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Strategic Sewage Disposal Scheme
Environmental Impact Assessment Study

Briefing Document on
Option Evaluation and Comparison

September 1998

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1. INTRODUCTION

1.1 Purpose of this Document

The purpose of this Briefing Document, which has been prepared by the Consultants, Montgomery Watson-Binhai Joint Venture, is:

1. to present the revised option comparison and evaluation criteria, incorporating significant refinements which resulted from the discussions on Consultation Document 1 (Discussion Note on Criteria and Options, March 1997);

2. to present the outcome of the option comparison and evaluation, which has been undertaken in Phase 1 of the SSDS EIA based on the refined sets of criteria. The outcome is a set of feasible and acceptable options, the advantages and disadvantages of which are highlighted.

1.2 Previous Work

Every day Hong Kong discharges around 1.5 million m3 of screened sewage to Victoria Harbour. The SSDS is intended to provide a sewage collection, treatment and disposal system in stages for these discharges in order to protect Victoria Harbour and the surrounding Hong Kong and Mainland waters.

The first stage of the Scheme includes the construction of a collection system serving Kowloon and eastern Hong Kong Island, treatment facilities on Stonecutters Island and an outfall discharging into the western harbour. In July 1994, the Government commissioned the Review of SSDS Stage II Options to consider a wide range of alternatives for the long term treatment process and location of sewage treatment works and associated outfalls. An International Review Panel (IRP) was appointed to oversee the Consultants' work and to provide independent advice to the Government on the findings.

The IRP recommended that Chemically Enhanced Primary Treatment (CEPT) with low dosage of iron salt and probably polymer addition is a cost effective solution for Stage I and would provide flexibility for the subsequent development of Stage II options. The IRP also recommended that a comprehensive EIA Study should be carried out. Following the recommendation of the IRP, the Government commissioned the SSDS EIA Study in parallel with the implementation of the Stage I works.

1.3 The SSDS EIA

The current study, commissioned in 1996 by the Environmental Protection Department, is being undertaken by a joint venture consultancy of Mainland and Hong Kong consultants in two phases:

- Phase 1: to determine the acceptable alternatives and hence to develop an agreed long-term sewage treatment and disposal option for the SSDS, and;

- Phase 2: to carry out a detailed Environmental Impact Assessment on the construction and operation of the next stages of the project.

Phase 1 of the study has focused on:

- development of sets of criteria to be used for option development, evaluation and comparison (and later for Environmental Impact Assessment);

- data collection, surveys and laboratory work to characterise existing environmental conditions and wastewater and effluent characteristics;

- development and evaluation of options, and comparison of the acceptable alternatives.

1.4 Structure

This document contains the following secti ons to facilitate comment and discussion:

Section 2 and 3 introduce and describe the sets of option evaluation and comparison criteria;

Section 4 summarises the development and assessment of the long-list of options;

Section 5 describes the more detailed assessment of the acceptability of the short-list of options;

Section 6 summarises the advantages and disadvantages of the remaining acceptable alternatives;

Section 7 sets out the next steps.

2. THE NEED FOR EVALUATION AND SELECTION CRITERIA

To ensure that the optimum sewage treatment and disposal option will be selected, it was important to develop an adequate, comprehensive and realistic set of criteria for option evaluation. The criteria must cover the marine environment, onshore environment, engineering, economic and social aspects. Some of the criteria are quantitative, such as contaminant concentrations in seawater, but some are necessarily qualitative, for example engineering flexibility. These criteria are used for the following purposes:

(a) to establish which potential project components are feasible, i.e. to determine whether the various sewage treatment levels, pumping stations, conveyance systems and outfalls will suffer from inherent and insurmountable environmental, planning or engineering problems which would preclude their implementation;

(b) to evaluate and compare the various options by means of mathematical models, risk assessment models and other methods;

(c) as the basis for the option selection process, in which an appropriate balance is needed between the various criteria, and;

(d) to carry out the detailed Environmental Impact Assessment and recommendation of mitigation measures for the selected option.

3. EVALUATION AND SELECTION CRITERIA

3.1 Marine Environmental Criteria

3.1.1 Beneficial Uses and Water Quality Objectives

Water Quality Objectives (WQOs) are statutory requirements for the long-term protection of beneficial uses of the marine waters. Eight beneficial uses (BU) are defined for Hong Kong waters. Some beneficial uses apply throughout HK's territorial waters, e.g. the protection of marine life, whilst others apply locally (see Table 1 and Figure 1).

On the other hand, a four-category classification is used in the PRC. Waters to the south of Hong Kong are classified as Category 1 waters.

The Hong Kong and Mainland WQOs are summarised in Annex A.

Table 1: Beneficial Uses in Local Marine Waters[1] (see also Figure 1)

Hong Kong	Mainland
BU-1: source of food for human consumption; BU-2: resource for commercial fisheries/marine fish culture; BU-3: habitat for marine life; BU-4: bathing, during March - October; BU-5: "secondary contact" recreation (e.g. diving, wind-surfing, sailing); BU-6: domestic and industrial purposes; BU-7: navigation and shipping; BU-8: aesthetics/general amenity.	Category I Waters: zones of fisheries, marine reserves, and protection of endangered aquatic species Category II Waters: zones of marine fish culture, bathing beaches, recreation or secondary contact, industrial use related to human consumption Category III Waters: zones of general industrial uses, aesthetic enjoyment and tourism Category IV Waters: zones of harbour use and exploitation of marine resources

[1] The Beneficial Uses shown in Table 1 have not been proposed by the Consultants: these have been defined previously by the Hong Kong and PRC Governments

3.1.2 Water Quality Criteria

The SSDS EIA did not attempt to set or recommend WQOs. It was, however, necessary for this study to define criteria against which sewage treatment and disposal options could be compared and on the basis of which it can be demonstrated whether each option is environmentally acceptable. The set of marine water quality criteria are related to the Beneficial Uses and the hydrodynamic conditions.

After evaluating the various local and national objectives and standards, it was concluded that these alone do not provide a comprehensive set of criteria. Therefore, the adopted criteria also draw on international experience and practice to ensure that all aspects of the marine environment are adequately covered in the evaluation process.

An important distinction in deriving the criteria and conducting the associated risk assessments is that aquatic and wildlife assessments aim to protect *populations* (both local populations and species populations), whereas the purpose of the human health criteria and assessments is to protect *individuals*.

The Water Quality Criteria have been divided into three categories:

- those required for the "near-field", i.e. very close to the location at which treated effluent is discharged;
- other criteria for general water quality;
- special requirements for particular beneficial uses.

3.1.3 Mixing Zones and Near-Field Water Quality Criteria

When effluent is discharged to the marine environment, it mixes rapidly with the surrounding seawater and forms a buoyant jet due to the density difference between the effluent and seawater. Within a few minutes, this rapid mixing process typically dilutes the sewage by about 50-100 times in the near field, and the area in which this process occurs is called the "initial dilution zone". The size of initial dilution zone at various outfall locations is shown in Annex D.

Even where a high degree of treatment is provided, there will be an area near the outfall, before this rapid mixing process is complete, where contaminant concentrations are higher than in the surrounding waters and where the WQOs will not be achieved. This area is called the "mixing zone". It is recognised by local and international regulatory agencies that the existence of such a zone is permissible to allow utilisation of environmental assimilative capacity, provided that it is carefully designed to prevent significant adverse effects to passing organisms or the water body as a whole.

To ensure that the discharge of effluent is environmentally acceptable, a two tier approach was adopted (summarised in Table 2) to ensure that there will be no toxic effect on the marine environment in the near field:

1. **Criteria for individual substances,** which are specifically of concern locally and for which scientifically based environmental standards exist. In particular, substances such as heavy metals and cyanide were selected in view of their widespread use in Hong Kong's electroplating, printed circuit board and dyeing industries.

   Ferric chloride is currently being used for the treatment process in SSDS Stage I. Residual iron can cause potential problems for fish when the iron concentration is more than 1 mg Fe/L. However, it would be present in concentrations in the treated effluents as a fraction of this. Therefore it was not included as a criterion, as marine waters concentrations will not cause any problems to fish, nor induce any significant oxygen demand, or produce discoloration.

2. **Whole effluent toxicity criteria,** as adopted by the US EPA. Toxicity was investigated by direct toxicity testing at laboratories both in Hong Kong and overseas, using SSDS catchment wastewater and effluent samples and a range of local and standard species, to ensure that the effects of all other substances and synergistic effects are fully incorporated into the evaluation.

Table 2: Near-Field Water Quality Criteria

Parameter			Value
Criteria for Individual Parameters/Substances			
Dissolved oxygen (water column average)		*	〈 4 mg/L
Dissolved oxygen (bottom 2 m)		*	〈 2 mg/L
Suspended solids		**	increase [10 mg/L
Unionised ammonia	annual average	*	[0.021 mg/L
	4-day average		[0.035 mg/L
	one-hour average		[0.233 mg/L
pH		*	6.5 - 8.5, and change < 0.2
Temperature		*	change [2℃
Sulphide			< 0.02 mg/L
Cyanide			< 0.005 mg/L
Total residual chlorine (for options incorporating chlorination)			<0.008 mg/L
Surfactants			< 0.03 mg/L
Copper			< 0.005 mg/L
Nickel			< 0.005 mg/L
Total chromium			< 0.05 mg/L
Zinc			< 0.02 mg/L
Mercury		***	<0.00005 mg/L
Arsenic		***	< 0.02 mg/L
Phenol			<0.005 mg/L
Whole Effluent Criteria			
Acute toxicity (Note 5)			< 0.3 acute toxicity units
Chronic toxicity (Note 6)			< 1.0 chronic toxicity unit

Note 1 * indicates that this value and its interpretation is identical to the current Hong Kong statutory WQO;
Note 2 ** indicates a value proposed for consistency with the most stringent PRC Mainland standard;
Note 3 *** criterion added as a result of comments on Consultation Document No.1;
Note 4 The absence of * or ** indicates that there is no numeric Hong Kong WQO for these parameters;
Note 5 Acute toxicity criterion is based on 96-hour LC50 values, where one acute Toxicity Unit (TU) is defined as *TU (acute)=100/LC50*, where LC50=% of effluent which gives 50% survival of the most sensitive of the range of species tested. The factor 0.3 transforms LC50 toxicity to LC1. This is to ensure that the concentration of the effluent at the edge of the initial dilution zone will be less than the concentration at which 1% of the biota will be affected such that no increase in mortality would be expected after initial dilution;
Note 6 i.e. concentrations at the edge of the initial dilution zone will be less than the No Observed Effect Concentration, based on the most sensitive of the range of species tested.

3.1.4 Other Criteria for General Water Quality

Having proposed the criteria in Table 2 to protect against acute and chronic effects, the following additional water quality criteria were considered necessary for all waters beyond the near-field:

Nutrients

Excessive concentrations of nutrients can lead to harmful algal growth and red tides, especially in enclosed waters. However, such algal growth is affected by flushing effects in open waters, and it was therefore considered that the Total Inorganic Nitrogen (TIN) WQO of 0.1 mg/L for the Lamma Channels, which are fast flowing, open waters, is too stringent. The same would apply to the Lema Channel, and the advice of the IRP during previous studies supports this view.

Recently, the PRC has adopted the TIN standard for Category 1 waters of 0.2 mg/L[2]. This value was considered to be more realistic for the Lamma and Lema Channels and was adopted for option evaluation. For the other water control zones, the current TIN WQO's were adopted. These guideline values, which vary depending upon the sensitivity of each water body, are listed in Table 3.

Nutrients are conservative pollutants. Apart from discharges from Hong Kong, the Pearl River currently carries large nutrient loads to the Lema Channel. The Consultants recommend that reduction of nutrient loads should be examined in a regional context.

[2] PRC National Sea Water Quality Standards (GB 3097-1997)

Table 3: General Criteria for Nutrients

Parameter	Desirable Concentration Outside Mixing Zone (annual water column average)	
	HK Waters	**Mainland Waters South of Hong Kong**
Total Inorganic Nitrogen	[0.2 mg/L Southern Waters (Note 1) [0.3 mg/L Mirs Bay [0.4 mg/L W & E Buffer Zones and Victoria Harbour [0.5 mg/L NW Waters	[0.2 mg/L
Total Inorganic Phosphorus	[1/10 TIN criterion	[0.015 mg/L

Note 1: The existing WQO for Southern Waters of HK is 0.1 mg/L. This requirement is a long-term goal. Options were not rejected based on this criterion.
Note 2: Size of mixing zone for the above parameters is less critical than for parameters listed in Table 2.

Oxygen Demand

Although Mainland standards contain limits for oxygen demand as well as for dissolved oxygen, there is no such requirement for marine waters in countries such as the USA, Europe and Australia.

Whilst the criteria for dissolved oxygen provide the necessary protection to marine life, the newly adopted Mainland standard for biochemical oxygen demand ([1 mg/L) was also used in the option evaluation.

Coliforms

Mainland standards also contain limits for coliforms for general marine waters, as follows:

- total coliforms should not exceed 10,000/L;
- faecal coliforms should not exceed 2,000/L.

To achieve these standards within a short distance of the outfall, disinfection would be required which would rely on continual use of either chemicals (for chlorination and dechlorination) and/or energy (for ultra violet irradiation). Before implementing disinfection, it is therefore necessary to ensure that the standards are consistent with the fundamental rationale that the criteria should be based on beneficial uses.

On the other hand, it was identified that the existing Hong Kong WQO's do not include a specific criterion to protect against the potential transmission of disease agents from man to marine mammals through sewage effluent discharge. The conclusion from a detailed literature survey carried out in this study was that cetaceans may be vulnerable to a wide range of pathogens, including some which are also known to infect humans and which may be present in wastewater in significant concentrations. No studies of marine mammals have shown any direct linkage of infections by any of these pathogens with a human sewage source. However, there are obvious practical constraints in proving any such direct link, and many researchers have highlighted the potential for such transfer. Hence, it should be recognised that pathogens in sewage effluent could represent a potential threat to the health of the populations of Indo-pacific humpbacked dolphin and black finless porpoise in Hong Kong and neighbouring waters.

In the absence of evidence for any particular numeric standard for protection of cetaceans, the areas predicted to be affected by elevated coliform and pathogen levels for the potential outfall sites and treatment levels were evaluated in relation to the areas frequented by local cetaceans. Recent surveys provide evidence for a "home range" in the Pearl Estuary and around Lantau Island for the local population of Indo-Pacific hump-backed dolphin. Although the home range of the black finless porpoise has not been established due to insufficient survey data, there have been frequent sightings near South Lantau, West Lamma and, less frequently, further east.

3.1.5 Criteria for Specific Zones

Proposed criteria for the evaluation of specific marine waters are proposed in Table 4. These are in addition to the requirements for general water quality and toxicity protection listed in Section 3.1.3 and those for nutrients described in Section 3.1.4.

Table 4: Additional Water Quality Requirements for Specific Zones or Beneficial Uses

Parameter	Value	Where Applicable
Dissolved Oxygen (water column average)	> 5 mg/L * > 6 mg/L	HK marine fish culture zones (BU-2) Mainland Category 1 waters
BOD	< 1 mg/L	Mainland Category 1 waters
Coliforms	1,800 *E.coli*/L* 6,100 *E.coli*/L* 200,000 *E.coli*/L 10,000 total coliforms/L 2,000 faecal coliforms/L	HK Bathing waters (BU-4, Mainland Category 2 waters); HK Secondary contact recreation (BU-5), HK marine fish culture zones (BU-2); HK Flushing or industrial use (BU-6) Mainland Category 1 waters
Total Inorganic Nitrogen (annual water column average)	< 0.1 mg/L*	HK Semi-enclosed bays, e.g. Tai Tam Bay, Port Shelter, Sham Wan (South Lamma)

Note 1: * indicates that this value and its interpretation is identical to the current Hong Kong statutory WQO;
Note 2: in addition, special consideration is required for potential impacts of pathogens in areas frequented by cetaceans.

3.1.6 Ecological and Human Health Risk Assessments

To support the criteria described above, the Consultants have used a risk-based approach to judge whether the risks of the options are real and significant and, if so, their magnitude and character. The methodologies for conducting the aquatic, wildlife and human health risk assessments are based on those developed in the United States, which is where both hazard and then risk assessment methodologies have been developed.

Exposure can occur through a variety of pathways. However, not all pathways are significant for all receptors. The following pathways which were identified to be complete and significant were evaluated in the risk assessment:

- direct contact with surface water and uptake through the gill for aquatic life;
- food and water ingestion for marine mammals (dolphin and porpoise);
- food and water ingestion pathways for humans.

An important consideration of both the ecological and human health risk assessments was the bioconcentration of chemicals through direct contact with water (e.g. respiration through gills or uptake through epithelial tissues), and the bioaccumulation of chemicals through both dietary exposure and direct contact with water.

The assessment covered the risks from the following types of potential contaminant in SSDS effluent:

- Metals;
- Organochlorine Compounds;
- Monocyclic Aromatic Hydrocarbons;
- Polycyclic Aromatic Hydrocarbons;
- Halogenated Aliphatic Compounds;
- Organophosphate Pesticides;
- Herbicides;

- Other Organic Compounds.

The Consultants carried out the risk assessment in two stages:

- the screening-level risk assessment used very conservative assumptions concerning exposure and effects for the purpose of eliminating risk elements (e.g. receptors, media, chemicals) that are either posing negligible risks or are not at risk;

- the detailed risk assessment was designed to judge whether the risks are significant and, if so, their magnitude, using more comprehensive site data to reduce the conservatism of assumptions and increase overall confidence in the risk predictions.

3.1.7 Summary of Water Quality Criteria

In summary, the Consultants have run water quality models, conducted whole effluent toxicity tests and carried out risk assessments to:

- determine which of the options can provide protection of beneficial uses by achieving the proposed water quality criteria;

- provide additional information for the comparison of the remaining options (i.e. those which are predicted to achieve the water quality criteria).

3.2 Onshore Environmental Criteria

3.2.1 Introduction

The onshore environmental criteria for air, noise, visual impact and terrestrial ecology are primarily dictated by legislation and planning guidelines in Hong Kong. The Consultants considered that these criteria are appropriate and used them to determine firstly whether any sites or options should be discarded because of insurmountable or unacceptable environmental disadvantages. Subsequently, these criteria formed part of the detailed evaluation and comparison of options. The Consultants will also use these criteria to carry out detailed impact assessment on the construction and operation for the selected option and recommend mitigation measures.

3.2.2 Noise, Air and Visual Impacts

The assessment for noise and air quality takes into account both the number of sensitive receivers who could be affected by any construction activity or the operation of any sewerage facility, and the proximity of such receivers to the sites or facilities. The number of visually sensitive receivers has also been evaluated.

3.2.3 Terrestrial Ecology

Impacts of options on terrestrial ecology are being assessed based on the extent of undisturbed land required for an option or the further disturbance which additional development and facilities would cause, and the ecological importance of any such areas.

3.2.4 Waste Management

For the assessment of waste management impacts, the main issues identified for the construction period were any need for disposal of dredged material, and the quantity of other spoil for disposal. The major issues identified during operation were the quantities and acceptable disposal methods for wastewater sludge.

3.3 Engineering Criteria

3.3.1 Site Constraints and Compatibility

Before evaluating a particular option in detail, it must be demonstrated that sufficient land is available and that its construction would not be precluded by insurmountable planning or land resumption constraints or unacceptable interruptions to other activities. Ideally, an option should not cause the cancellation or rescheduling of projects which are already planned, or cause interface problems to potential projects which are currently under investigation. However, land and interface problems were not regarded as overriding constraints, as it was considered necessary for a full range of treatment processes (see Section 4.3) and disposal options (Section 4.4) to be included in the short-listed options for detailed assessment.

All short-listed options take into account the facilities constructed under SSDS Stage I, and aim to optimise the benefits of those facilities as part of the long-term system.

3.3.2 Construction Issues

The Consultants evaluated the environmental impacts of construction using the criteria described in Section 3.2. The degree of engineering uncertainty in each option was taken into account in calculating the potential cost implications. This uncertainty applies particularly to the Lema Channel. The geology of this areas is not well known, but major faults have been identified towards the middle of the channel, and the area surrounding the Dangan Islands has been classified as higher seismicity than Hong Kong.

A separate issue is how quickly environmental improvements can be achieved for each option. This assessment has two components:

1. evaluation of the construction time for the entire option (and to achieve all those marine environmental criteria which are possible by action within Hong Kong);
2. evaluation of whether a phase of the system can be completed significantly earlier in order to provide an incremental benefit.

3.3.3 Flexibility

Flexibility is a qualitative criterion to reflect the extent to which strategies are able to respond to future changes in circumstances. The strategy should be as flexible as possible. In particular:

a) the strategy should be resistant to changes in local development planning or industrial strategy which could result in:

- increase or decrease of wastewater flows and loads;
- further reclamation, which could affect the assimilative capacity of marine waters.

b) the strategy should recognise that there are uncertainties associated with environmental criteria and pollution control. Whilst the Consultants have undertaken the main evaluation of options on the basis of current targets for water quality and source control, the following criteria will also be important:

- the extent to which each short-listed option could achieve environmental objectives even if there is a failure to achieve source control targets;
- the effects of a large change in pollution from neighbouring territories;
- the ability to upgrade the strategy in response to implementation at some future juncture of more stringent environmental controls or objectives.

3.3.4 Operational Issues

In addition to recurrent costs, operation and maintenance issues and criteria for pumping stations, tunnels and shafts, treatment works, sludge transport/disposal, and outfalls include:

- ease or complexity of operation;
- accessibility and safety;
- any ongoing interference to other activities (for example to port operations or maintenance dredging);
- consistency of project components with other facilities with which the operating agency is familiar, and the need for training;
- reliability and security of operation, risks from other activities, and consequences of failure.

3.4 Economic/Financial Criteria

The Consultants have calculated the following for each of the short listed options, in accordance with well established procedures:

- capital cost, including all ancillary works such as cavern formation, covering of sewage treatment works, access roads, mitigation measures etc.;
- cost of operation and maintenance.

3.5 Social Criteria

Community concerns in addition to those covered by the environmental and economic criteria described above might include issues such as:

- need for land resumption/resettlement;
- *fung shui* issues and proximity to burial grounds or to sites of historical and cultural importance;
- potential alternative uses of land;
- impacts to road or marine traffic;
- perceived potential effect on the pattern of commercial fishing activities.

4. OPTIONS DEVELOPMENT

4.1 Introduction: Option Components

This section summarises the development of options in two steps:

- assessment of potential option components;
- assessment of the resulting long-list of options.

Potential options comprise the following types of component:

i. collection points, at which wastewater currently discharges from the sewerage system;

ii. one or more sites at which pumping or treatment facilities are provided;

iii. a range of levels of treatment;

iv. one or more outfall sites;

v. conveyance systems to link the collection points, pumping/treatment facilities and outfall(s).

Since (i) exist and (v) depends on (i) - (iv), the generation of options largely depended upon alternatives for (ii), (iii) and (iv).

4.2 Potential Treatment Sites

Seven potential treatment sites were identified either in the Brief or during the initial months of the study. The locations are illustrated in Figure 2. However, some of these were discarded on the basis of the following considerations:

- reliance on major reclamation, or potential projects which cannot be confirmed at present;
- clashes with existing or planned surrounding land uses which could not be sufficiently mitigated;
- disturbance of terrestrial and marine ecology in identified areas of scientific importance;
- unacceptably long construction times.

Table 5 summarises the key points of the assessment and indicates the remaining potential treatment site options. Whatever the outcome of this study, the Consultants consider that the flexibility criterion is very important to allow for possible later treatment upgrades.

4.3 Potential Levels of Treatment

After the *SSDS Stage II Options Review*, the Government decided that the minimum level of treatment shall be CEPT. For options development, the Consultants considered the broad categories of wastewater treatment and effluent quality (e.g. CEPT, disinfection and biological) as shown in Table 6. All of these levels of treatment were represented in the detailed options evaluation. The performance of the CEPT process is shown in Annex C.

As noted in Table 6, a range of treatment technologies would be capable of achieving these broad treatment standards. However, the Consultants consider that those requiring very large land areas, e.g. aerobic lagoons, are not suitable for Hong Kong.

4.4 Potential Outfall Locations

Various potential outfall sites were defined in the study Brief, and the Consultants have considered these on the basis of the criteria described in Section 3 as well as the bathymetry and hydrodynamic conditions at each location. The options are listed in Table 7 and illustrated in Figure 2.

The option in the Western Fairway was considered to suffer insurmountable problems because of substantial interference to port activities during construction or operation, or due to risks to the outfall diffuser from sink-type anchors, and was discarded. This left the following list of potential outfalls and outfall combinations:

i. Stonecutters Island;

ii. East Lamma;

iii. West Lamma;

iv. SE Lamma;

v. East Lamma + Stonecutters Island;

vi. West Lamma + Stonecutters Island;

vii. SE Lamma + Stonecutters Island;

viii. East Lamma + West Lamma;

ix. East Lamma + West Lamma + Stonecutters Island.

4.5 Short-Listed Options

Following the above analysis, the Consultants considered that the remaining components described in Sections 4.2 - 4.4 would not suffer from inherent and insurmountable planning or engineering problems which would preclude their implementation. Furthermore, the options had passed the initial screening tests for environmental performance. However, prior to finalising the short-list of options, an analysis was undertaken of the optimum location for the primary treatment (CEPT) of flows from the remainder of the SSDS Catchment (Stage III/IV). The options considered were:

- Route Layout 1, in which the Stage III/IV sewage would be directed to the Stonecutters Island Sewage Treatment Plant for primary treatment with Stage I flows;
- Route Layout 2, in which the Stage III/IV sewage would be directed to a new sewage treatment plant at Mount Davis for primary treatment;
- Route Layout 3, in which the Stage III/IV sewage would be directed to new sewage treatment plant at Lamma Island for primary treatment.

The options were then assessed using the onshore environmental, economic, engineering and social criteria. It was concluded that Route Layout 1 is preferable because:

- no need to construct either a cavern or a structural cover in which to house a sewage treatment works;
- lower visual impact;

- no construction work in undisturbed land or partially disturbed land (unlike Mount Davis STW option in Route Layout 2, which would affect local ecology);

- transport distance for sludge after dewatering is lower than for Routes 2 and 3;

- economy of scale (both capital and operating costs) in providing treatment at a single location;

- Route Layout 1 provides the opportunity for phasing (i.e. Stage III/IV can be completed and commissioned in advance of completion of Stage II), if appropriate;

- Route Layout 1 (and Layout 2) provide more flexibility for future upgrades to sewage treatment, since the Lamma Quarry site is not partially utilised for CEPT;

- The main facilities associated with SSDS pumping and treatment will be located at Stonecutters Island and Lamma Quarry in Route Layouts 1 and 3. Social issues are likely to be greatest for Route Layout 2, since an additional community (at Mount Davis) may have concerns about the project;

- The outcome is insensitive to the choice of weightings between the four major criteria (onshore environment; economy; engineering; social).

The short-list of options was determined based on the components listed in Tables 5, 6 and 7 and the above conclusions and taking into account the following factors:

- there are constraints at the various treatment works sites (e.g. there is insufficient land at Stonecutters Island to provide biological treatment for the entire flow),

- it would be illogical for options providing treatment at Lamma Quarry to discharge back to Victoria Harbour via the Interim Outfall at Stonecutters Island;

- a long outfall (e.g. 8 - 10 km south of Lamma) is not required for effluent which has received biological treatment.

These options were then incorporated into the scenarios for water quality modelling shown in Table 8. Annex B also shows these short-listed options in diagrammatic form.

Table 5: Potential Treatment Sites

Location	Description and Identified Considerations	Carried forward
1. Green Island	Considered as potential site of a major sewage treatment works for the Stage III/IV catchment. Planning of the Green Island reclamation has not allowed for an area of land on which to construct a major sewage treatment works. Even if an area of the required size could be made available at this stage, the planned surrounding land uses would not be compatible, Programme for the reclamation works is uncertain and not compatible with the intended programme for the later stages of the SSDS. Therefore, it was determined that this option would not be considered further.	×
2. Mount Davis	This potential treatment site would require formation of space by excavation of a network of caverns, with entrance tunnels from the western hillside. This form of construction has been successfully used at Stanley STW, and also for the refuse transfer station at Mount Davis, but the scale required for primary treatment for the Stage III/IV catchment would be much larger. Although major part of the STW would be in cavern, some ecological disturbance would result from access road and shoreline facility for sludge transfer.	✓
3. Lamma Quarry	Substantial land area (> 20 ha) available at existing quarry. Size adequate for biological treatment. If BNR considered, a compact layout will be required if reclamation or cutting back the hillside is to be avoided. The quarry site is of no significant ecological value. Nearest sensitive receivers are at Lo So Shing and Sok Kwu Wan. Planning intent is to restore the quarry for recreational uses. A covered sewage treatment works can be compatible with this intention. However, a current study is also examining its potential use for housing.	✓
4. Mount Stenhouse	A cavern under Mount Stenhouse was considered as a possible location for biological treatment of SSDS Catchment flows. It should be recognised that Stanley STW will treat an average flow of 11,200 m^3/day, whereas the average flow from the SSDS catchment is projected to be over 2,000,000 m^3/day. Disturbance of the terrestrial ecology would be inevitable due to noise during construction of cavern portals and ventilation shafts, and by removal of vegetation at these sites and for access routes. Access from the sea would have to be provided to operate and maintain such a works. Since the site is an SSSI and a proposed Country Park, and the adjacent potential works area is a site of archaeological interest and close to a gazetted beach, it was concluded that even a cavern solution is incompatible with the surrounding land uses and conservation zones. Furthermore, it would be extremely expensive and very time-consuming to construct.	×
5. North-East Lantau Port	This site would be alongside Container Terminal 13, which is currently in the planning stage with no firm programme. The Container Terminal would be leased to private developers and therefore it may be difficult to acquire a large piece of land for a STW. All of the NE Lantau container terminals would have to be constructed first, and the programme for construction of the later terminals is very uncertain at this stage. Therefore, it was determined this option would not be considered further.	×
6. Reclamation west of Lamma	A reclamation on this site could be considered as a contingency option in the event that no other sites for the necessary treatment process could be confirmed. Such an option would have environmental and time disadvantages (e.g. compared to Lamma Quarry).	[✓]
7. Stonecutters Island	Site already formed, but there are major constraints on expansion within available land area. Nearest sensitive receivers are the military site and Mei Foo Sun Chuen. Container terminal and refuse transfer are other adjacent land uses. Stage 1 primary STW (CEPT) has been constructed and commissioned. Possible site for addition of primary treatment for remainder of SSDS Catchment (Stage III/IV) and disinfection.	✓

✓ = carried forward for more detailed assessment; [✓] = carried forward as contingency option only;
× = discarded (not carried forward for more detailed assessment)

Table 6: Potential Levels of Treatment

Abbreviation	Description	Where feasible	Sub-options and comments
C	Chemically enhanced primary treatment (CEPT)	All locations listed in Table 5	Sufficient space at Stonecutters Island for all SSDS catchment flows; Primary treatment sub-options: ● Different chemicals (e.g. ferric chloride, alum, polymer); ● Different does rates
C/D	CEPT + Disinfection	All locations listed in Table 5	Primary treatment sub-options (as above); Chlorination or UV disinfection could be provided either at the CEPT site (e.g. Stonecutters Island) or along the outfall route (e.g. at Lamma)
C/B	CEPT + Biological treatment	Insufficient area for biological treatment at Stonecutters Island or Mount Davis	Primary treatment sub-options (as above); Biological treatment designed to increase BOD removal and also to provide a degree of nitrification particularly in the summer. Range of treatment technologies/ sub-options available.
C/B/D	CEPT + Biological treatment + Disinfection	Insufficient area for biological treatment at Stonecutters Island or Mount Davis	Primary treatment sub-options (as above); Biological treatment as described above; Chlorination or UV disinfection
P/BNR	Primary treatment + Biological nutrient removal	Insufficient area at Stonecutters Island or Mount Davis. Reclamation or cutting back the hillside required at Lamma Quarry	Biological nutrient removal envisaged as a possible part of a regional nutrient control strategy. In this option it is assumed that the degree of CEPT practised upstream is reduced to alleviate potential limitations such as low alkalinity, pH depression or inappropriate BOD_5/TKN ration and ensure a high level of nitrification and denitrification. Range of treatment technologies/sub-options available.
P/BNR/D	Primary treatment + Biological nutrient removal + Disinfection	Insufficient area for biological treatment at Stonecutters Island or Mount Davis. Reclamation or cutting back the hillside required at Lamma Quarry	Biological nutrient removal as described above; Chlorination or UV disinfection

Table 7: Potential Outfall Sites

Location	Description and Identified Considerations	Carried forward
Stage 1 outfall from Stonecutters Island (Interim Outfall)	Construction completed in early 1997. Interim outfall to discharge Stage 1 flows to western harbour. Also potential permanent emergency outfall. Water depth (< 12 m) relatively shallow compared to other sites; The Stage I outfall would fail to achieve the water quality criteria for unionised ammonia and dissolved oxygen. Use of the Stage I outfall to discharge reduced flows as part of a permanent solution was therefore considered. However, the proportion of the total SSDS flow which could be discharged while achieving the water quality criteria would be very small and substantial engineering modifications would be required to maintain functional operation at such flows. Such modifications would be costly and would adversely affect the flow which could be discharged if the Stage I outfall is ever required as an emergency outfall for the ultimate SSDS. The options utilising the Stage I outfall as a permanent supplementary outfall were therefore not considered further.	✗
A. West of Mount Davis	Within HK Territorial waters; Depth 1 km offshore > 20 m. Major shipping lane (over 98% of all ocean going vessels use the Western Fairway, which cannot be diverted. It would be impossible to site a diffuser in the Western Fairway for both construction and operational reasons, because construction of the diffuser would be disruptive to marine traffic and to maintenance dredging. Further west are two more fairways and several main anchorage zones, in which the sink-type anchoring system is used. Consideration was given to an extended outfall, crossing the Western Fairway using construction methods that are non-disruptive to port operations, for example by tunnelling. However, no suitable site for the diffusers is evident due to unacceptable risk of anchors damaging the diffuser.	✗
B. Approximately 3 km South-west of Lamma	Within HK Territorial waters; Water depth > 20 m Potential location and orientation adjusted to take account of shipping lanes, south Lamma marine park proposal, and prevailing currents;	✓
C. Approximately 3 km East of Lamma	Within HK Territorial waters; Water depth > 20 m Potential location and orientation adjusted to take account of shipping lanes, south Lamma marine park proposal, and prevailing currents;	✓
D. Approximately 8 - 10 km south or south-east of Lamma	Outside HK Territorial waters; Water depth > 25 m Site D was indicated in the Brief. Two alternative sites identified: • Site D1 is further north and east when compared to the original Outfall Site D to reduce the influence of the outfall on the conservation areas near Dangan Island and Wailingding, be located well clear of the main shipping lanes, and avoid the need to cross the major fault zone in the Lema Channel (although this would need to be checked thoroughly by geotechnical surveys). However, Site D1 is within the area in which key undersea telecommunications cables are located. • Site D2 is further east to reduce the influence of the outfall on the conservation areas near Wailingding; be located well clear of the fish culture zones at Po Toi and the main shipping lanes; avoid clashes of the diffuser with undersea cables. However, Site D2 does not avoid the need to cross the major fault zone in the Lema Channel.	✓

Table 8: Scenarios Included in Detailed Water Quality Assessment

Scenario	Development	STW Option		Outfall Option		
		Stonecutters Island [7]	Lamma Quarry [3]	West Lamma [B]	East Lamma [C]	Southeast Lamma [D]
2a	Year 2016	C			C	
2b	Year 2016	C/D			C/D	
3a	Year 2016	C		C		
3b	Year 2016	C/D		C/D		
4a	Year 2016	C				C
4b	Year 2016	C/D				C/D
5a	Year 2016	C		C	C	
5b	Year 2016	C/D		C/D	C/D	
6a	Year 2016	C	B		B	
6b	Year 2016	C	B/D		B/D	
7a	Year 2016	P	BNR		BNR	
7b	Year 2016	P	BNR/D		BNR/D	
8a	Year 2016	C	B	B		
8b	Year 2016	C	B/D	B/D		
9a	Year 2016	P	BNR	BNR		
9b	Year 2016	P	BNR/D	BNR/D		
10	Year 2016	No SSDS, but other sewerage projects (e.g. Siu Ho Wan STW, Sham Tseng STW) implemented				

Note: Scenario 1 was the existing situation
Identifiers in [ ] relate to the locations shown in Figure 2
P = Primary Treatment C = Chemically Enhanced Primary Treatment; D = Disinfection
B = BOD removal; BNR = Biological Nutrient Removal

5. ASSESSMENT OF SHORT-LIST OF OPTIONS

5.1 Introduction

Section 5 describes the findings of the more detailed assessment of the sixteen short-listed options

5.2 Marine Environment

5.2.1 Marine Surveys

Comprehensive marine surveys were carried out in both Hong Kong and Mainland waters during the SSDS EIA study to supplement information from previous studies and routine monitoring. The programme comprised hydrodynamic, water quality, sediment quality and ecological surveys, including examination of contaminants in biota samples. The surveys were undertaken as appropriate in summer, autumn, winter and spring, and during neap tides and spring tides.

The existing water quality in Southern Waters and the Lema Channel is relatively good compared to Victoria Harbour (see also Section 5.2.3). Long-term pollution is reflected in the low diversity of the benthic communities found in the surveys in Victoria Harbour. Elsewhere, ecological survey results show that the community of benthic animals and plankton are in normal condition, with normal community diversity and evenness. Dominant fish species and commercial species identified in the surveys are listed in Annex F. However, in common with the results of previous studies and surveys, few adult individuals and high numbers of juveniles were found. The catches and average body lengths of important commercial species were low, indicating overfishing in the survey area. Low concentrations of heavy metals and trace organics were found in the 160 samples of fish, shrimp and squid tissue samples which were tested.

5.2.2 Types of Assessment

In addition to near-field modelling to compare the near field conditions for the parameters listed in Tables 3 and 4, the following methods and assessments have been carried out by the Consultants:

- three-dimensional far-field modelling to estimate the sizes of any mixing zones and to determine whether the water quality criteria would be achieved at sensitive receiver sites;
- detailed risk assessments for human health, aquatic life and marine mammals;
- assessments of potential water quality changes at ecological sensitive receivers for which no specific criteria exist.

The results of these assessments are summarised in Table 9 and described below.

5.2.3 Water Quality Modelling

Dissolved Oxygen

Existing water quality in Victoria Harbour does not achieve either of the criteria specified for dissolved oxygen in Table 2. All of the short-listed options would improve average dissolved oxygen concentrations by about 1 mg/L, thus enabling these criteria to be reliably achieved in Victoria Harbour (see examples[3] in Figure 3 which shows conditions in the wet season and conditions in the dry season).

The effect on waters close to the potential outfalls was quantified. Options which provide CEPT and discharge via the shorter outfalls would result in dissolved oxygen reductions of about 0.2 mg/L, while those with biological treatment would result in reductions of about 0.1 mg/L. The longer outfall options would result in reductions of about 0.15 mg/L. Figure 3 indicates the extent of the areas affected for various options. None of the short-listed options are expected to result in failures of the criteria in Table 2 (i. e. 〈 4 mg/L depth average; 〈 2 mg/L for bottom waters). Furthermore, the options would not jeopardise the existing water quality objectives for marine fish culture zones (〈 5 mg/L depth average), and would achieve the Mainland dissolved oxygen objectives on an annual average basis with concentrations of 6.3 - 6.8 mg/L in the Lema Channel.

Oxygen Demand

Options discharging into Mainland waters would require only a small mixing zone (< 1 km^2) beyond the initial dilution zone to achieve the Mainland standard for BOD ([1 mg/L).

Suspended Solids, pH and Temperature

All of the options would achieve the criteria for suspended solids, pH and temperature.

Coliforms

All options bring about substantial improvements in coliform concentrations in Victoria Harbour (see Figure 3). However, the model predictions show that concentrations above 10,000 *E.coli*/ 100 mL would still occur close to the seawall based on the conservative assumption that 10% of the wastewater continues to discharge via storm drains. Further improvements can be expected through full implementation of the Sewerage Master Plans.

In the absence of disinfection, coastal beneficial uses would be at risk from such discharges at the East Lamma and West Lamma sites (or from a twin outfall at the two sites) when assessed on the basis of the coliform criteria in Table 4. Such discharges would also potentially affect areas known to be frequented by dolphins and porpoises. Although the diffusers would be within Hong Kong waters, there would be areas south of the territorial boundary which would not achieve the Mainland standards (see Section 3.1.4). Application of biological treatment would reduce the areas of impact of the East Lamma and West Lamma options, but would not remove the concerns about coastal beneficial uses and habitats of dolphins and porpoises.

[3] Figure 3 shows the influence of the potential further reclamations as well as the effect of potential SSDS outfalls

Coastal beneficial uses would not be at risk from coliforms in CEPT effluent discharged at the SE Lamma outfall site, and this outfall site is remote from any areas known to be frequented by Indo-Pacific Humpbacked dolphins. It is not known, however, whether this area is frequented by other marine mammals (e.g. porpoises). Furthermore, a large mixing zone would need to be agreed in respect of the Mainland standards (see Section 3.1.4) if this option was to be implemented.

Based on the modelling results, the locations of sensitive receivers and the size of mixing zones, the Consultants concluded that none of the non-disinfection options would satisfy the criteria for secondary contact recreation zones, Mainland criteria or precautionary approach for protection of dolphins and porpoises. **All of these options were therefore rejected.**

All of the coliform criteria would be achieved at the edge of the initial dilution zone (and therefore at all sensitive receivers) in all options in which disinfection would be implemented, irrespective of whether CEPT or biological treatment is applied upstream. Based on the modelling results, it is considered reasonable to apply at least 99.9% removal of coliforms as a precautionary measure for protection of marine mammals. This would lead to concentrations of < 600 *E.coli*/ 100 mL after initial dilution.

Ammonia

Figure 3 shows ammonia nitrogen values for the wet season and dry season. The water quality criteria in Table 2 are specified for the more toxic form, unionised ammonia, concentrations of which depend upon pH, temperature and salinity in the marine environment. In the worst case (wet season) conditions, concentrations of unionised ammonia are approximately 8% of the ammonia nitrogen concentration in surface waters, whereas in deeper water in the wet season and throughout the water column in the dry season the ratio is about 4%.

The first value for unionised ammonia specified in Table 2 ([0.021 mg/L annual average) is the existing statutory water quality objective for Hong Kong. Modelling results showed that this criterion would not be achieved in Victoria Harbour without the SSDS, but that the criterion could be achieved by all of the short-listed options. In view of the potential toxicity of unionised ammonia, further checks were undertaken by comparison with the 4-day and one-hour USEPA criteria ([0.035 and [0.233 mg/L respectively), and these were also found to be achieved by all options in the worst case conditions (the values for CEPT with outfalls into Hong Kong waters would be < 0.025 mg/L and < 0.072 mg/L respectively).

Nutrients

Inorganic nitrogen concentrations in Victoria Harbour have consistently approached the criterion of < 0.4 mg/L during recent years, and this criterion was breached in the Rambler Channel in 1995 and 1996 and in the various parts of the Victoria Harbour in 1995. Orthophosphate values in this region were also commonly reported to be > 0.04 mg/L.

The nutrient criteria have generally been achieved in Southern Waters (south of Lantau, south of Lamma and south of Hong Kong Island), where typical inorganic nitrogen values are 0.09 - 0.18 mg/L and orthophosphate is in the range 0.015 - 0.020 mg/L. Existing water quality in the Lema Channel is influenced by nutrients from the Pearl River, but still achieves the criteria set out in Table 3 (0.2 mg/L inorganic nitrogen, 0.015 mg/L inorganic phosphorus).

For all options the model outputs show a substantial drop in the inorganic nitrogen concentration in the Victoria Harbour area, so that the water quality objective would be achieved in this area. Phosphate concentrations would also fall considerably, enabling the criterion of [0.040 mg/L to be comfortably achieved in Victoria Harbour.

All options would remove a substantial proportion of total phosphorus, but only the BNR options would remove a substantial proportion of inorganic nitrogen. All options would achieve the inorganic nitrogen criteria listed in Table 3. However, even if the SSDS incorporates nitrogen removal it is not possible to achieve the long-term goal of [0.1 mg/L in Hong Kong’s Southern Waters and bays because of the influence of discharges from the Pearl River. For options discharging to Southern Waters without nitrogen removal, increases in total inorganic nitrogen close to the outfall sites would be from about 0.14 mg/L to about 0.17 mg/L, but within the bays at South Lamma the increase would be limited to 0.01 mg/L. The options would generally have little impact on inorganic phosphorus concentrations in Southern Waters or the Lema Channel, although options incorporating chemically enhanced primary treatment would result in a marginal reduction in such concentrations.

Metals, Sulphide, Phenol, Cyanide and Trace Organics

The criteria for nickel, chromium, copper, zinc, mercury, arsenic, ammonia, sulphide, phenol and cyanide as listed in Table 2 can comfortably be achieved by effluent from either CEPT or biological treatment. The options would also achieve the newly adopted Mainland standards[4] for Category 1 waters at the edge of the initial dilution zone for all of these constituents except for mercury, for which existing concentrations of 0.2 μg/L have been monitored in Southern Waters compared to the new Category 1 standard of 0.05 μg/L. The options would result in an increase in mercury concentration at the edge of the initial dilution zone of about 0.003 g/L on average.

Constituents which were not listed in Table 2 but were detected in SSDS catchment wastewater were analysed with respect to risk-based values (see Section 5.2.4). The same procedure was also used for constituents which were <u>not</u> detected in the effluent or wasterwater by posing the question in the risk assessments: *what if these substances are present in the effluent at or just below the detection limit?*

Whole Effluent Toxicity

Bioassays were conducted with both SSDS wastewater samples and with effluent generated by a purpose built pilot plant using the CEPT process. These tests were conducted by two laboratories (one overseas and one in Hong Kong) using a total of six different test organisms (see Table 10), with a variety of wastewater and effluent concentrations (i.e. a range of percentages of wastewater/effluent and seawater).

Table 10: Test Organisms used in SSDS EIA Whole Effluent Toxicity Tests

Overseas Tests (in USA)	Local Tests (City University)
Fish Larval Development *Menidia beryllina*	Amphipod *Melita longidactyla*
Mysid *Mysidopsis bahai*	Barnacle Larvae *Balanus amphitrite*
Bivalve Embryo Larval Development *Mytilus edulis*	Fish *Lutjanus argentimaculatus*

The whole effluent toxicity tests confirmed that a moderate degree of toxicity is associated with SSDS catchment wastewater and with CEPT effluent derived from this wastewater as follows:

- the results of the acute tests undertaken locally indicate the minimum effluent LC50 value[5] calculated for a test organism (fish) was 44% effluent. The lowest LC50 value obtained in the local tests was for the pilot plant influent (a test on barnacles resulted in a LC50 of 30.4%);

- the chronic toxicity tests conducted overseas produced a minimum LC50 value for CEPT effluent of 30.6% (bivalve). The lowest LC50 value obtained in the overseas tests was 12.3% for an SSDS composite wastewater sample (bivalve);

- the minimum NOEC value[6] calculated in the chronic tests (undertaken by international laboratory) was 6.2% effluent for the mussels (bivalve) embryo development test;

The criteria set for protection against acute and chronic toxicity would be achieved by all options which utilise CEPT. No samples of SSDS effluent following biological treatment were available for comparison with those obtained after CEPT, but it is likely that biological effluent would be less toxic than CEPT effluent.

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4 The new standards came into effect in July 1998. The Category 1 standard for Hg has been altered from 0.5 μg/L to 0.05 μg/L

5 The lower the LC50 value, the higher the toxicity of the effluent to the particular marine organism

6 The lower the NOEC value, the higher the toxicity of the effluent to the particular marine organism

5.2.4Human Health and Ecological Risk Assessments

The detailed ecological and human health risk assessments assessed potential additional risks of exposure to chemicals associated with SSDS effluent, as described in Section 3.1.6. Risks associated with exposure pathways arising from the immediate vicinity of the potential outfalls were evaluated, thus providing conservative estimates of the risks directly associated with eact SSDS option. Ecological and human health risks (expressed as hazard quotients) for organochlorine compounds, monocyclic aromatic hydrocarbons, polycyclic aromatic hydrocarbons, halogenated aliphatic compounds, organophosphate pesticides, herbicides or other organic compounds which were actually detected in SSDS catchment wastewater are presented in Annex E.

The human health risk assessment evaluated two principal exposure pathways; the consumption of fish and shellfish collected in the vicinity of the effluent discharge at a zone of initial dilution, and incidental ingestion of water from swimming close to the zone of initial dilution.

None of the chemicals evaluated were identified as posing non-carcinogenic risks to either children or adults under any of the exposure scenarios examined. Moreover, none of the chemicals which were identified above the detection limits in the sewage effluent would pose any potential carcinogenic risks. For chemicals which were below detection limits in the sewage effluent, a very conservative approach was adopted by assuming that these chemicals occur at the detection limit in both wastewater and effluent. Using this assumption, potential carcinogenic risks were identified for only three of these undetectable chemicals (i.e., benzidine, dieldrin and aldrin). In fact, organochlorine pesticides such as dieldrin and aldrin are extremely insoluble in water. These substances are adsorbed very strongly on the surface of suspended particles, and are therefore readily removed in the CEPT process even if they are present in the wastewater.

The aquatic life risk assessment evaluated possible risks to a balanced aquatic community at the zone of initial dilution for each of the four proposed outfall locations. An assessment using standard water quality guidelines identified PCBs, DDT and dieldrin as potential chemicals of concern (COCs). These chemicals were not detected in the SSDS effluent above their detection limits (and are either banned in Hong Kong or are prohibited from discharges to sewer). A more detailed assessment screened out toxicity data from the guideline values that do not apply to exposure of aquatic life through the water column, and concluded that even detection limit concentrations of these three chemicals would not pose a risk of concern to aquatic life. These findings are supported by the results of the whole effluent toxicity tests.

The wildlife risk assessment evaluated possible risk to the dolphin and porpoise. Ingestion of prey (fish and shellfish) and water ingestion were the exposure pathways evaluated. There were no specific toxicity data for these species, and therefore surrogate data and factors of safety had to be employed. There were also uncertainties associated with the adopted area use factors, particularly for the longer outfall options. The assessment identified three chemicals (i.e., PCBs, dieldrin, and DDT) as COCs. These chemicals were not, however, detected above their respective detection limits. Therefore, risks associated with these chemicals were predicted based on detection limit concentrations and this assumption probably overestimates risk to the dolphin and porpoise.

Overall, the risks predicted for human health, aquatic life and wildlife (the Indo-Pacific Humpbacked dolphin and finless porpoise) are low. The only chemicals identified to be of potential concern (PCB's, DDT, dieldrin, aldrin, benzidine) were not detected in the SSDS wastewater or effluent, and were therefore assumed in the risk assessment to be present at the detection limit. These types of substances are prohibited from being discharged to sewers, and the use of DDT is banned in Hong Kong. Furthermore, due to their extreme insolubility in water, PCB's and organochlorine pesticides such as DDT, dieldrin and aldrin would be readily removed in the CEPT process[7] or in biological treatment. The actual risk of any of the options is therefore minimal.

[7] As these chemicals were not present above their detection limits, the % removal could not be confirmed in the SSDS EIA wastewater and effluent characterisation trials

Table 9: Summary of Performance Assessment for Marine Environment

Treatment	C	C/D	C	C/D	C	C/D	C	C/D	C/B	C/B/D	P/BNR	P/BNR/D	C/B	C/B/D	P/BNR	P/BNR/D
Outfall Location	EL	EL	WL	WL	SEL	SEL	EL/WL	EL/WL	EL	EL	EL	EL	WL	WL	WL	WL
WQ Modelling Scenario Number	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b	7a	7b	8a	8b	9a	9b
Dissolved oxygen	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
BOD (PRC)	✓	✓	✓	✓	≈	≈	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Suspended solids	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Coliforms: human health	✗	✓	✗	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓
Coliforms: cetaceans	✗	✓	✗	✓	✗	✓	✗	✓	✗	✓	✗	✓	✗	✓	✗	✓
TIN: open waters	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
TIN: bays	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈
TIP	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	≈	≈	✓	✓	≈	≈
Toxic metals	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Toxic inorganics	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Trace organics	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Acute toxicity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Chronic toxicity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Human health risk	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Marine life risk	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Abbreviations:

Abbreviations:	✓	=	acceptable (based on numerical criteria)
	≈	=	cases where existing/background conditions make it impossible for SSDS to achieve the criteria (e.g. TIN criterion for bays at South Lamma, in which the existing TIN concentrations already marginally exceed the 0.1 mg/L objective and for which Scenarios 2a, 2b, 6a, 6b would increase TIN concentrations by < 0.015 mg/L), or where a small mixing zone would be required outside initial dilution zone (e.g. for BOD in Mainland waters in Scenarios 4a, 4b)
	✗	=	unacceptable (based on numerical criteria)
	WL	=	West Lamma (Site B)
	EL	=	East Lamma (Site C)
	SEL	=	longer outfall south or south-east of Lamma (Sites D, D1, D2)
	P	=	Primary Treatment
	C	=	Chemically Enhanced Primary Treatment
	D	=	Disinfection
	B	=	BOD removal
	BNR	=	Biological Nutrient Removal

5.2.5 Sensitive Receivers

The following paragraphs briefly summarise the projected water quality in relation to the potential impacts of the SSDS on specific sensitive receivers.

Beaches and Secondary Contact Recreation Areas

The nearest beaches and secondary contact recreations zones to the potential outfall sites are at Lamma, southern Hong Kong Island and eastern Cheung Chau. The application of disinfection in any of the Femaining options will provide security of micro-biological water quality for all of these areas. Not only will the statutory water quality objectives be achieved (these are expressed as geometric means), but this disinfection will also protect these areas even in unusual hydrodynamic or meteorological conditions (e.g. when both the wind and tidal movement is onshore towards the beaches). None of the options would cause increased turbidity or affect the general amenity in these recreation areas.

Marine Fish Culture, Fisheries and Plankton

The application of disinfection in the remaining options will ensure protection of micro-biological water quality for marine fish culture zones, even in unusual hydrodynamic or meteorological conditions. The specific dissolved oxygen criterion for these zones would also be achieved.

The water quality assessments, whole effluent toxicity tests and risk assessments also demonstrate that the options will not have an adverse impact on marine organisms close to the outfall sites. The average initial dilution achieved during wet season is around 75x (see Annex D for range of dilutions achieved). This is large compared with the requirement of 11x dilution to ensure no acute toxicity and 16x dilution to ensure no chronic toxicity to the marine organisms.

More specifically, these assessments together with the survey results demonstrate that there would be no adverse effect on commercial trawling. Few adult individuals of important commercial species were found in the SSDS EIA surveys. Eggs and larvae of commercial species were found in the surveys throughout the Pearl Estuary, Southern Waters and Lema Channel areas. Zones designated as nursery grounds for commercial fish or shrimps are located at least 8 km west of any of the potential outfall sites in the vicinity of the Wanshan Islands and Guishan Island. Other zones designated as spawning grounds for commercial fish are located further north in the Pearl Estuary.

The average width of the initial dilution (see Annex D) is less than 100 m. Considering an average current velocity of 0.1 m/sec, it would only take about 16 minutes for a planktonic organism to pass through the initial dilution zone. This time frame is low compared with the acute and chronic toxicity test periods of 48 hours and 7 days, respectively.

Dolphins and Porpoises

Many pathogens are opportunists, and marine mammals may only be vulnerable to them when they are sick or stressed for other reasons. There is considerable evidence suggesting that certain chemicals can compromise marine mammal immune systems. The risk assessment indicates that there is minimal risk from any of the options to dolphins and porpoises (see Section 5.2.4).

The West Lamma outfall site is closest to areas in which the Indo-Pacific Humpbacked dolphin is sometimes sighted, and both West Lamma and East Lamma outfall sites are within the area inhabited by the finless porpoise. Specifically for protection of the Indo-Pacific Humpbacked dolphin, the longer outfall options [D, D1, D2] would be preferred, followed by the East Lamma site [C] and the West Lamma site [B].

As noted previously, undisinfected effluent from either the West Lamma or East Lamma outfall site would be a cause for concern for these dolphins and porpoises and therefore such options are not considered to be acceptable.

Potential Marine Park

No specific water quality objectives have been set for marine parks in Hong Kong. General requirements are often adopted for such zones. Although access to a marine park may be to some extent restricted, diving activities can be expected in the area to study the health of the marine environment. Consequently, options which discharge at East Lamma or West Lamma outfall sites but which do not disinfect would be undesirable, and such options have been rejected. In other respects, the remaining options are not inconsistent with the general requirements described above.

The initial dilution zone for all options would be outside the boundary of the marine park, based on the currently envisaged boundary. Hence, water quality would be protected to be better than the criteria listed in Table 2.

Coral Communities

Hong Kong is sub tropical, approximates to the northern boundary for hard coral occurrence and is influenced by the Pearl River. Consequently, coral reefs such as those in tropical waters (e.g. the Great Barrier Reef and those of the Philippines) have never existed in local waters. However, there are several sites in Hong Kong at which "coral gardens" have been identified which are worthy of protection, the majority of which are in the eastern waters (e.g. Port Shelter, Mirs Bay) where the conditions are closest to oceanic.

The East Lamma outfall is the nearest to identified coral communities of value in Southern Waters at Lamma, Round Island and Beaufort Island. Effluent characteristics and modelling results were used as a guide to potential impacts of the potential constituents of concern, which were identified to be settleable solids and nutrients.

Sedimentation from particulates in discharges or from dredging/construction are generally agreed to be a problem for coral communities. The incremental suspended solids concentrations after CEPT and initial dilution would be about 1.0 mg/L Concentrations of settleable solids in the water column would not increase at the Lamma, Round Island or Beaufort Island sites, because all options employ at least CEPT or biological treatment.

As shown by the water quality and risk assessments and whole effluent toxicity tests, there should be no toxic effects to these coral communities, and the effect of the outfall options on nutrients at these sites would be neutral.

Turtles

Populations of all species of turtles are declining worldwide to the extent that they are threatened with extinction and are protected by the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES). The major reason for this decline internationally is that large numbers are trapped and drowned in commercial fishing nets. Other contributing factors are habitat loss, boat strikes and egg and meat collection.

Of the three species which have been sighted in Hong Kong, only the Green Turtle (*Chelonia mydas)* is known to nest in Hong Kong at Sham Wan, Lamma, although five other beaches have been identified as suitable for nesting. Green turtles are known to nest regularly at Gangkou, 30km to the East of Hong Kong. While nesting is infrequent and irregular at Sham Wan, it is the only site in Hong Kong at which it occurs, and for this reason alone deserves special attention.

The risk to the health of turtles from the plume is likely to be minimal as the nearest potential outfall site is at least 5 km from the beaches in Sham Wan. Furthermore, turtles are not territorial, and are known to range widely in the oceans. Currently Green turtle populations world-wide are threatened by a disease called Green Turtle Fibropapilloma, There is no evidence to indicate that there is any link with anthropogenic activities. As adopted for precautionary protection of cetaceans, disinfection of the effluent will provide added insurance against any pathogens which could potentially be infectious to turtles.

Young turtles have a very low survival rate in the first year of life, mainly as a result of predation. They rapidly disperse into the open sea and probably stay in surface waters for the first few weeks. Hatching occurs in mid/late summer, at which time the plume from the outfall will most likely be trapped below 7m and not impact young turtles.

Flushing Water and Cooling Water Intakes

The bacterial quality criterion adopted in Table 4 for flushing or industrial use will be achieved by all of the options *provided that* wastewater collection is improved and that local pollution problems are successfully tackled by implementation of the Sewerage Master Plans and enforcement of the Water Pollution Control Ordinance.

5.3 Onshore Environment

Major onshore environmental concerns arose at the short-listing stage and related to the noise and ecological issues associated with the Mount Stenhouse site (see Table 5) and the choice of primary treatment site for Stage III/IV flows (see Section 4.5). The main differences between the short-listed options in relation to onshore environmental criteria relate to the distinctions between the following two categories:

- Options not involving biological treatment, for which facilities on Lamma Island would be limited to a pumping facilities and possibly UV disinfection, thus their onshore environmental impact would be relatively low;

- Options involving biological treatment, which would require a biological STW on Lamma Island to process the CEPT or primary treatment effluent of Stonecutters Island STW. These options would require a much larger land area at Lamma.

Noise

The projected noise at sensitive receivers was found to be acceptable according to the relevant standards for all of the remaining options. However, the following distinctions between the options were identified:

- Options utilising CEPT with an outfall to Hong Kong waters would have the lowest impact. Options with CEPT and a longer outfall would have a similar impact in terms of noise intensities, but over a prolonged period during construction of the long outfall;

- Options utilising biological treatment would result in higher predicted noise levels at sensitive receivers than those with lower levels of treatment.

Air

The main air quality issues were dust generation during construction and odorous gases during operation. All options were considered to be acceptable provided that suitable mitigation measures are taken to suppress dust and to prevent the formation of sulphides in the effluent.

Visual

Visual impacts of the relatively small facilities for the CEPT options would be very slight, particularly when compared with the existing uses at Lamma Quarry. However, the permanent impact of a large sewage treatment works would be of concern to local residents. It is suggested that this could be mitigated by using a covered treatment works design, providing the opportunity for landscaping and alternative (e.g. recreational) uses above.

Terrestrial Ecology

Of the two remaining sites under consideration, one is within an existing sewage treatment works boundary on existing reclamation and the other is an existing quarry site. No terrestrial ecology issues were identified for these two sites.

Waste Management

The key differences between the options are

- the quantity of primary/chemical sludge and surplus activated sludge which would be generated by the various options: total sludge quantities would be lowest for CEPT options, and highest for combinations of CEPT with biological treatment. Higher sludge quantities will result in greater transport and probably incineration[8] requirements in the future;

- the overall quantities of construction wastes/spoil generated by the options would be similar, as all options incorporate over 20 km of large diameter tunnels. If tunnelled, the longer outfall would generate a somewhat higher quantity, depending upon the final selection of outfall location (Site D, D1 or D2). Large quantities of rock derived from tunnelling should not be a major environmental concern provided that it is disposed of in accordance with the relevant regulations and procedures.

5.4 Engineering

Compatibility

Potential competing projects relate to the Lamma Quarry site. One of these is the proposed quarry rehabilitation to provide for recreational uses. This is not incompatible with a major sewage treatment works, since a covered treatment works design could be employed with recreational uses above, but it does introduce programming and interface issues.

Construction Issues

Construction risks relate primarily to the prevailing geological conditions. In this respect, options using a short outfall west of Lamma were identified as the more favourable options. Marine geophysical surveys and site investigations are required to confirm whether the remaining options would be affected by major faults in the vicinity of the East Lamma Channel and the Lema Channel. The longest outfall option considered (site D2) would almost certainly cross a major fault zone in the Lema Channel.

All options have the potential for incremental implementation, as discussed in Section 4.5, and all options would require further marine geophysical surveys. The main distinction between the remaining options is the overall construction period. This is estimated to be between 5 1/2 - 6 1/2 years for options discharging outside Hong Kong waters, depending upon which of the longer outfall sites is selected, and about 4 - 41/2 years for the options discharging within Hong Kong waters. It should be noted that the greater geological uncertainties for the longer outfall option also result in greater uncertainties in estimating its completion time.

Flexibility

Detailed environmental studies would be required before any future reclamations would be implemented, and these would need to consider the impact on marine water quality and the effectiveness of the SSDS. SSDS options which would discharge at Site B would be more susceptible to possible reclamation in the West Lamma Channel than the East Lamma or longer outfall options.

As noted in Section 3.3.3, whichever option is selected for SSDS Stage II, the long-term strategy should incorporate the capability for expansion or for a later treatment upgrade or (if an outfall to Hong Kong waters is implemented in Stage II) enhancement by construction of a longer outfall.

Operation

In general, high levels of treatment require greater operating expertise. The required level of expertise in operation of activated sludge plants is readily available in Hong Kong, and the biological treatment options have been developed based on more space efficient variants of this process.

Operational risks associated with the effluent transfer system would be common to all options. However, the risks from shipping or from geological faults would vary for the potential outfall locations.

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[8] a parallel study is in progress to determine the optimum method of sludge disposal for the future. Incineration is one of the options under consideration

5.5 Socio-Economic Issues

Costs

Capital and operating costs for all of the options which include disinfection are summarised in Table 11.

Socio-Economic Criteria

The optimum use of land is an important consideration. The use of 20 - 30 ha for biological treatment may be viewed as in conflict with other social needs (e.g. housing). However, the Consultants do not consider that this should be an important factor in the assessment. Irrespective of whether biological treatment is adopted as a component of SSDS Stage II, it is recognised that flexibility for future changes in environmental requirements can be built into the strategy by incorporating provisions to add a future treatment upgrade (e.g. to provide nutrient removal in the long-term).

Impacts of any of the options on road traffic or marine traffic would be minimal. Likewise, although major issues relating to sites of cultural heritage or archaeological interest were highlighted for some of the long-listed options, no such concerns have been identified for the short-listed options.

Table 11: Summary of Option Costs and Land Issues

Option Details: **Treatment** **Outfall**	**C/D** **EL**	**C/D** **WL**	**C/D** **SEL**	**C/D** **EL+WL**	**C/B/D** **EL**	**P/BNR/D** **EL**	**C/B/D** **WL**	**P/BNR/D** **WL**
WQ model scenario number	2b	3b	4b	5b	6b	7b	8b	9b
Capital costs (HK$ billion)	11.5	11.5	13	14	23	26	23	26
Recurrent costs (HK$ billion year)	0.9	0.9	0.9	0.9	2.0	2.3	2.0	2.3
Permanent land requirement (ha)	17	17	17	17	33	39	33	39

Above costs are at 1998 prices and are for SSDS Stage II (i.e. excludes Stage III/IV tunnels and preliminary treatment works upgrades). Cost for SE Lamma outfall option is for the longest outfall (site D2)
Land requirements include all facilities at Stonecutters Island and downstream treatment/disposal system
WL = West Lamma; EL = East Lamma; SEL = longer outfall south or south-east of Lamma
P = Primary Treatment; C = Chemically Enhanced Primary Treatment; D = Disinfection; B = BOD removal;
BNR = Biological Nutrient Removal

5.6 Conclusions

The main outcome of the performance assessment was that the potential impacts on the marine environment of discharges of SSDS effluent without disinfection were assessed to be unacceptable on the basis of the criteria defined in Section 3. All eight such options were therefore discarded.

The eight options which remain after the performance assessment are considered to be both *feasible* and to provide *acceptable environmental performance.*

6. SUMMARY OF FEASIBLE AND ACCEPTABLE OPTIONS

6.1 Introduction

The options which are both *feasible* and provide *acceptable environmental performance* can be considered as four main options (see Figure 4):

Option 1: providing CEPT and disinfection, with relatively short outfall(s) into Hong Kong waters at East or West Lamma;

Option 2: providing CEPT and disinfection, with a relatively long outfall into Guangdong waters (Site D, D1 or D2 in Figure 2);

Option 3: providing biological treatment and disinfection, with a relatively short outfall into Hong Kong waters at East or West Lamma;

Option 4: providing biological nutrient removal and disinfection, with a relatively short outfall into Hong Kong waters at East or West Lamma.

All of these options would provide very substantial improvements to water quality, including the achievement of all water quality objectives for Victoria Harbour. It should be remembered that other actions would also need to be implemented if every long-term water quality objective is to be achieved[9], because the SSDS is just one important component of the overall strategy for water pollution control in Hong Kong and the entire Pearl River Delta region.

6.2 Common Elements

In addition to the ability to upgrade the treatment process at a later stage, the components which are common to all remaining options are:

Stage III/IV

- upgrades of preliminary treatment works;
- transfer of flows to Stonecutters Island STW;
- expansion of CEPT at Stonecutters Island STW.

Stage II

conveyance of SSDS catchment primary effluent from Stonecutters Island STW to Lamma Island;

- disinfection facilities for all flows;
- pumping station at Lamma Island;
- a permanent outfall from Lamma Island into Hong Kong waters10.

The Consultants recommend that all of the above common components should *as a minimum* be implemented in SSDS Stages II and III/IV as part of the overall strategy to provide improvements to water quality as soon as possible. These common components would serve as the foundation for water quality protection which would permit incorporation of future enhancements (e.g. higher level of treatment or longer outfall) with minimal disruption and cost, should such enhancements be judged necessary.

Section 6.3 summarises key aspects of the four main options to assist in determining whether the actual scope of SSDS Stage II should include facilities in addition to these common elements.

6.3 Key Aspects of Each Option

6.3.1 Option 1: CEPT and Disinfection, with Outfall(s) into Hong Kong Waters

This option would achieve all of the water quality criteria specified in Tables 2, 3 and 4 with the exception of the long-term criterion for inorganic nitrogen (0.1 mg/L) in Southern Waters. The current situation does not achieve this criterion because of regional nutrient loads.

Although this option would discharge close to South Lamma, the risk assessments show that the risks to human health, aquatic life and cetaceans would be minimal, and no unacceptable impacts on the proposed South Lamma marine park have been identified.

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9 none of the options would achieve the long-term objective of 0.1 mg/L for inorganic nitrogen in Southern Waters

10 In the event that a long outfall is selected, this short outfall from Lamma would serve as an emergency outfall should use of the long outfall be temporarily interrupted. This would enhance the reliability of the overall system

Other key features of this option are:

- low land requirement;
- low onshore environmental impact;
- moderate capital and operating costs;
- moderate construction time.

6.3.2 Option 2: CEPT and Disinfection, with Outfall into Guangdong Waters

This option (discharging at Site D, D1 or D2) would discharge into deeper waters and provide better initial dilution characteristics than the other options. With the exception of the long-term criterion for inorganic nitrogen in Southern Waters (0.1 mg/L), all of the water quality criteria specified in Tables 2, 3 and 4 would be achieved, although a small mixing zone would be required to satisfy the Mainland Category I standard for oxygen demand at all times.

This option would not discharge close to the proposed marine park or habitat of the Indo-Pacific Humpbacked dolphin. The risk assessments show that the risks to human health, aquatic life and any other species of dolphin or porpoise which inhabit the vicinity would be minimal.

Other key features of this option are:

- low land requirement;
- low onshore environmental impact;
- low sensitivity to the effects of future reclamations;
- moderate capital and operating costs;
- some uncertainty associated with the geological conditions in the Lema Channel;
- relatively long construction periods.

The relative importance of the Time for Construction criterion is influenced by existing marine water quality conditions and the projected increases in pollution loads in the next five to ten years. Stage I of the SSDS provides interim improvements, but on its own was never expected to achieve the water quality objectives for Victoria Harbour and neighbouring water control zones. The water quality modelling work carried out in this study based on the latest development projections suggests that the remaining stages of the SSDS should be completed as soon as possible.

Option 2 requires a considerably longer outfall which would represent the critical path for completion. Assuming a reasonable rate of progress, this option would take between one and two years longer to construct than Option 1 or Option 3. In view of the geological uncertainties associated with major faults and higher seismicity in the Lema Channel and Dangan Islands areas, there would be a risk that construction times for Option 2 would in practice become even longer. Of the various potential outfall sites, Site D or D1 would be preferred to Site D2 for engineering reasons (less likely to encounter the worst of the major fault zone which is located in the Lema Channel) and because these could be completed more rapidly than for Site D2.

6.3.3 Option 3: Biological Treatment and Disinfection, with Outfall into Hong Kong Waters

This option would achieve all of the water quality criteria specified in Tables 2, 3 and 4 with the exception of the long-term criterion for inorganic nitrogen in Southern Waters (0.1 mg/L). The current situation is unsatisfactory for this criterion because of regional nutrient loads.

Although this option would discharge close to South Lamma, the risk assessments show that the risks to human health, aquatic life and cetaceans would be minimal, and no unacceptable impacts on the proposed South Lamma marine park have been identified.

The other key characteristics of this option are:

- high land requirement (which could be mitigated to some extent by designing a covered treatment works with recreational uses above);

- greater onshore impacts than for Options 1 and 2, although with appropriate mitigation measures these would not be unacceptable;
- high capital and operating costs;
- moderate construction time.

6.3.4 Option 4: Nutrient Removal and Disinfection, with Outfall into Hong Kong Waters

This option is similar to Option 3 except that nutrient removal would be incorporated into the biological treatment process.

It should be noted that all of the options will achieve the criteria for Victoria Harbour, the Western and Eastern Buffer Zones, Southern Waters and Mainland Waters south of Hong Kong. Even the nutrient removal options cannot achieve the long-term objective of 0.1 mg/L for total inorganic nitrogen (TIN) in Southern Waters because of nutrient loads carried into Southern Waters and the Lema Channel by the Pearl River. Furthermore, the Mainland marine water quality standard for Category 1 waters has recently been amended from 0.1 mg TIN/L for inorganic nitrogen to 0.2 mg TIN/L. The Consultants therefore conclude that:

- the viability of nutrient removal as part of SSDS Stage II is doubtful;
- any need for reduction of nutrient loads should be examined in a regional context;
- the ability to upgrade the treatment process at a later stage should be retained as part of the long-term strategy.

Option 4 would discharge into waters which are frequented by cetaceans, but the associated risks are considered to be minimal. Although this option would discharge close to South Lamma, no unacceptable impacts on the proposed South Lamma marine park have been identified.

The other key characteristics of Option 4 are:

- a greater land requirement than for Option 3 (the option could be designed as a covered treatment works with recreational uses above), therefore some reclamation may be needed, or additional land formed by cutting back the hillside;
- greater onshore impacts than for Options 1 and 2. With appropriate mitigation measures these would generally be acceptable, but options requiring reclamation in So Kwu Wan would require further detailed study;
- high capital and operating costs;
- moderate construction time (or a long construction period if reclamation is required).

6.3.5 East Lamma and West Lamma Outfall Sites

The differences in environmental performance between the East and West Lamma sites are minimal. No significant benefits were identified in the use of outfalls at both of these locations. Therefore, the choice between the East Lamma and West Lamma outfall sites would depend upon the results of further sensitivity tests, the likelihood of reclamations in the western harbour, and the results of future geophysical surveys.

6.3.6 Summary of Key Differences

The key distinctions between the four options are summarised in Table 12.

7. NEXT STEPS

After selection of the Stage II option, Phase II of the study will continue to:

- undertake schematic design;
- undertake sensitivity testing;
- conduct the detailed EIA for construction and operational phases;
- determine mitigation measures and recommend monitoring and auditing procedures.

Table 12: Key Differences between Feasible and Acceptable Options for SSDS Stage II

Details and Main Criteria	Option 1	Option 2	Option 3	Option 4
Primary Treatment	CEPT	CEPT	CEPT	Primary
Biological Treatment	No	No	Yes	Yes
Nitrogen removal	No	No	No	Yes
Disinfection	Yes	Yes	Yes	Yes
Outfall	West Lamma or East Lamma (Site B or Site C)	SE Lamma: towards Lema Channel (Site D, D1 or D2)	West Lamma or East Lamma (Site B or Site C)	West Lamma or East Lamma (Site B or Site C)
Marine Environment	Achieves all criteria which it is possible for SSDS alone to achieve			
Onshore Environment	Limited impacts	Limited impacts	Moderate (but acceptable) impacts	Moderate impacts. Options requiring reclamation would require further study
Time for completion (from selection of option to completion of construction)*	7 1/2 - 8 years	8 1/2 - 10 years	7 1/2 - 8 years, provided that Lamma Quarry site is allocated for the biological STW	8 - 8 1/2 years (or 91/2 - 10 years if reclamation required)
Other Engineering Issues	Further geophysical surveys required	Uncertainties associated with faults and higher seismicity in Lema Channel and Dangan Islands areas	Further geophysical surveys required	Further geophysical surveys required
Capital costs (HK$ billion)	11-12	12 - 13	22 - 23	25 - 26
Recurrent costs (HK$ billion/year)	0.9	0.9	2.0	2.3
Land requirement	17 ha	17 ha	33 ha	39 ha

* this is the best estimate at this stage assuming rapid commencement of geological surveys

ANNEXES

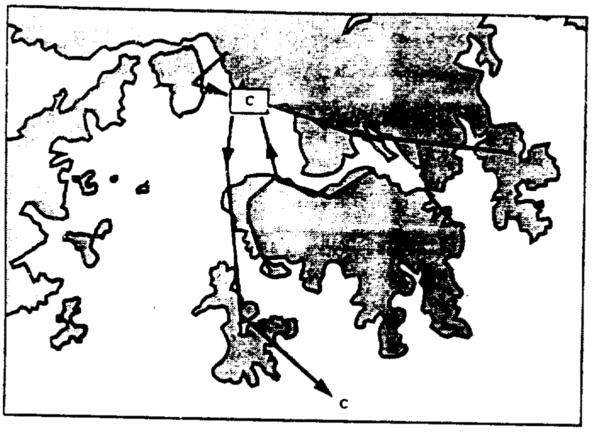
Annex A:	Seawater Quality Objectives in Hong Kong and Mainland
Annex B:	Short-Listed Options for Detailed Assessment
Annex C:	SSDS Catchment Wastewater Quality and CEPT Effluent Quality
Annex D:	Initial Dilutions and Size of Initial Dilution Zone at Potential Outfall Sites
Annex E:	Risk Assessment Results
Annex F:	Fishery Resources in Main Areas of Interest

Annex A
National and Hong Kong Seawater Quality Objectives

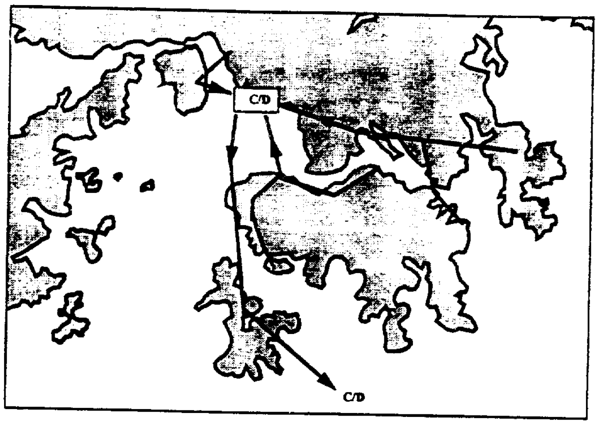
Indicator	Hong Kong					China (GB3097-1997)			
	Fish culture BU-2	Marine life BU-3	Bathing BU-4	Secondary contact recreation BU-5	Flushing, industry, shipping & landscape BU-6, 7, 8	Category I (Oceanic biologic resources)	Category II (Bathing place, fish culture)	Category III (Industry)	Category IV (Harbour)
Aesthetic	No objectionable odours or discoloration of the water. Tarry residues, floating wood, articles of glass, plastic, rubber or any other substance should be absent. Mineral oil should not be visible on the surface. Surfactants should not give rise to a lasting foam. There should be no recognisable sewage - derived debris					No abnormal colour, odour or taste in seawater. No oil slick, foam on the water surface.			No objectionable colour, odour or taste in seawater. No noticeable oil slick, foam on the water surface.
Coliforms (count/L)	<6,100 *E Coli*		<1,800 *E Coli*	<6,100 *E Coli*	<200,000 *E Coli*	<10,000 total <2,000 faecal			nil
Dissolved Oxygen (mg/L)	>5	>4	>4	>4	>4	>6	>5	>4	>3
	bottom 2 m > 2								
BOD_5 (mg/L)						[1	[3	[4	[5
COD_{Mn} (mg/L)						[2	[3	[4	[5
Unionised Ammonia (mg/L)	<0.021					[0.020			
Inorganic nitrogen (mg/L)	<0.1 - 0.5 (depends on location)					[0.20	[0.30	[0.40	[0.50
Inorganic phosphorus (mg/L)						[0.015	[0.03	[0.40	[0.50
SS (mg/L)	<30% increase					artificial increase [10	artificial increase [10	artificial increase [100	artificial increase [150
pH	6.5 - 8.5, change<0.2					7.8-8.5; variation [0.2		6.8-8.8; variation [0.5	
Phenol (mg/L)			<0.05			[0.005	[0.010	[0.05	
Crude oil (mg/L)	crude oil should not be visible on the surface								
Petroleum Products (mg/L)						[0.05		[0.30	[0.50
Mercury (mg/L)						[0.00005	[0.0002		[0.0005
Cadmium (mg/L)						[0.001	[0.005	[0.010	
Lead (mg/L)						[0.001	[0.005	[0.01	[0.05
Total Chromium (mg/L)						[0.05	[0.10	[0.20	[0.50
Nickel (mg/L)						[0.005	[0.010	[0.020	[0.050
Arsenic (mg/L)						[0.02	[0.03	[0.50	
Copper (mg/:)						0.005	0.01	[0.50	
Zinc (mg/L)						[0.02	[0.05	[0.10	[0.50
Selenium (mg/L)						[0.01	[0.02		[0.05
Cyanide (mg/L)						[0.005		[0.10	[0.20
Sulphide (mg/L)						[0.02	[0.05	[0.10	[0.25
Pesticides (mg/L)									
DDT (mg/L0						[0.00005	[0.0001		
Malathion (mg/L)						[0.0006	[0.001		
Methyl Parathion (mg/L)						[0.0005	[0.001		
Surfactants (mg/L)						[0.03	[0.10		

Note: See Table 1 for more detailed description of the four National water quality categories

Annex B - Short-Listed Engineering Options for Detailed Assessment



Engineering Option used in Scenario 2a



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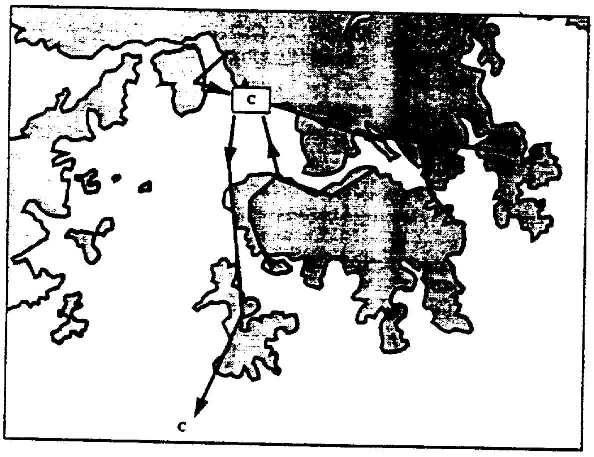

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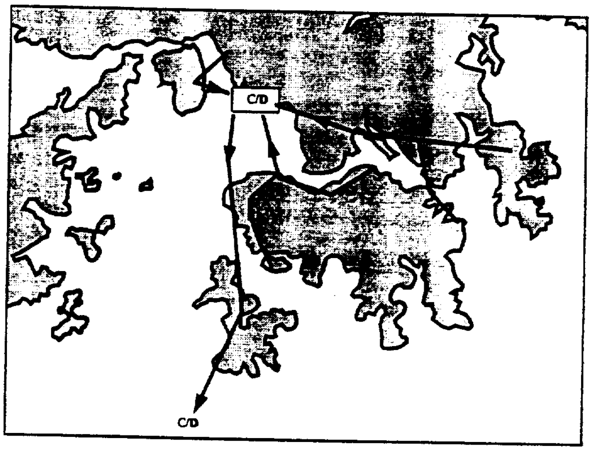

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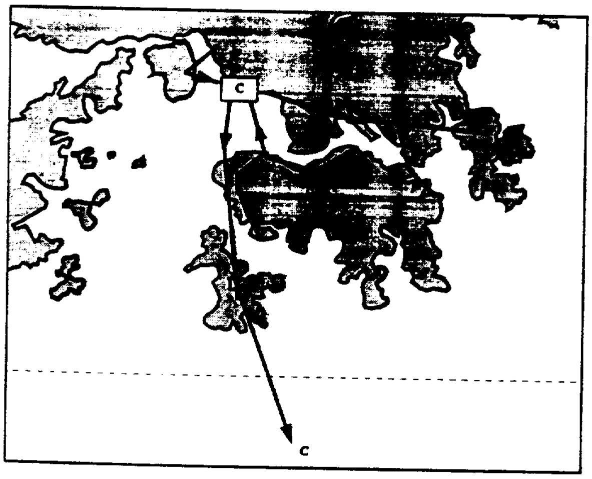

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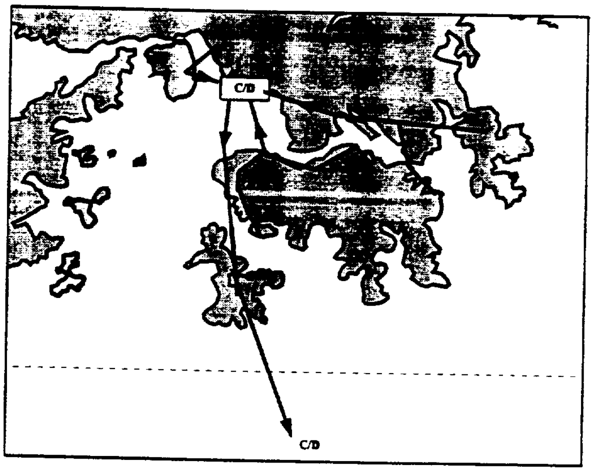

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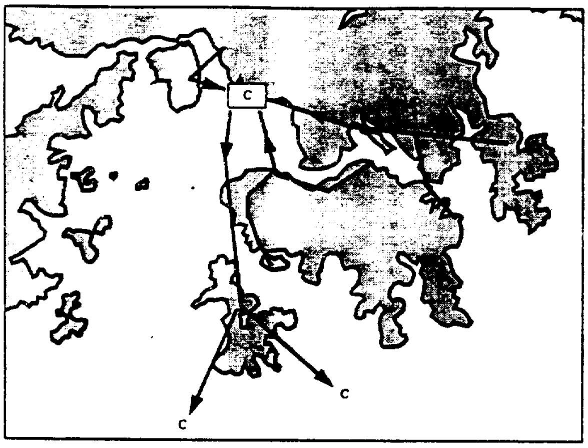
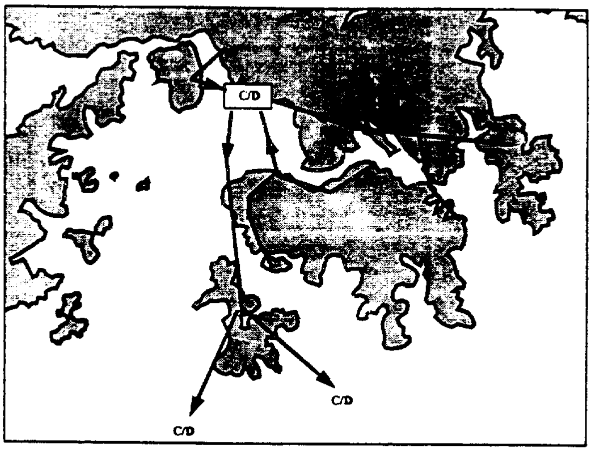


Engineering Option used in Scenario 5a



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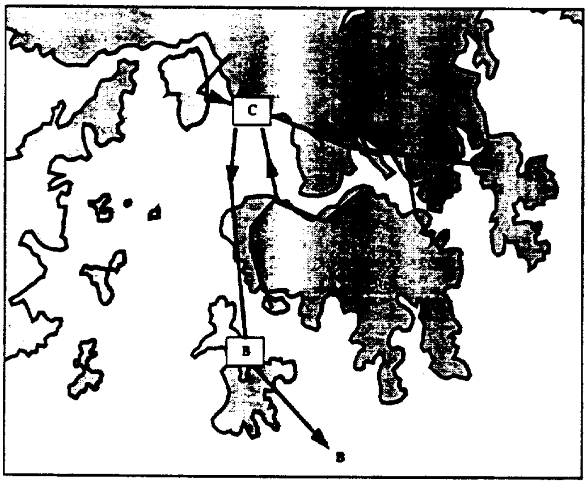
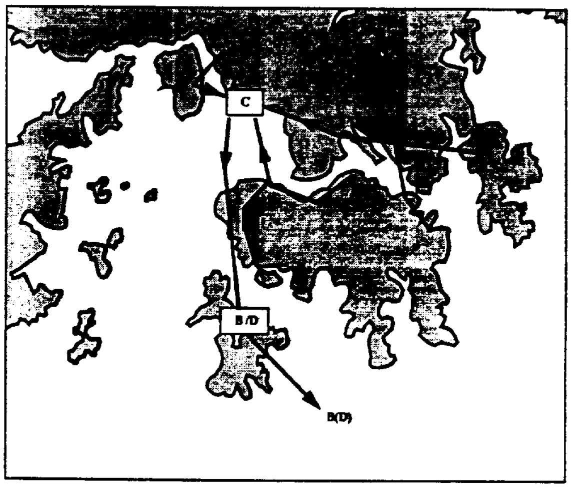


Engineering Option used in Scenario 6a



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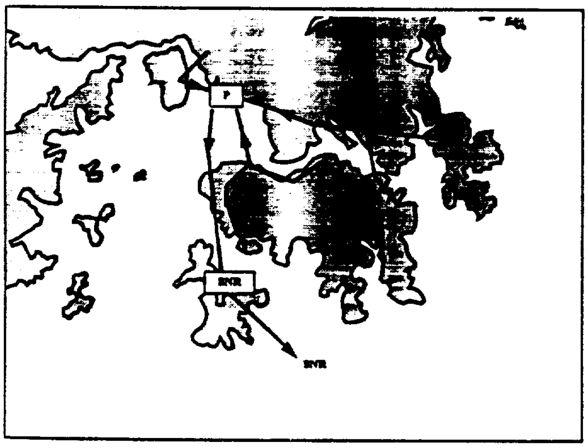
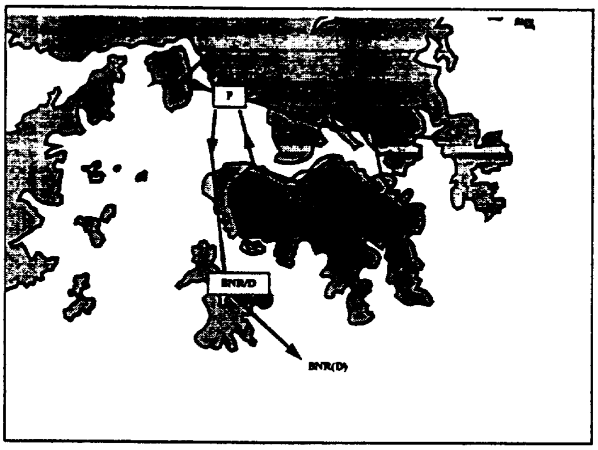


Engineering Option used in Scenario 7a



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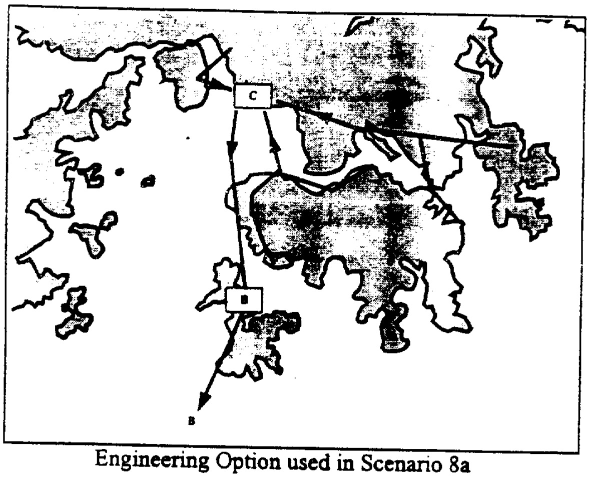
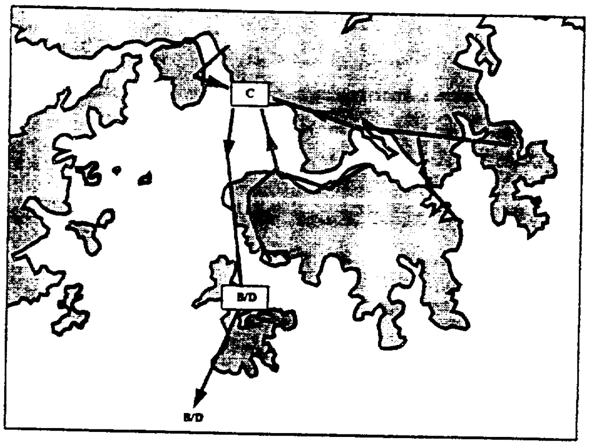
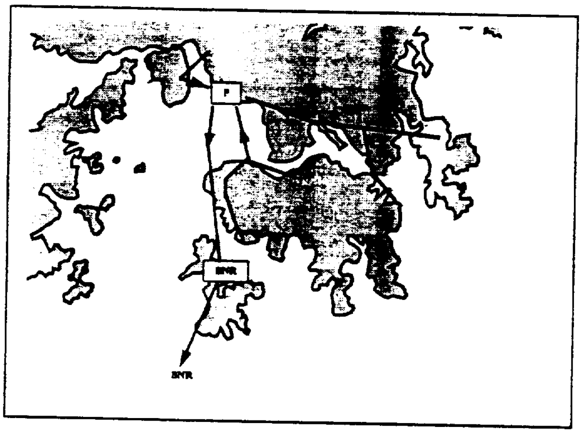


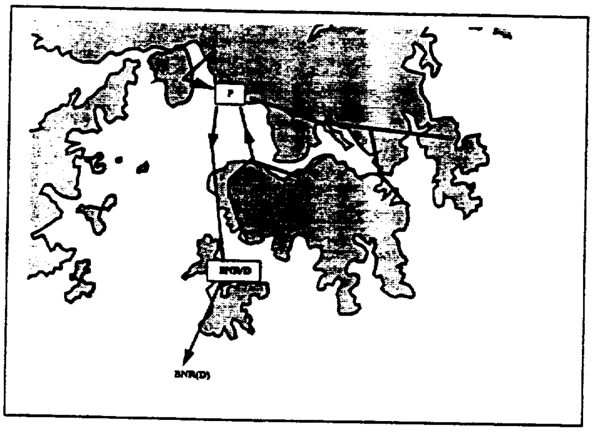
Engineering Option used in Scenario 8a



Engineering Option used in Scenario 8b



Engineering Option used in Scenario 9a



Engineering Option used in Scenario 9b

Annex C
SSDS Catchment Wastewater Quality and CEPT Effluent Qulaity

	Units	Wastewater Conc.	CEPT Effluent	CEPT + Disinfection Effluent	Conc. after outfall dilution (25X dilution)*	Conc. after outfall dilution (75X dilution)*	Background conc.	Total conc. (25X dilution)	Total conc. (75X dilution)
SS	mg/l	201	60	60	2.4	0.80	-	2.4	0.80
BOD	mg/l	239	107	107	4.28	1.43	0.89	5.17	2.32
Grease & Oil	mg/l	31	9.3	9.3	0.37	0.12	0.034	0.40	0.15
Total Nitrogen	mg/l	37	28	28	1.12	0.37	0.37	1.49	0.74
NH_3-N	mg/l	21	19	19	0.76	0.25	0.17	0.93	0.42
Total Phosphorus	mg/l	4.8	1.9	1.9	0.08	0.03	0.023	0.10	0.05
Orthophosphate	mg/l	2.8	1.1	1.1	0.04	0.02	0.012	0.05	0.03
Surfactant	mg/l	3.2	0.6	0.6	0.02	0.01	-	0.02	0.01
Sulfide	mg/l	0.6	0.03	0.03	0.001	0.0004	-	0.001	0.0004
Cu	µg/l	40	10	10	0.4	0.13	0.95	1.35	1.08
Cr	µg/l	20	4	4	0.16	0.05	0.17	0.33	0.22
Ni	µg/l	20	10	10	0.4	0.13	0.77	1.17	0.90
Zn	µg/l	150	40	40	1.6	0.53	1.55	3.15	2.08
Hg	µg/l	0.6	0.4	0.4	0.015	0.005	0.2	0.22	0.21
As	µg/l	6.9	5.2	5.2	0.21	0.07	1.46	1.67	1.53
Cyanide	µg/l	80	60	60	2.4	0.8	-	2.4	0.80
Phenol	µg/l	10	10	10	0.4	0.13	-	0.4	0.13
E. coli	Count/l	1.64×10^8	8.15×10^7	8.15×10^4	3.26×10^3	1.09×10^3	900	4.16×10^3	1.99×10^3

*25 times dilution represents the 90 percentile condition in the wet season, whereas 75 times represents average wet season conditions. As shown in Annex D, the average initial dilution in the dry season is approximately 2 times of the corresponding wet season values.

Annex D: Initial Dilutions and Size of Initial Dilution Zone at Potential Outfall Sites (based on outline designs, ambient current conditions and flow of 26 m^3/sec)

1) Initial Dilutions in Various Seasonal and Current Conditions

Option	Season	Assurance Probability								
		90%	80%	70%	60%	50%	40%	30%	20%	10%
East Lamma	wet	29	49	63	70	77	84	93	103	113
	dry	59	103	124	140	149	178	211	248	289
West Lamma	wet	23	48	63	73	76	84	94	103	117
	dry	92	117	143	158	168	182	223	286	341
SE Lamma/ Lema Channel	wet	34	52	69	89	99	108	120	130	144
	dry	156	176	210	231	245	276	348	412	470

2) Size of Initial Dilution Zone in Various Seasonal and Current Conditions

a) Probability Distributions of Longitudinal Distance (m) of the Initial Dilution Zone

Option	Season	Assurance Probability								
		90%	80%	70%	60%	50%	40%	30%	20%	10%
East Lamma	wet	27.3	28.1	29.0	30.5	31.1	32.0	33.3	39.5	41.7
	dry	31.7	34.7	39.7	46.2	58.1	70.4	76.8	108.4	127.0
West Lamma	wet	26.7	27.5	27.9	30.3	32.3	33.7	36.5	41.2	44.7
	dry	31.7	35.8	41.7	49.5	53.9	61.4	90.7	142.3	193.6
SE Lamma/ Lema Channel	wet	32.3	33.8	35.6	40.6	47.9	50.6	57.2	66.0	73.3
	dry	49.9	62.4	70.3	86.6	103.3	131.3	179.6	206.5	244.9

b) Predicted Initial Dilution and Area of Initial Dilution Zone of 50% Cumulative Probability

Option	Diffuser Length (m)	Initial Dilution		Area of Initial Dilution Zone (km^2)	
		wet	dry	wet	dry
East Lamma	2,592	77	149	0.039	0.076
West Lamma	2,346	76	168	0.033	0.057
SE Lamma/ Lema Channel	2,160	99	245	0.035	0.085

Annex E: Risk Assessment Results
Highest Hazard Quotients for Detected Chemicals for Each Assessment

Assessment	Outfall	Chemical	Risk Definition	Hazard Quotient/Prob.	Risk	Condition
Human lifetime carcinogenic, water ingestion or seafood	East Lamma West Lamma SE Lamma	-	Risk if Prob. > 1.00E-06	-	N	No such chemicals detected
Human child non-carcinogenic, water ingestion	East Lamma West Lamma SE Lamma	Chromium VI Chromium VI Chromium VI	Risk if HQ > 1	1.43E-03 1.58E-03 1.03E-03	N N N	wet season, 90% frequency dilution, wastewater wet season, 90% frequency dilution, wastewater wet season, 90% frequency dilution, wastewater
Human child non-carcinogenic, seafood consumption	East Lamma West Lamma SE Lamma	Mercury Mercury Mercury	Risk if HQ > 1	7.99E-04 1.14E-03 1.93E-03	N N N	wet season, 90% frequency dilution, wastewater wet season, 90% frequency dilution, wastewater wet season, 90% frequency dilution, wastewater
Human adult non-carcinogenic, water ingestion	East Lamma West Lamma SE Lamma	Chromium VI Chromium VI Chromium VI	Risk if HQ > 1	7.63E-04 8.45E-04 5.50E-04	N N N	wet season, 90% frequency dilution, wastewater wet season, 90% frequency dilution, wastewater wet season, 90% frequency dilution, wastewater
Human adult non-carcinogenic, seafood consumption	East Lamma West Lamma SE Lamma	Mercury Mercury Mercury	Risk if HQ > 1	7.97E-04 1.14E-03 1.93E-03	N N N	wet season, 90% frequency dilution, wastewater wet season, 90% frequency dilution, wastewater wet season, 90% frequency dilution, wastewater
Aquatic Life	East Lamma West Lamma SE Lamma	Malathion Malathion Malathion	Risk if HQ > 1	4.03E-01 4.46E-01 2.91E-01	N N N	wet season, 90% frequency dilution, CEPT wet season, 90% frequency dilution, CEPT wet season, 90% frequency dilution, CEPT
Dolphin	East Lamma West Lamma SE Lamma	Mercury Mercury Mercury	Risk if HQ > 1	1.28E-01 1.42E-01 9.22E-02	N N N	wet season, 90% frequency dilution, CEPT wet season, 90% frequency dilution, CEPT wet season, 90% frequency dilution, CEPT
Finless Porpoise	East Lamma West Lamma SE Lamma	Mercury Mercury Mercury	Risk if HQ > 1	4.37E-01 4.84E-01 3.15E-01	N N N	wet season, 90% frequency dilution, CEPT wet season, 90% frequency dilution, CEPT wet season, 90% frequency dilution, CEPT

Annex E: Risk Assessment Results

Highest Hazard Quotients for Non-Detected Chemicals for Each Assessment

(assuming that non-detected chemicals are present at the detection limit)

Assessment	Outfall	Chemical	Risk Definition	Hazard Quotient/Prob.	Risk	Condition
Human lifetime carcinogenic, water ingestion	East Lamma	Benzidine	Risk if Prob. > 1.00E-06	6.69E-05	P	wet season, 90% frequency dilution, wastewater
	West Lamma	Benzidine		7.41E-05	P	wet season, 90% frequency dilution, wastewater
	SE Lamma	Benzidine		4.82E-05	P	wet season, 90% frequency dilution, wastewater
Human lifetime carcinogenic, seafood consumption	East Lamma	Benzidine	Risk if Prob. > 1.00E-06	9.78E-06	P	wet season, 90% frequency dilution, wastewater
	West Lamma	Benzidine		1.40E-05	P	wet season, 90% frequency dilution, wastewater
	SE Lamma	Benzidine		2.37E-05	P	wet season, 90% frequency dilution, wastewater
Human child non-carcinogenic, water ingestion	East Lamma	Sulphide	Risk if HQ > 1	8.90E-03	N	wet season, 90% frequency dilution, wastewater
	West Lamma	Sulphide		9.86E-03	N	wet season, 90% frequency dilution, wastewater
	SE Lamma	Sulphide		6.42E-03	N	wet season, 90% frequency dilution, wastewater
Human child non-carcinogenic, seafood consumption	East Lamma	Aldrin	Risk if HQ > 1	1.33E-03	N	wet season, 90% frequency dilution, wastewater
	West Lamma	Aldrin		1.90E-03	N	wet season, 90% frequency dilution, wastewater
	SE Lamma	Aldrin		3.22E-03	N	wet season, 90% frequency dilution, wastewater
Human adult non-carcinogenic, water ingestion	East Lamma	Sulphide	Risk if HQ > 1	4.75E-03	N	wet season, 90% frequency dilution, wastewater
	West Lamma	Sulphide		5.26E-03	N	wet season, 90% frequency dilution, wastewater
	SE Lamma	Sulphide		3.42E-03	N	wet season, 90% frequency dilution, wastewater
Human adult non-carcinogenic, seafood consumption	East Lamma	Aldrin	Risk if HQ > 1	1.33E-03	N	wet season, 90% frequency dilution, wastewater
	West Lamma	Aldrin		1.90E-03	N	wet season, 90% frequency dilution, wastewater
	SE Lamma	Aldrin		3.22E-03	N	wet season, 90% frequency dilution, wastewater
Aquatic Life	East Lamma	p,p’-DDT/Dieldrin	Risk if HQ > 1	3.23E+00	P	wet season, 90% frequency dilution, CEPT
	West Lamma	p,p’-DDT/Dieldrin		3.57E+00	P	wet season, 90% frequency dilution, CEPT
	SE Lamma	p,p’-DDT/Dieldrin		2.33E+00	P	wet season, 90% frequency dilution, CEPT
Dolphin	East Lamma	PCBs	Risk if HQ > 1	9.31E+00	P	wet season, 90% frequency dilution, CEPT
	West Lamma	PCBs		1.03E+01	P	wet season, 90% frequency dilution, CEPT
	SE Lamma	PCBs		6.71E+00	P	wet season, 90% frequency dilution, CEPT
Finless Porpoise	East Lamma	PCBs	Risk if HQ > 1	2.33E+01	P	wet season, 90% frequency dilution, CEPT
	West Lamma	PCBs		2.58E+01	P	wet season, 90% frequency dilution, CEPT
	SE Lamma	PCBs		1.68E+01	P	wet season, 90% frequency dilution, CEPT

N = No risk, even if non-detected chemicals are present at the detection limit;
P = Potential risk if non-detected chemicals are present at the detection limit. However, this is very unlikely (see Section 5.2.4)

Annex F: Fishery Resources in Main Areas of Interest

	Near Outfall Site A (Green Island)	Near Outfall Site B (W. Lamma)	Near Outfall Site C (E. Lamma)	Near Outfall Site D (SE. Lamma)
Catch (kg/hour)				
Hang Trawl	116	42	41	12
Beam Trawl	37	15	10	9
Otter Trawl	13	37	90	64
Dominant Commercial Species	*Caranx kalla;* Charybdis feriatus; Collichthys lucidus; Cynoglossus macrolepidotus;* Clupanodon punctatus;* Formio niger*; Johnius belengeri; Leiognathus brevirostris;* Loligo duvaucelii;* Metapenaeus affinis;* Pampus argenteus; Pneumatophorus japonicus; Sardinella jussieu; Scomberomorus guttatus;**	*Caranx kalla*; Collichthys lucidus; Cynoglossus macrolepidotus;* Engrulis japonicus; Formio niger,* Gastrophysus spadiceus; Harpiosquilla raphidea; Harpodon nehereus;* Lepturacanthus savala; Loligo beka; Oratosquilla oratoria;* Pseudorhombus arsius;* Pneumatophorus japonicus; Sardinella jussieu; Sardinella nymphaea; Scomberomorus guttatus*; Thrissa dussumieri; Thrissa kammalensis;* Trachurus japonicus;* Trichiurus brevis; Trichiurus haumela;* Trypauchen vagina;*	*Argyrosomus argentatus;* Caranx kalla;* Cynoglossus macrolepidotus;* Engraudis Japonicus; Formio niger,* Gastrophysus spadiceus; Hapiosquilla raphidea; Lepturacanthus savala; Loligo duvaucelii;* Llateolabrax japonicus; Oratosquilla oratoria;* Portunus sanguinolentus; Pampus argenteus; Platycephalus indicus;* Pneumatophorus japonicus; Sardinella jussieu; Thrichiuris haumela; Thrissa kammalensis;* Trachurus japonicus;* Trichiurus haumela;**	*Amblyotrypauchen arctocephalus; Argyrosomus argentatus;* Caranx kalla;* Collichthys lucidus; Cynoglossus macrolepidotus;* Epinephelus tauvina; Engraulis japonicus; Harpiosquilla raphidea; Harpodon nehereus; Leiognathus bindus; Metapenaeus ensis;* Oratosquilla anomala;* Oratosquilla oratoria;* Osteomugil ophuysenl; Pampus argenteus; Platycephalus indicus;* Pseudorhombus arsius;* Sardinella jussieu; Saurida tumbil;* Thrissa kammalensis*; Trachurus japonicus;* Trichiurus haumela*; Trypauchen vagina;*

Source: SSDS EIA study surveys
* *commercial species listed by AFD.* The catches and average body lengths of important commercial species were low: few adult individuals and relatively high numbers of juveniles were found.

FIGURES

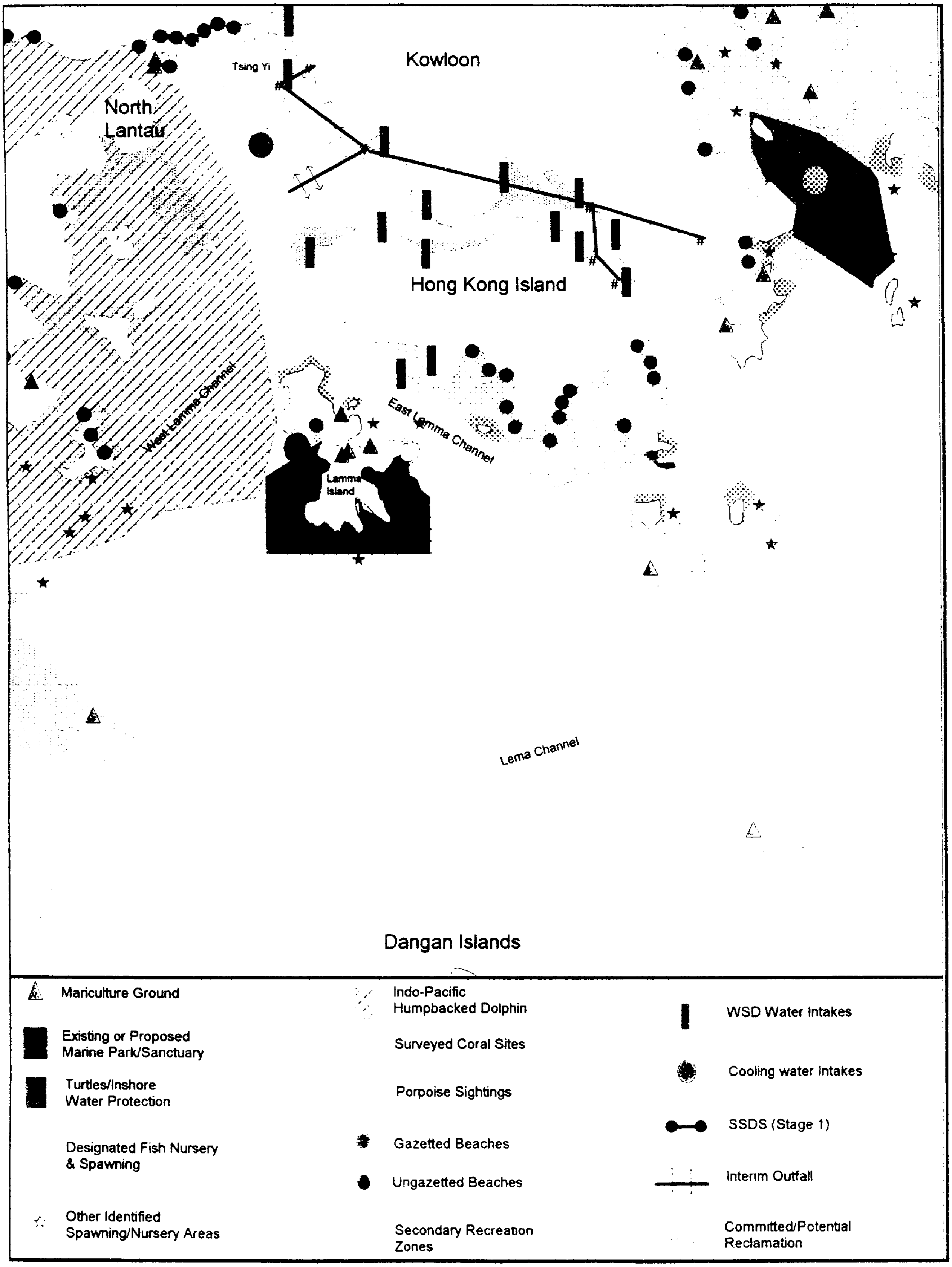


Figure 1 : Marine Sensitive Receivers and Beneficial Uses

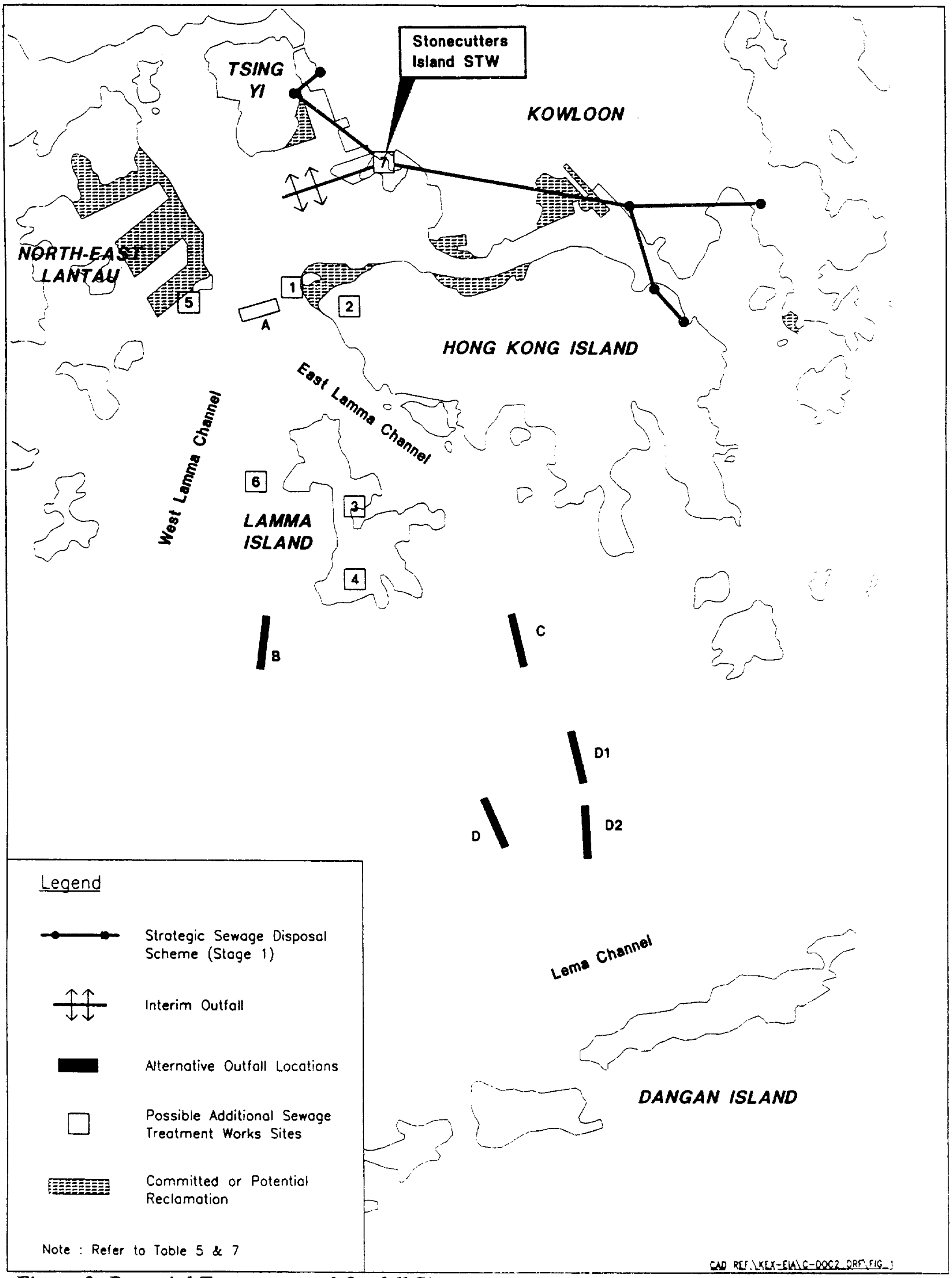
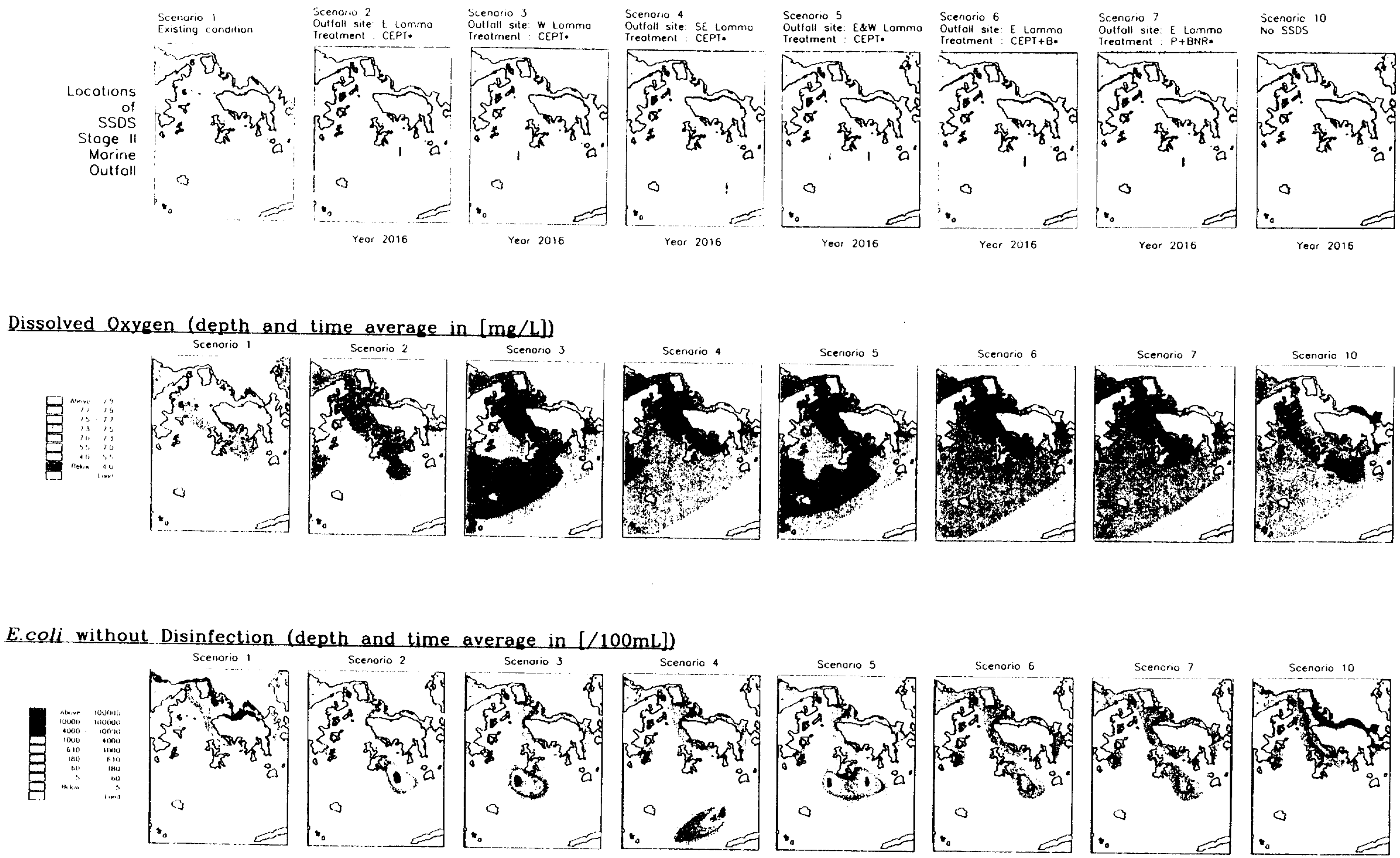


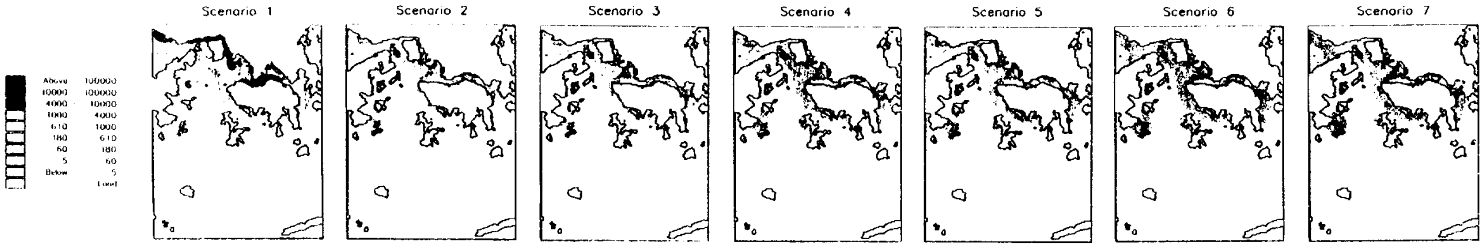
Figure 2: Potential Treatment and Outfall Sites

FIG.3: WATER QUALITY MODELLING RESULTS - DRY SEASON

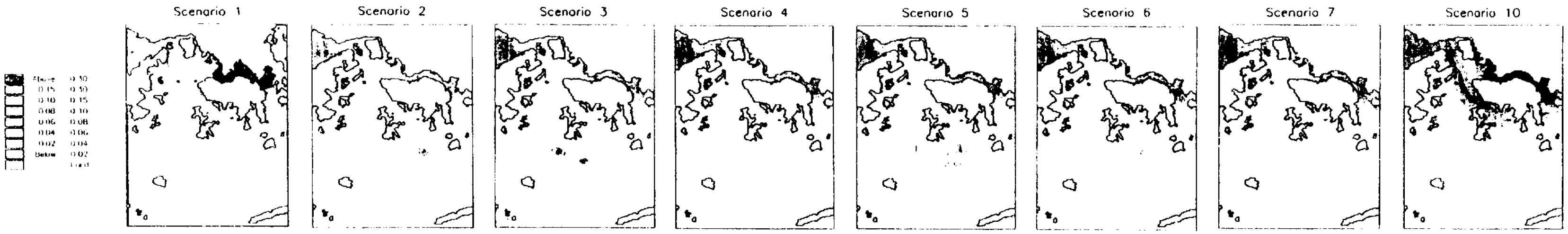


*CEPT = Chemically Enhanced Primary Treatment
B = BOD Removal
BNR = Biological Nutrient Removal

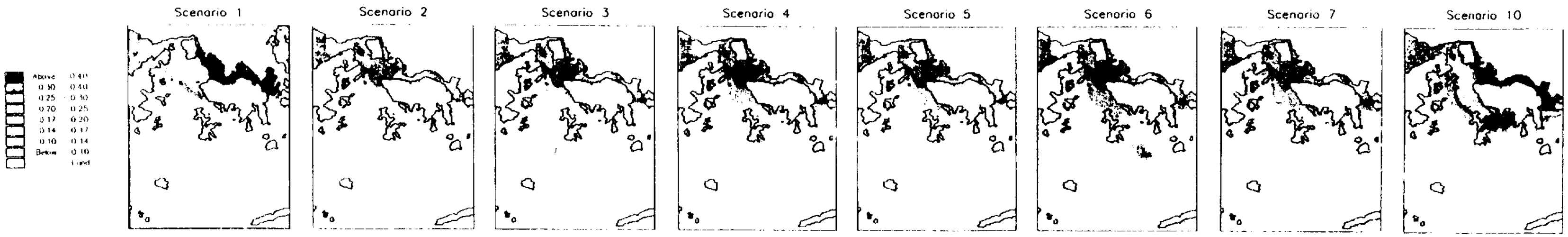
E.coli with Disinfection (depth and time average in [/100mL])



Total Ammonia-Nitrogen (depth and time average in [mg/L])



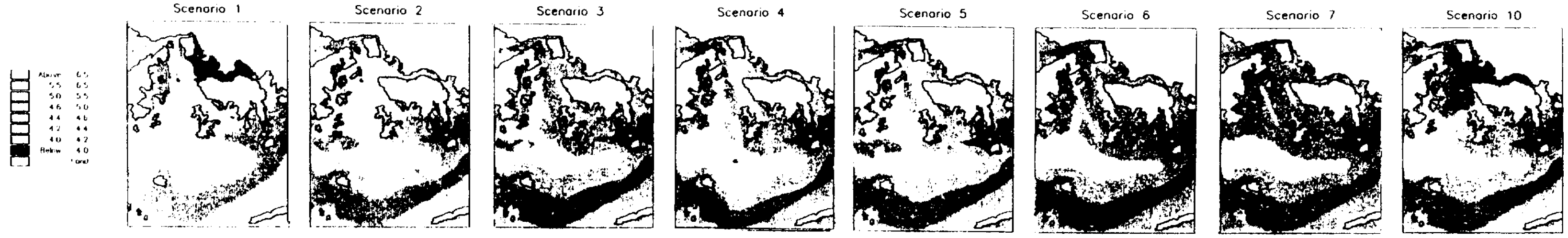
Total Inorganic Nitrogen (depth and time average in [mg/L])



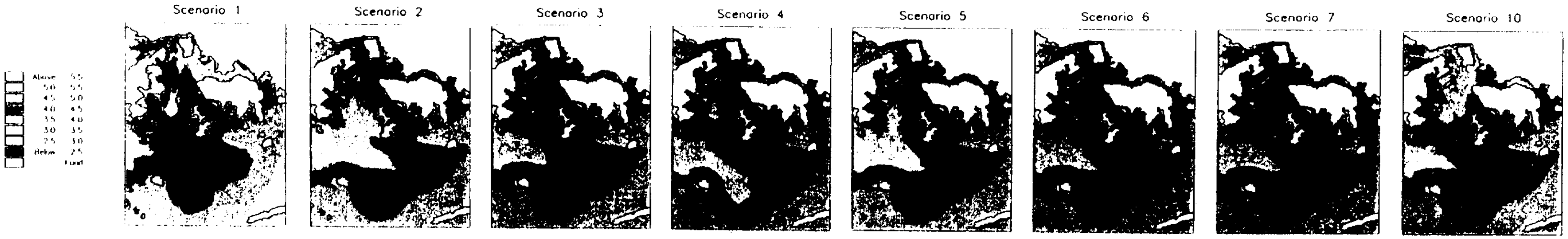
*CEPT = Chemically Enhanced Primary Treatment
B = BOD Removal
BNR = Biological Nutrient Removal

FIG.3(cont'd): WATER QUALITY MODELLING RESULTS - WET SEASON

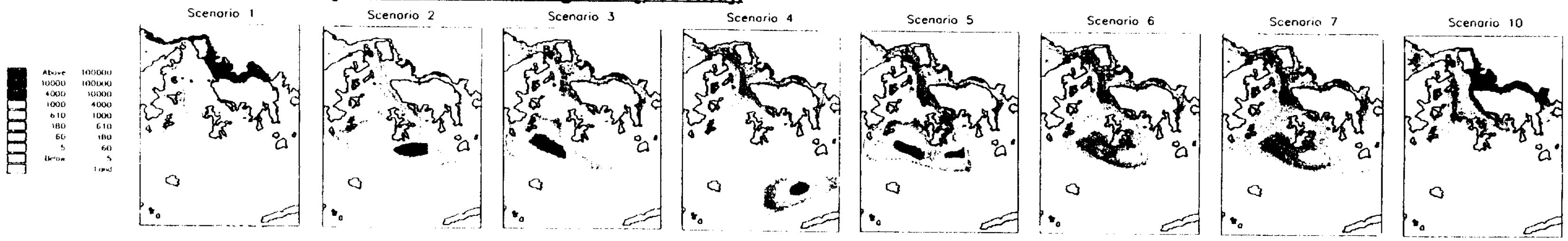
Dissolved Oxygen (depth and time average in [mg/L])



Dissolved Oxygen, Bottom Layer (time average in [mg/L])

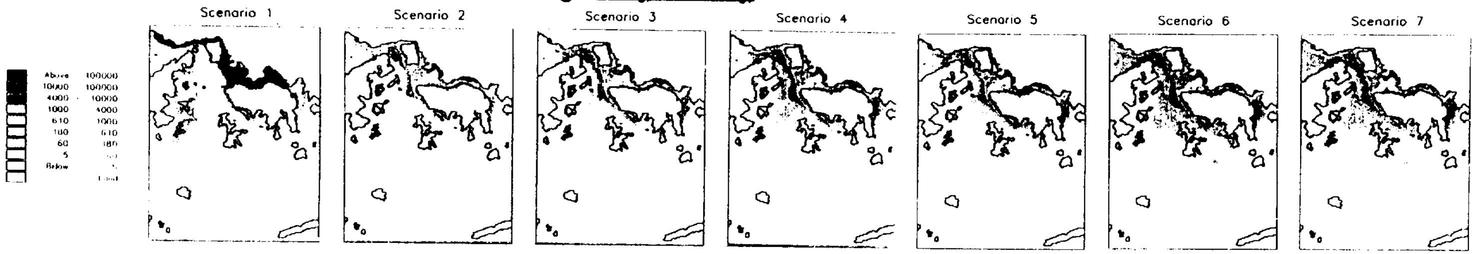


E.coli without Disinfection (depth and time average in [/100mL])

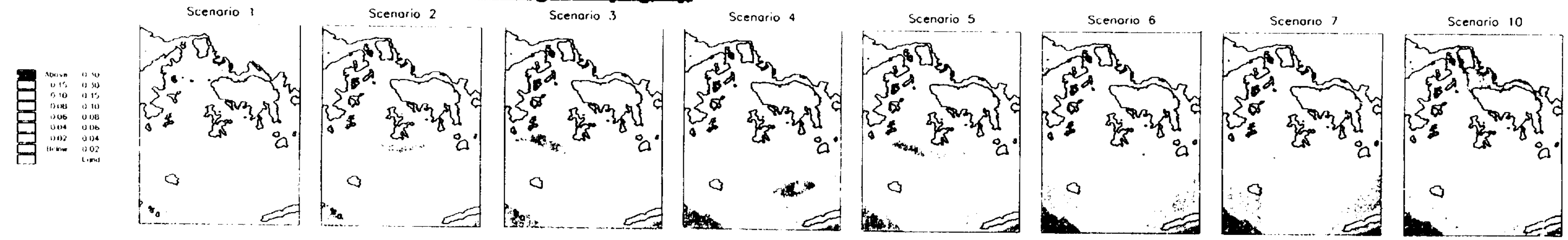


*CEPT = Chemically Enhanced Primary Treatment
B = BOD Removal
BNR = Biological Nutrient Removal

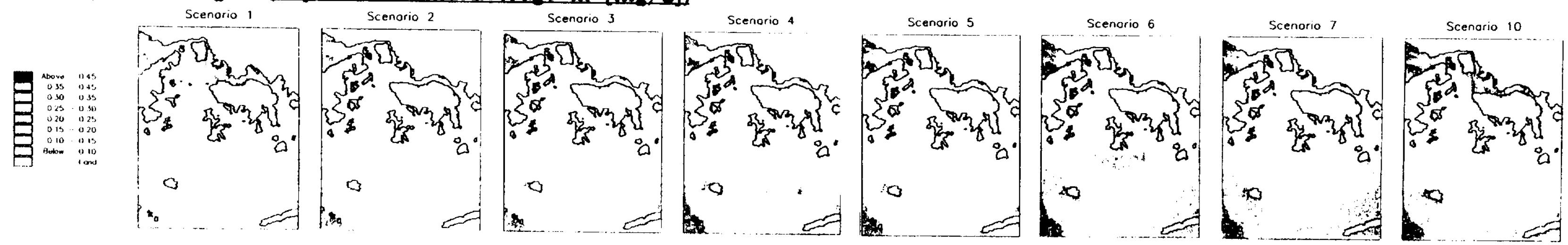
E.coli with Disinfection (depth and time average in [/100mL])



Total Ammonia-Nitrogen (depth and time average in [mg/L])



Total Inorganic Nitrogen (depth and time average in [mg/L])



*CEPT = Chemically Enhanced Primary Treatment
B = BOD Removal
BNR = Biological Nutrient Removal

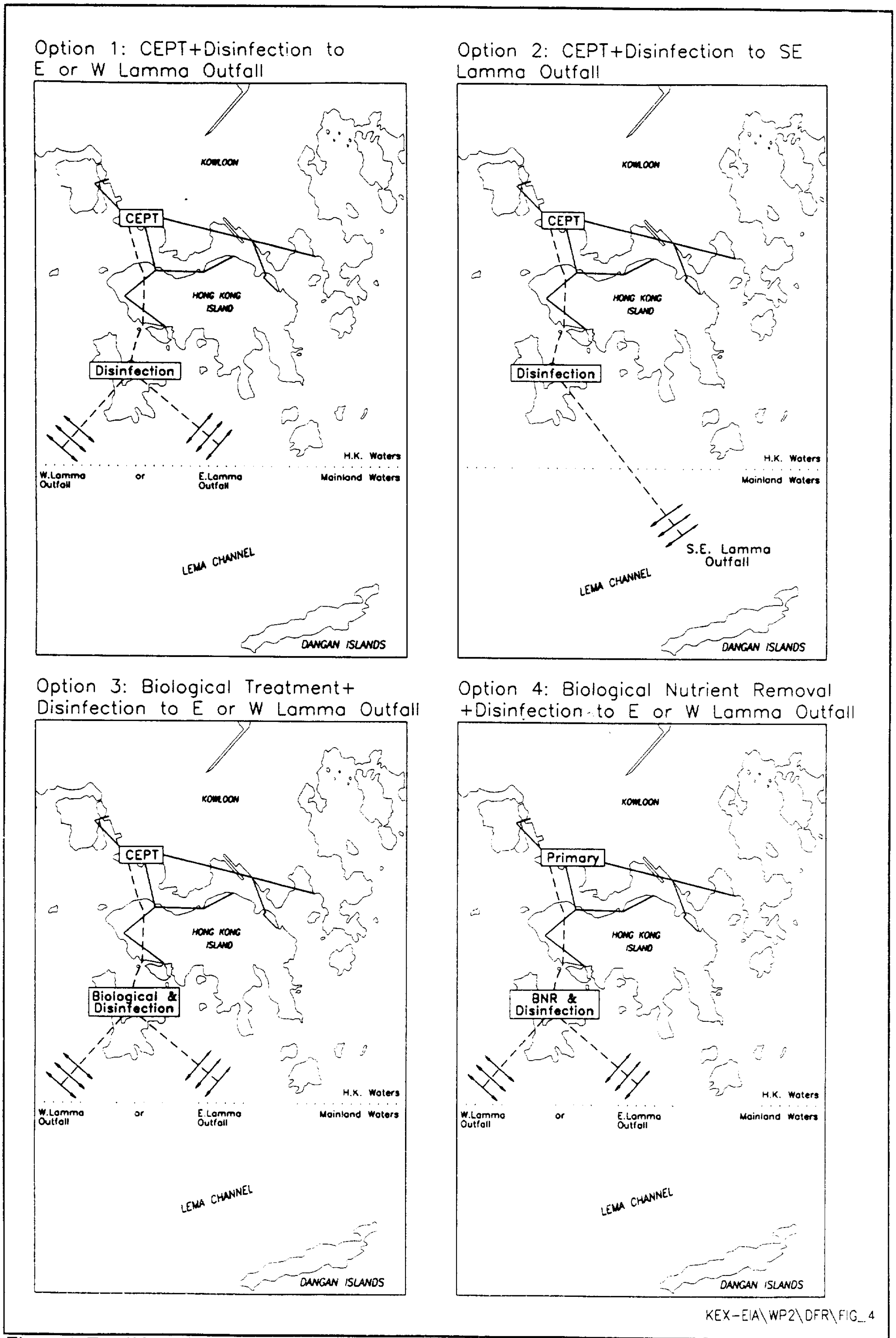


Figure 4: Feasible and Acceptable Options