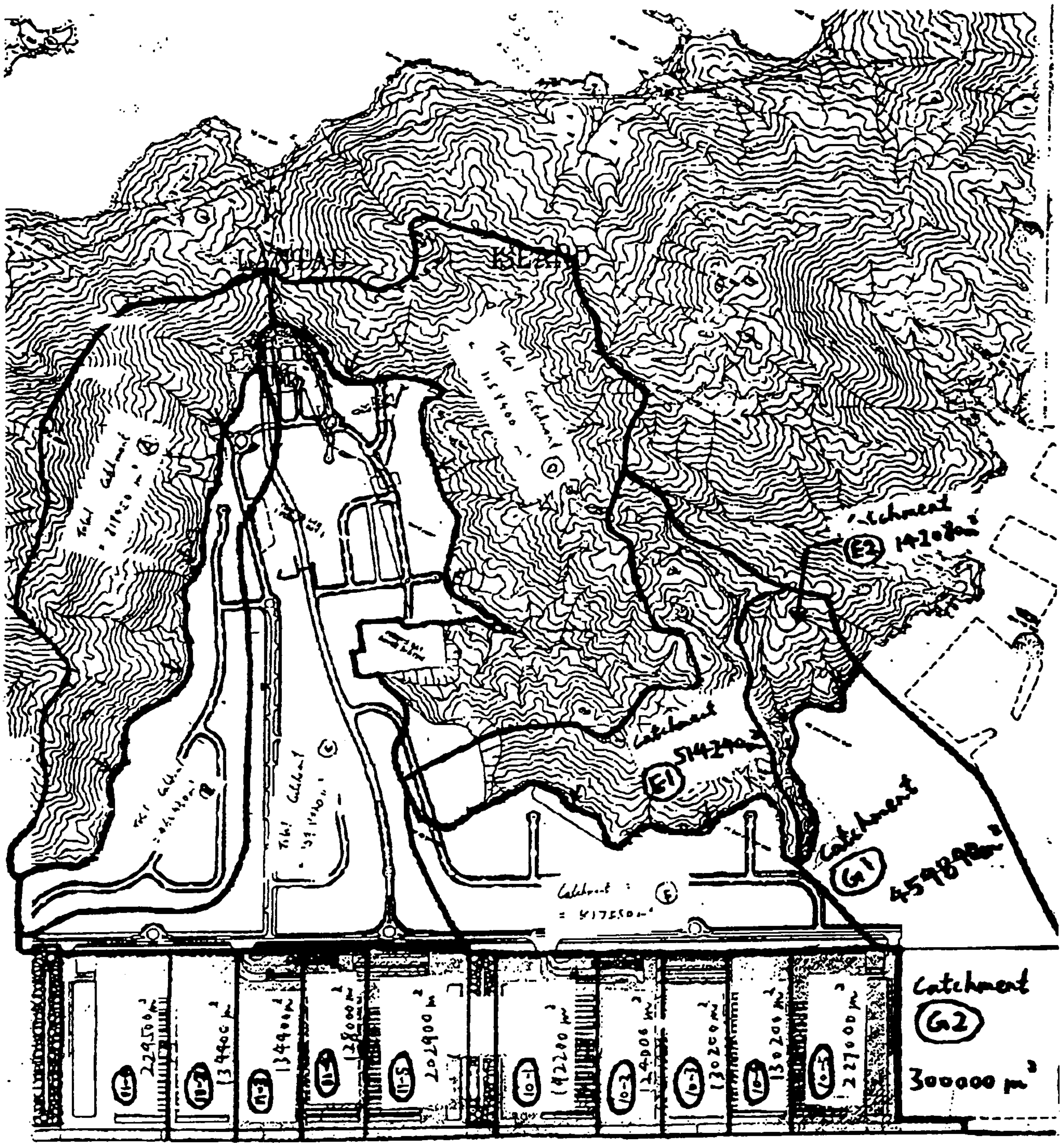

CT10 & 11 DETAILED DESIGN

STORMWATER CATCHMENTS

Fig. No. A3.5

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APPENDIX A4

Near Field Assessments for Sediment Plumes

APPENDIX A4 CT10 & 11 Near Field Assessments for Sediment plumes

Methodology :
Based on a method presented in
"A Model for the Estimation of the Concentrations ans Spatial Extent of Suspended Sediment Plumes"
by R. E. Wilson
(Ref : Estuarine and Coastal Marine Science (1979), Vol 9, pp 65-78)

The method basically solves the governing advective diffusion equation for sediment transport for a continuous source in relatively shallow water. The concentrations are vertically averaged over the depth. Settling of the sediments are considered. Horizontal diffusion of the sediment is assumed to follow the 4/3 power law for oceanic diffusion. Further details can be found in the paper

Basic Parameters

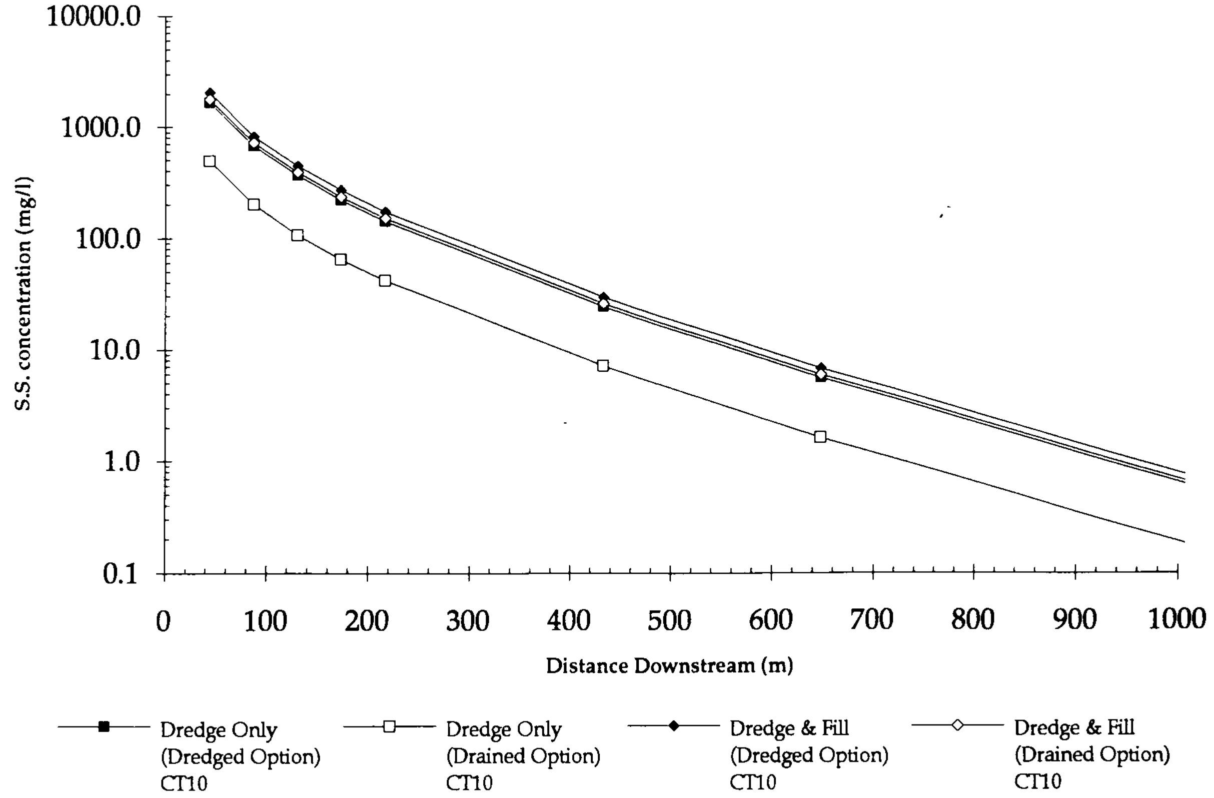
Setting velocity W =	0.005 m/s	(assume Stoke's Law)
Diffusion velocity w =	0.01 m/s	(suggested by Wilson 1979)
Average tidal current u =	0.1 m/s	
Water depth D =	10 m	
Average time between tides To =	6 hr	
Tidal excursion L =	2160 m	

Concentration at distance x = Q/(pi)/w^2/D/To*I
where I at distance x' = x/uTo :

x' =		0.02	0.04	0.06	0.08	0.1	0.2	0.3	0.5	1
I =		7.1337	2.8718	1.5419	0.9315	0.6004	0.1023	0.0234	0.0017	3E-06

S.S. concentration (mg/l) at distance x, with sediment loss rate Q (kg/s) :										
x (m)=		43.2	86.4	129.6	172.8	216	432	648	1080	2160
Q (kg/s) =										
Dredge Only (Dredged Option) CT10	16	1682.0	677.1	363.5	219.6	141.6	24.1	5.5	0.4	0.0
Dredge Only (Dredged Option) CT11	16	1682.0	677.1	363.5	219.6	141.6	24.1	5.5	0.4	0.0
Dredge Only (Drained Option) CT10	4.7	494.1	198.9	106.8	64.5	41.6	7.1	1.6	0.1	0.0
Dredge Only (Drained Option) CT11	4.7	494.1	198.9	106.8	64.5	41.6	7.1	1.6	0.1	0.0
Dredge & Fill (Dredged Option) CT10	19.6	2060.5	829.5	445.3	269.1	173.4	29.5	6.8	0.5	0.0
Dredge & Fill (Dredged Option) CT11	26.9	2827.9	1138.4	611.2	369.3	238.0	40.6	9.3	0.7	0.0
Dredge & Fill (Drained Option) CT10	17.1	1797.7	723.7	388.5	234.7	151.3	25.8	5.9	0.4	0.0
Dredge & Fill (Drained Option) CT11	7.7	809.5	325.9	175.0	105.7	68.1	11.6	2.7	0.2	0.0

S.S. Distribution for CT10



S.S. Distribution for CT11