Proposed Expansion of Container Port Facilities in Botany Bay, NSW

Coastal Process and Water Resources Issues

Volume 2: Water Quality Investigations

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Proposed Expansion of Container Port Facilities in Botany Bay, NSW

Coastal Processes and Water Resources

Volume 2: Water Quality Investigations

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PREFACE

This report is one of a series formed of three volumes. All reports have been prepared for Sydney Ports Corporation by Lawson and Treloar as part of water resources issues and coastal processes investigations undertaken to describe and quantify the potential impacts of proposed expansion of container port facilities in Port Botany, NSW.

Although each report is complete in itself, all reports draw upon the others for supporting information.

The reports prepared for this study are:-

1. Volume 1: Hydrologic and Hydraulic Studies
2. Volume 2: Water Quality Investigations (This Volume)
3. Volume 3: Waves, Currents and Coastal Process Investigations.

EXECUTIVE SUMMARY

ES1. BACKGROUND

This study involved an assessment of the potential impacts on water quality of the proposed port expansion at Port Botany. Details of the nature of the port expansion can be found in Appendix A.

The study involved four key components:

- identification and description of the catchment areas and receiving water environments of specific interest to the study
- assessment of baseline water and sediment quality data for those catchment areas and receiving waters to establish observed existing conditions in the area of interest
- numerical modelling of key constituents under existing conditions to establish a common and consistent baseline for the purposes of comparison
- numerical modelling of key constituents under the post port expansion conditions to identify likely impacts of the proposed port.

Since the contributions of some sources of pollutants to the area of interest are negligible compared to the other sources, they were omitted from the comparative studies. The numerical modelling assessments do not include stormwater runoff that flows directly to the Bay from Kingsford Smith airport (to the Mill Stream channel), runoff from the existing port to Brotherson Dock, nor runoff from the proposed expanded port. Details of the assessment of stormwater and proposed treatment systems for the proposed port can be found in a separate report (ARUP, 2002). Details of the assessment of stormwater and proposed treatment systems for the Patrick Terminal (draining to Brotherson Dock) can also be found in a separate report (Parsons Brinkerhoff, 2002).

ES2. BASELINE WATER AND SEDIMENT QUALITY

An assessment of the baseline water and sediment quality data was undertaken to establish observed existing conditions in the area of interest.

The area of interest was divided into four sub-areas for assessment:

- catchments (freshwater) draining to the proposed port area (Springvale Drain, Floodvale Drain, Foreshore Beach stormwater drainage systems and the Mill Pond catchment)
- Penrhyn Estuary (estuarine) (the receiving waters for flow from Springvale and Floodvale Drains)
- Mill Stream (the receiving waters for flows from the Mill Pond catchment)
- open waters of Botany Bay in the immediate vicinity of Foreshore Beach (the receiving waters for the Foreshore Beach stormwater drainage systems as well as the open water area downstream of Penrhyn Estuary and the Mill Stream).

In general, there was satisfactory data coverage for the purposes of this study for water and sediment quality obtained by literature review and field study for dry weather or 'ambient' conditions. However, hydrocarbon species contamination was only well documented for Penrhyn Estuary waters and Botany Bay but not for the catchment areas, whilst data for metal contamination of sediments were sparse for Penrhyn Estuary. Physico-chemical data in dry weather conditions were measured during a field study as part of this investigation.

There was very limited data associated with water quality for wet weather or 'transient' conditions. Recommendations in light of this issue are provided below in Section ES4.

Catchments (Freshwater)

The results show that catchment water quality (i.e. tributary flows from those areas upstream of the proposed Port expansion area of Botany Bay, being Springvale Drain, Floodvale Drain, the Foreshore Beach and Mill Pond catchments) is characterised by low levels of Dissolved Oxygen (DO) and high nutrient levels, coupled with a high biochemical oxygen demand (BOD). Total petroleum hydrocarbon levels were well in excess of ANZECC (2000) guidelines, and limited metals data suggest that levels for Cadmium, Lead, Mercury, Zinc and Copper can greatly exceed guideline levels. Faecal Coliforms have been reported at concentrations of up to 120,000 cfu/100mL (e.g. in the Mill Pond, just upstream of Foreshore Road) which is well in excess of the associated ANZECC (2000) guideline (1000 cfu/100mL for secondary recreational contact).

Penrhyn Estuary (Estuarine)

Water quality data for Penrhyn Estuary show high nutrient levels, in particular for Phosphorous (maximum recorded was 8.2mg/L, ANZECC (2000) trigger value is 0.03mg/L). Whilst BOD was high, Dissolved Oxygen levels were acceptable and within guideline levels. Total Petroleum Hydrocarbons (TPH) levels have been recorded well in excess of guideline levels but Aromatic Hydrocarbons are well below trigger levels. Data for other hydrocarbon groups reported are not covered by ANZECC (2000) guidelines. Metals analysis data for the estuary are sparsely reported, however, limited data shows that levels of Aluminium, Cadmium, Copper, Lead, Manganese and Zinc can greatly exceed guideline trigger levels. Faecal Coliform levels have been recorded as high as 11,800 cfu/100mL, which is well in excess of the guidelines for primary or secondary recreational contact.

Sediment quality data were scant for the estuary, however, there are data for Chromium and Mercury. The maximum recorded level for Chromium is approaching the upper level for the guideline range for this metal (up to 223µg/g, guideline range is 80-370µg/g). For Mercury, guideline levels (upper bound) were exceeded by as much as 36 times.

Mill Stream

The Mill Stream is also characterised by high nutrient levels (in particular for Total Phosphorous) and levels of Dissolved Oxygen below ANZECC (2000) guidelines. Whilst there were no available data for hydrocarbons, limited metal data show that for Cadmium, Copper, Iron, Lead and Zinc ANZECC (2000) guideline levels can be substantially exceeded. The maximum recorded levels of faecal coliforms (120,000 cfu/100 mL) also exceeded secondary contact guidelines.

Botany Bay (In the Vicinity of Foreshore Beach)

Nutrient concentration data for the Bay area of interest were scant, however, available data show that Total Nitrogen levels have not been recorded above the ANZECC (2000) trigger level. For Total Phosphorous, the trigger level may be slightly exceeded. Whilst there were no available data for specific hydrocarbon levels in the bay, total hydrocarbon levels have been recorded well in excess of ANZECC (2000) guidelines. As with Penrhyn Estuary, available data show that Aluminium, Cadmium, Chromium, Manganese, Mercury and Zinc have been measured at considerably elevated levels in some locations. In the case of Mercury, the trigger level has been exceeded by approximately three orders of magnitude. Maximum Faecal Coliform levels are extremely high (4.2×10^7cfu/100mL) and represent significant sewer overflow sources in wet weather conditions within all of the catchments in the local region.

For the Bay, Birch (1996) has reported contaminant levels in sediments for a variety of metals, hydrocarbons and nutrients. For metals the data show that ANZECC (2000) trigger levels (upper) were not exceeded, except where the mud fraction of the sediment was analysed alone. ANZECC (2000) does not provide trigger levels for hydrocarbon or nutrient contamination of sediments.

Summary

Available data indicate that high levels of nutrients and low DO of catchment inflows are diluted by the receiving waters of Penrhyn Estuary and Botany Bay towards more satisfactory levels. Total Petroleum Hydrocarbons (TPH) levels in the input waters also become reduced in the Estuary and Bay, but may be above guideline levels. In contrast, metal contaminants have been recorded at very high levels in the fresh water inputs and receiving waters and sediment, indicating that they may be accumulating in the sediments over time.

All available data show that sampled locations in the Catchments, Mill Stream, Penrhyn Estuary and Bay show highly elevated Faecal Coliform levels. However, levels in the receiving waters were recorded at much higher levels than the freshwater inputs. This is primarily due to the frequency of sampling but may also be due to sources outside of the catchment areas considered as part of this study (e.g. the Georges or Cooks Rivers).

ES3. IMPACTS OF THE PROPOSED PORT EXPANSION

Following on from the data analysis and review of the existing conditions, numerical modelling of the catchment and estuary was undertaken. The numerical modelling approach was adopted as this mode of assessment provides a common and consistent baseline for the purposes of comparison of time series results at points of interest under both the existing conditions and the conditions likely to occur under the proposed port expansion. This mode of results comparison allows the relative effect of the proposed port expansion to be readily defined.

Numerical modelling was undertaken in two modes, transient conditions (a catchment runoff event) and ambient conditions (dry weather conditions). Some parameters were modelled only for ambient conditions whilst others were assessed for both ambient and transient conditions.

The following key changes between the existing case and the proposed port expansion scenario were identified:

- Behaviour of nutrients (Nitrogen and Phosphorous)
  - Ambient conditions in the existing case for Penrhyn Estuary do not exceed ANZECC (2000) guidelines. Under the proposed port scenario, Penrhyn Estuary would see an increase in the level of the average concentrations, but not above ANZECC (2000) guidelines.
  - Transient conditions would see an increase in the level of the peak concentration observed within the estuary in the region described by Locations C to B and then B to D. Only a marginal increase would occur at Location C. The duration for which an elevated level occurs would be extended. For example, the present peak level of TN concentration at Locations B and D would now be maintained for about 24 hours, instead of the present duration of 2 hours. It is not appropriate to compare transient conditions directly with ANZECC (2000) guidelines.
  - Behaviour of conservative contaminants
  - Ambient conditions - based on the observed concentrations in the catchment (under its existing conditions) ANZECC (2000) guidelines are already exceeded in the estuary for concentrations of metals in the dissolved phase. Under the proposed port scenario there will continue to be exceedence of some ANZECC (2000) guidelines.
- Suspended sediments plumes and deposition
  - Ambient conditions - siltation depths under the proposed port scenario will be similar to the existing case, in the order of a maximum localised rate of 2.6 cm/annum within the inner Penrhyn Estuary. Under the proposed port scenario, no siltation will occur at the shorelines, the fine silt discharged from the Foreshore Beach shoreline drains being dispersed to more tranquil areas so that siltation depths at the shoreline are too small to evaluate. However, as a result of reduced flushing of the estuary there will some increase in siltation.
  - Transient conditions - Under the existing conditions suspended sediment plumes are dispersed from Penrhyn Estuary. Under the proposed port scenario, suspended sediment plumes would be confined to the 130 m wide channel, where higher concentrations than those observed in the existing case would occur. However, those higher concentrations would typically not persist for longer than about 4 hours.
  - Ambient Temperature changes - only small changes would occur under the proposed port expansion scenario. Ambient temperatures would reduce at three locations in the outer estuary mainly because water depths there would be slightly deeper. However, there would be likely increases in depth averaged temperatures in the order of 0.3^{o}C within the inner Penrhyn Estuary under summer conditions due to the proposed habitat enhancement works. This temperature increase is considered to be negligible.

- Ambient Dissolved Oxygen changes - small reductions in the average DO concentration will occur following the proposed port expansion, but in no circumstances does the DO level approach 6.5mg/L (noting that 4 mg/L is an indicative trigger level for some organisms).
- Faecal coliform concentrations
  - Ambient conditions - Under the existing scenario, the median faecal coliform concentrations are less than 150 cfu/100mL (ANZECC, 2000 primary recreational contact trigger level). Under the proposed port scenario, median faecal coliform concentrations will also be less than 150 cfu/100mL. Maxima under the proposed port scenario do not exceed 100 cfu/100mL, which is less than the 80th percentile limit of 600 cfu/100mL specified in ANZECC (2000) (also for primary recreational contact).
  - Transient conditions within Penrhyn Estuary are such that under the proposed port expansion scenario there is an increase in peak concentration (and an extension of the duration of the increased faecal coliform levels) with the highest concentrations occurring close to Springvale and Floodvale Drains. Peak concentrations would be reduced at the possible site for a future boat-ramp and beach facilities under the proposed port scenario (as shown in Appendix A). It is not appropriate to compare transient conditions directly with ANZECC (2000) guidelines.

ES4. CONCLUSIONS

In general the impact of the proposed port expansion has been demonstrated by both ambient and transient conditions modelling. The ambient conditions modelling indicates that, whilst there will be an increase in ambient condition concentrations due to the proposed port expansion, the ANZECC (2000) guidelines for contaminants examined will not be exceeded. However, the transient conditions modelling indicates that some changes in the levels of contaminants over the existing case may be observed for short periods of time. These conditions are not comparable with ANZECC (2000) guidelines.

A means of reducing contaminant loads delivered from both ambient and transient inflows from the catchments of Floodvale and Springvale Drains to Penrhyn Estuary would be through the installation of a single or series of stormwater quality improvement devices (SQIDs).

Two separate devices could be installed immediately downstream of the inflow points of Floodvale and Springvale Drains. The primary mechanism of reducing the contaminant load from the catchment delivered to the estuary would be through the capture of coarse and suspended sediments. Other natural and anthropogenic materials (gross pollutants, litter and the like) could also be captured within such a structure.

As a guide, these types of devices have the potential to reduce pollutant loads delivered to the estuary by up to 40%. It should be noted that the management of the catchment is the responsibility of groups other than Sydney Ports Corporation (SPC) and thus SPC is not able to control those loads being delivered to the receiving waters from the catchment.

Given the limited data set associated with wet weather or 'transient' conditions, it may be prudent to consider wet weather event monitoring to provide further background information. Wet weather monitoring has a number of logistical issues and there is no guarantee that the design of the sampling methodology would be sufficient to cover all possible occurrences, particularly due to the inherent difficulties in forecasting such an event. As a consequence, it may be appropriate to consider the installation of in-situ water quality samplers and probes before, during and after the port construction to monitor water quality.

1. INTRODUCTION

This report has been prepared to identify:-

- the current status of water quality within the area of interest of the proposed port expansion, and
- the likely impact of the proposed port expansion on water quality (in the Penrhyn Estuary areas specifically and then Botany Bay in general).

A locality plan showing the existing Bay shoreline is shown in Figure 1.1, whilst the proposed port layout is provided in Appendix A.

The broadscale methodology adopted for this report includes:

- A review of previous investigations
- A review of available data
- Data collection
- Catchment modelling
- Estuary modelling.

This report therefore is set out in the following manner:-

- Catchment overview (Section 2)
- Receiving water overview (Section 3)
- Review of existing available data (Section 4)
- Field data collection (Section 5)
- Catchment modelling (Section 6)
- Estuary modelling (Section 7), and
- Impacts and management of proposed Port Development (Section 8).

2. CATCHMENT OVERVIEW - EXISTING CONDITIONS

An overview of the catchments that drain to the proposed port area has been provided to aid later discussion of water quality processes and issues and impacts for the proposed port development.

The study area comprises four main catchments that drain to the receiving waters of interest (Section 3); these being the Mill Pond catchment, the Springvale catchment, the Floodvale catchment and the Foreshore Beach catchments (Figure 2.1). The total area of the four catchments is 2470 ha. The respective sizes of the four catchments are shown in Table 2.1.

Table 2.1 Catchment Areas

Name	Mill Pond	Springvale	Floodvale	Foreshore
Area (ha)	1773	240	118	339

These four catchments cover parts or all of the suburbs of Botany, Mascot, Banksmeadow, Daceyville, Eastlakes, Pagewood, Maroubra Junction, Kingsford, Randwick, Kensington, Bondi Junction, Waverley, Paddington, Queens Park and Centennial Park. The regional climate in which these catchments lie is generally temperate. The average annual rainfall is approximately 1100 mm (Sydney Airport), about 60% of which falls between January and June.

The catchments are the major sources of stormwater and its associated pollutants that impact upon the water quality in the Bay area adjacent to the proposed Port Botany expansion project. The Mill Pond Creek Catchment Stormwater Management Plan (Willing and Partners, 1999) identifies that the most likely sources of contaminants is run-off from the various land uses and features in the catchment, including:-

- Residential
- Industrial/commercial
- Open space
- Roads
- Sewer overflows
- Construction
- Land fill
- Sewer leakage, and
- Exfiltration into stormwater system from underground storage tanks.

The report indicates that the main contaminants of concern from the catchment include:-

- Oil & grease
- Sediment
- Nutrients
- Bacteria
- Litter, and
- Organic material and toxicants (heavy metals, pesticides, ammonia).

In general, the drainage assets within the catchment are managed by local Councils (including City of Botany Bay Council, Randwick City Council, Waverley City Council, Woollahra Council and South Sydney City Council). In some cases, drainage assets are managed by Sydney Water Corporation. These are discussed in Section 2.4. Other assets are managed by Sydney Airports Corporation Ltd (Section 2.5) or the Sydney Ports Corporation (Section 2.6).

Since the contributions of some sources of pollutants to the area of interest are negligible compared to the other sources, they were omitted from the comparative studies. The numerical modelling assessments do not include stormwater runoff that flows directly to the Bay from Kingsford Smith Airport (to the Mill Stream channel), runoff from the existing port to Brotherson Dock, nor runoff from the proposed expanded port. Details of the assessment of stormwater and proposed treatment systems for the proposed port can be found in a separate report (Arup, 2002). Details of the assessment of stormwater and proposed treatment systems for the Patrick Terminal (draining to Brotherson Dock) can also be found in a separate report (Parsons Brinkerhoff, 2002).

2.1 CATCHMENT CHARACTERISTICS

2.1.1 Mill Pond Catchment

The Mill Pond catchment (Figure 2.1) encompasses Centennial Park in the upper reaches to its north and the Botany Wetlands to its south. The Centennial Park ponds and the Botany Wetlands are connected by a stormwater drainage system and discharge to a channel referred to as the Mill Stream, which discharges to the Bay adjacent to the third (or parallel) runway of Kingsford Smith Airport.

Centennial Park consists of ten interconnecting ponds. These ponds receive stormwater runoff from a catchment of 590 hectares, which includes the former Showground site, Sydney Football Stadium, Sydney Cricket Ground (SCG) and parts of the suburbs of Randwick, Paddington, Bondi Junction and Queens Park. There are six direct stormwater inlets into the pond system from the surrounding suburbs. The ponds are connected by a series of internal stormwater drains, most of which run underground (Willing and Partners, 1999).

The Centennial Park ponds not only maintain the cultural, aesthetic and ecological integrity of the upper catchment, but also play an important role in stormwater flow attenuation and stormwater quality treatment.

The Botany Wetlands are a cascade of eleven ponds and adjoining land forming a green corridor in the lower parts of the catchment of approximately 4 km in length and 56 ha in area. They are a resource of national, regional and state significance being the largest freshwater wetlands in the Sydney region and contain some of the area's remaining indigenous vegetation and significant native fauna. The wetlands hold intrinsic ecological and aesthetic qualities (Willing and Partners, 1999), and also play an important role in stormwater flow attenuation and water quality treatment.

The natural landform of the Mill Pond catchment comprises rounded sand dunes and expanses of gentle slopes with local depressions and exposed water tables. Elevations vary from sea level to around 30 mAHD at the highest point on sandy dunes on the Eastlakes Golf Course and rise to about 70 mAHD near Centennial Park. The maximum catchment elevation is approximately 100 mAHD at the north-eastern corner of the catchment along Botany Street, Bondi Junction.

According to the Geological Series Sheet No 9130 (NSW Department of Mineral Resources, 1983), the soil type in the Mill Pond catchment is *medium to fine-grained 'marine' sand with podsols*, also known as the Botany Sands. These Botany Sands provide an extensive, generally shallow (i.e. not far below the ground level) groundwater aquifer that is closely linked to the surface water features.

2.1.2 Springvale and Floodvale Drains

Springvale and Floodvale Drains discharge stormwater to Botany Bay via Penrhyn Estuary (Figure 2.1).

The northern part of the catchments contains mainly residential landuse with some large open space areas such as Jellicoe Park, Mutch Park and part of the Bonnie Doon Golf Course.

The southern part of the catchments contain mainly industrial land use with various large and small scale developments including petroleum industries, food processing plants, chemical industries, shipping container areas and light industry. Botany Golf Course, located between Botany Road and Foreshore Road, is a significant open space. There are also substantial open areas in the vicinity of Floodvale and Springvale Drains between the Botany Freight Railway and McPherson Street. These open areas are largely low-lying, swampy land that act as flood storage areas for overflows from the trunk drains. Except for the swampy area where the soils consist of peat, sandy peat and mud, the soils in both catchments are Botany Sands (NSW Department of Mineral Resources, 1983).

The total length of Floodvale Drain is 2.9 km, with about 2.1 km of closed conduit and 0.8 km of open channel. The total length of Springvale Drain is about 3.9 km, comprised of 2.5 km of closed conduit and 1.4 km of open channel (SKP, 1992 and SKM, 1996).

2.1.3 Foreshore Beach

The Foreshore Beach stormwater drainage system has five outlets along the Foreshore Beach. Except for the open area between Botany Road and Foreshore Road, other parts of the catchment are residential and industrial. The total length of the five drains (closed conduits) is approximately 5.5 km (City of Botany Bay, undated).

2.2 STORMWATER QUALITY IMPROVEMENT DEVICES

There are fifteen existing and planned stormwater quality improvement devices (SQIDs) in the Mill Pond catchment, most of which are within the SCG and the former

Show Ground (Willing & Partners, 1999). Other features, such as the chain of ponds in the Mill Pond catchment, act as surrogate stormwater quality improvement features.

A number of stormwater quality improvement devices are located within the other catchments including a trashrack on Springvale Drain at McPherson Street.

It should be noted that a number of devices are proposed within the catchments. These were identified as part of the Stormwater Management Plan prepared under the NSW EPA directive to Councils for the Mill Pond and Floodvale and Springvale Drain catchments (Willing and Partners, 1999). (Note that Floodvale and Springvale Drains were also included in this report even though the title of the report suggests otherwise). Once implemented, these proposed devices are likely to reduce the overall load of pollutants delivered to the Bay from the catchment.

This report has been prepared upon the basis of the current status of the catchment (ie assuming none of the proposed devices have been implemented as yet).

2.3 EPA LICENCED PREMISES

A number of premises within the catchments are licensed under the NSW EPA's load-based licensing regulations. This effectively means that a number of premises are likely to discharge loads of pollutants on a regular basis into the stormwater systems that discharge to the Bay in the area of interest. A summary of the 17 generic types of premises (as defined by the EPA) generally within the catchment area is provided below (approximately 50 premises):

- Bulk Cargo Handling
- Chemical Storage - Other Chemical Storage
- Chemical Storage - Storage of Petroleum and/or Petroleum Products (with assessable pollutants)
- Concrete Batching
- Crushing, Grinding or Separating Works
- Hazardous, Industrial or Group A Waste Generation or Storage
- Hazardous, Industrial or Group A or Group B Waste Processing
- Miscellaneous Licensed Discharge to Waters (at any time)
- Other Agricultural Crop Processing
- Other Chemical Processing
- Paint Production
- Paper Production using Recycled Materials
- Petrochemical Production
- Plastics Production
- Scrap Metal Recovery
- Soap or Detergent Production
- Waste Storage, Transfer, Separating or Processing.

A summary of the types of pollutants licenced for discharge, regardless of the premises type and the limits of the licence discharge concentration, is provided in

Table 2.2. Note that this table is a summary only and not all premises types have the same pollutant types or the same pollutant concentration ranges.

Table 2.2 Summary of Load Based Licensing Pollutant Types for Catchments for All Premises Types

Pollutant	Discharge Maximum Concentration (mg/L)
Oil & Grease (mg/L)	10
Chlorine (free residual) (mg/L)	0.5 - 1.5
pH	6.5 - 9
Turbidity (NTU)	50
BOD (mg/L)	20
Total Suspended Solids (mg/L)	30 -50
Total Nitrogen (mg/L)	No numerical value given. Instead stated as 'Estuarine Waters Guidelines' (NB: ANZECC (2000) reports 0.3 mg/L)
Zinc (mg/L)	No numerical value given. Instead stated as 'Estuarine Waters Guidelines' (NB: ANZECC (2000) reports 15 μ g/L)
Total Volume of Flow (kL/day)	50-150,000

2.4 SYDNEY WATER CORPORATION ASSETS

There are two main assets managed by Sydney Water Corporation (SWC) within the catchment: -

- Mill Pond drainage system (upstream of Foreshore Drive)
- South and Western Suburbs Ocean Outfall Sewer (SWSOOS) carrier (traverses the Mill Pond, Floodvale and Springvale Drain catchments).

The SWSOOS system receives the highest number of licensed trade waste discharges (321 licences) and the highest daily volume of trade waste (47.7 ML/day) in comparison to other sewerage systems operated by SWC. The SWSOOS system receives the highest volume of trade waste discharge because its catchment is the largest and it collects wastewater from the heavily industrialised area immediately north of Botany Bay. The majority of trade waste discharge into the SWSOOS system however originates from the Botany area.

Flows from the SWSOOS can surcharge and be delivered to the catchments from time to time. SWC/SKM (1998) report that over 90% of the major sewers in the SWSOOS system have a capacity exceeding 2 x Peak Dry Weather Flow (PDWF), with approximately half the major sewers having a capacity greater than 4 x PDWF. The major sewers which have capacity less than 2 x PDWF include the section of the SWSOOS in Botany. As such, the limited capacity of the SWSOOS in this area results in overflow issues in this location.

As a guide to the quality of overflows in the Floodvale and Springvale Drain catchment areas, water quality testing of sewage was undertaken by SWC at the ICI

Botany site sewer at Beauchamp Road, Mascot (now ORICA) (SWC/SKM, 1998). Data from this exercise is shown in Table 2.3.

Table 2.3 Likely Sewage Overflow Quality in Botany Area*
(after SWC/SKM, 1998)

Parameter	Value (mg/L)
Average Dry Weather Flow	4.8 (ML/day)
Ammonia (N)	0.90
Delta BHC	0.00010
Total Aluminium	1.9
Total Arsenic	0.005
Total Chlordanes	0.00050
Total Copper	0.21
Total Iron	2.9
Total Lead	0.0170
Total Mercury	0.00752
Total Nickel	0.0260
Total Silver	0.0010
Total Zinc	0.54

*Period of Sampling: February 1994 to November 1994

In addition to the data in Table 2.3, the Sewer Overflow Licencing Program (SOLP) EIS (1998) reports on typical raw sewage microbiological characteristics, which include:-

- Faecal coliform levels of 2.5 x 10^{7} cfu/100 mL (median) and *C. perfringens* levels of 1.3 x 10^{5} cfu/100 mL (median);
- Virus cultures present for reoviruses, adenoviruses and enteroviruses on most sampling occasions
- *Giardia* concentrations of 30,000 cysts/L (median) and *Cryptosporidium* concentrations of 32.2 cysts/L (median).

The SWSOOS crosses the Mill Stream upstream of Foreshore Road. Visual inspection of the Mill Stream on the 16 February 2002 indicated the flow to be of a greyish colour with a significant odour (Sulphurous-type gas). There is a significant sewer overflow location at this point which was a likely contributor to degraded water quality (Sydney Water Sewer Overflow Licencing Project (SOLP) Environmental Impact Statement, SWC/SKM, 1998).

Note that whilst SWC operates a series of assets in the catchment, the closest water quality monitoring sites to assess the impacts of SWC operations within the greater Botany Bay area currently in operation are at:-

- Mouth of the Cooks River
- Woolooware Bay.

A number of monitoring sites are also located in the upper tributaries in the Cooks and Georges River. All of the sites are generally beyond the immediate area of interest for this study.

It should be noted that as part of WaterPlan 21, Sydney Water is delivering *SewerFix*, a $2 billion program of activities that will improve the management and capacity of the sewerage system (Sydney Water Corporation, 2002).

The aims of *SewerFix* are to:-

- Achieve no dry weather overflows at sewage pumping stations
- Reduce the frequency of chokes to less than 60 per 100km of pipe
- Reduce the volume of wet weather overflows by 80-90 per cent
- Reduce the total volume of all overflows by 50 per cent
- Reduce the number of odour complaints from each sewage asset to three per year.

Sydney Water Corporation reports that the *SewerFix* program is currently concentrating on sewage pumping stations and sewer pipes. Most recently, a Review of Environmental Factors (REF) for the Rehabilitation of the South and Western Suburbs Ocean Outfall Sewer has been published (Sydney Water Corporation, 2002). This REF states that three sections of the Lower SWSOOS will be repaired in the future within the area of interest (Airport, Perry Street, Matraville and Flat Roof, Bunnerong Road). Once these works are implemented, it is reported they will reduce the frequency of sewer overflows (within the catchments of interest to this study), from 200 events per 10 years to 120 events per 10 years.

2.5 SYDNEY AIRPORT CORPORATION ASSETS

The Sydney Airport Corporation Ltd (SACL) operates a significant asset in the Kingsford Smith Airport. Runoff from the airport areas discharges via a number of systems to Botany Bay, the Mill Stream and the Cooks River.

2.6 SYDNEY PORTS CORPORATION ASSETS

The Sydney Ports Corporation (SPC) operates a significant asset in the existing Port Botany Terminal. Runoff from the Port areas discharges via a number of systems, generally to Brotherson Dock, with some portions discharging to Springvale Drain.

Those portions discharging to Springvale Drain have been incorporated in the assessments for this study. Those areas that drain to Brotherson Dock have not been considered but are the subject of assessment under the Patrick Container Terminal Upgrade EIS (Parsons Brinkerhoff, 2002). Stormwater runoff from the proposed port will generally discharge to the open Bay side of the Port with treatment of the runoff to be provided before discharge. As such these areas have also not been considered as part of this study but are dealt with separately by ARUP (2002).

3. RECEIVING WATER OVERVIEW - EXISTING CONDITIONS

The proposed port development lies within the Botany Bay receiving water environment. Key waterways adjacent to the proposed Port include Penrhyn Estuary, Foreshore Beach and the Mill Stream.

The receiving water system operates in a complex manner and the water quality of the wider Botany Bay environment (i.e. beyond the proposed port expansion) is affected by a variety of processes and additional sources including:

- Inflows from surface runoff from various small foreshore catchment areas around the entire Bay perimeter (small catchment areas forming distributed sources around the Bay)
- Inflows from surface runoff from minor tributaries (tributaries draining medium sized catchment areas forming point sources around the Bay)
- Inflows from surface runoff from major tributaries (tributaries draining significant catchment areas and those forming major inflow points at the western boundaries of the Bay, e.g. Cooks River and Georges River)
- Surface runoff from significant infrastructure sited within or around the Bay (e.g. Sydney Airport)
- Discharges from vessels (both commercial and recreational)
- Groundwater inflows (e.g. from the Botany Aquifer)
- Direct rainfall to the surface of the Bay
- Atmospheric exchange
- Oceanic exchange
- Chemical transformations within the water column
- Uptake and release of constituents from Bay sediments, and
- Biological uptake and release of constituents.

A process diagram illustrating the tidal flows and locations of major inflows to Botany Bay is shown in Figures 3.1 and 3.2. A short description of the main areas of interest for this study are provided in the following sections.

3.1 PENRHYN ESTUARY

Penrhyn Estuary is a small waterway that lies at the outlet of both Springvale and Floodvale Drains. The estuary is a human-formed system as a result of the original development of Port Botany in the late 1970's. It is bounded by Foreshore Road to the north, Penrhyn Road to the east and a sand dune system to the west.

The estuary is characterised by a sand flat area with two channels from the two inflow points meeting midway within the system to form a single channel. The upper reaches of the Springvale inflow branch have been colonised by mangroves, the fringe of the estuary has some saltmarsh and some parts of the deeper areas of the estuary have seagrass beds (The Ecology Lab, 2003).

At low tide, much of the bed is exposed and shows an incised low flow channel that narrows at the downstream end before opening out to the main bay area. Thin layers of mud can be seen on the seabed upstream of a narrow constriction near the present boat ramp.

Photographs of the system at high and low tide can be seen in Figures 3.3 - 3.4.

The water quality in this area is primarily affected by both inflows from the incoming (or flood tide) from the Bay and surface runoff from the Floodvale and Springvale Drain catchments (Section 2.1.2). Groundwater also has a role in the quality of inflow.

The quality of inflow to the estuary from the Bay is dependent on the processes operating in the Bay. For example, flood flows from the ocean may be directed into the estuary as indicated on Figure 3.2.

Further details on the water quality of Penrhyn Estuary can be found in the analysis of available data for the existing condition in Section 4.4.1.

3.2 MILL POND/MILL STREAM

The Mill Stream is defined as the channel that flows adjacent to the Parallel Runway from Foreshore Road down to the Bay. Upstream of Foreshore Road is a series of ponds referred to in this report as the Botany Wetlands, which form part of the Mill Pond catchment.

The Mill Stream is a highly modified system, constructed as part of the Parallel Runway infrastructure to convey flows from the Mill Pond catchment to the Bay. The channel has vertical walls and a flat bed and is approximately 2m deep.

The system is tidal to the weir upstream of Foreshore Road. The weir has a level of 1.48 m AHD (SMEC, 1992) whereas mean high water springs (MHWS) tidal level is 0.66 m AHD and the highest astronomical tide (HAT) is 1.05 m AHD (Lawson and Treloar, 2003b). Thus the weir protects the Botany Wetlands from tidal inundation.

Further details on the water quality of the Mill Pond/Mill Stream can be found in the analysis of available data for the existing condition in Section 4.4.1.

3.3 FORESHORE BEACH

The Foreshore Beach area runs between the Mill Stream outlet and the mouth of Penrhyn Estuary, therefore both systems affect the water quality in the beach area. In addition, the water quality of Foreshore Beach is affected by inputs from the five stormwater outlets along its length.

A description of the water quality of Foreshore Beach, based on available data, is provided in Section 4.4.1.

3.4 BOTANY BAY

As outlined above, the water quality in the Bay is affected by a variety of factors with contaminant inflows and outflows dominated by oceanic inflows (on the incoming tide) and discharges from the major catchments (on the outgoing tide). The tidal range of the Bay is essentially the same as the ocean tide. Full details of the tidal behaviour of the Bay system can be found in Lawson and Treloar (2003b).

The major catchments of the Bay that are likely to have the most observable impact on water quality are those of the Georges River and the Cooks River. The Georges River catchment is approximately 900 km^2 whilst the Cooks River is approximately one tenth of the size at 98 km^2. The tidal reach of the Georges River extends a distance of 50 km from Dolls Point upstream to the Liverpool weir whilst the tidal reach of the Cooks River extends only 11 km upstream. As a consequence, tidal inflow and outflow from the Cooks River is much smaller than the Georges River. Hydrodynamic modelling of the Bay (Lawson and Treloar, 2003b) indicates that the flow structure of the Bay is dominated by astronomical tides flowing into and out of the Georges River (Figure 3.1 and 3.2).

Whilst both the Georges River and the Cooks River are considerable sources of contaminants, the wider Bay area is considerably well flushed due to the width and depth of the entrance of Botany Bay. The size of the entrance affords the Bay a significant tidal exchange and allows for the translation of pollutants from the Bay to the ocean on each ebb tide.

Further details on the water quality of the nearshore Bay areas relevant to this study can be found in the analysis of available data for the existing condition in Section 4.4.1.

4. REVIEW OF AVAILABLE DATA - EXISTING CONDITIONS

An assessment of the baseline water and sediment quality data was undertaken to establish observed existing conditions for a range of pollutants in the area of interest.

An overview of the available data is presented in two categories, water and sediment. Sources of data are outlined in Section 4.1, the methodology for the assessment of the baseline data is provided in Section 4.2, water and sediment quality guidelines to compare the data with are provided in Section 4.3 and the results of the comparison establishing the existing conditions are discussed in Section 4.4.

4.1 SOURCES OF DATA

A significant volume of data was available to establish a baseline data set of the current water quality and sediment conditions observed in the vicinity of the proposed port expansion.

Data sources for both water and sediment quality include:-

- City of Botany Bay Council (ongoing)
- NSW Environment Protection Authority (EPA) (ongoing)
- Sydney Water Corporation (ongoing)
- Various studies by ORICA (a major industrial land holder within the catchment)
- Previous studies of the area for the Parallel Runway for the Sydney Airport (Kinhill, 1990)
- Previous studies of the area for the Penrhyn Road Boat Ramp (Johnstone Environmental Technology, 1993)
- Previous studies of the area by Sydney Water Corporation (e.g. Hill and Ball, 1994)
- Research and other investigations (e.g. Birch, 1996, Albani et al - *in progress*, van Senden et al, 1993).

Data (both published and unpublished) were identified via the following searches and reviews:-

- Review of the data and information summarised as a result of the Healthy Rivers Commission's Inquiry into Botany Bay (Final Report, 2001)
- Search of the CANRI (Community Access to Natural Resources Information) database for water and sediment quality metadata
- Contact with City of Botany Bay Council (CBB)
- Contact with Sydney Airports Corporation Limited (SACL)
- Abstracts search of databases including ENGINE and STREAMLINE
- Internet search using appropriate keywords.

4.1.1 Water Quality (Catchment and Receiving Waters)

Data Collected By City of Botany Bay Council

The Council of the City of Botany Bay (CBB) has collected water quality data across the local government area (LGA) since 1996. Grab samples of water were collected by Council technical personnel and analysed by an external laboratory. The data were made available by Council in electronic format to aid the preparation of this report.

Samples are generally collected by Council under dry weather conditions. Whilst sampling dates are reported, details of the actual time of sample collection were not available.

The data indicate that some sites are influenced by estuarine waters (generally indicated by the conductivity values derived for each sample). This influence has relevance for the application of ANZECC (2000) guidelines (Section 4.3).

Council has identified the following sites, shown in Figure 4.1, which are relevant to this investigation. Note that Council has not collected samples at all of these sites on all occasions (some sites have had not been sampled at all). These sites are listed in Table 4.1.

Table 4.1 City of Botany Bay Council Water Quality Sampling Sites*

Site Name	Site Number	Estuarine Influence?
Springvale Interceptor Drain	Council Site 21	No estuarine influence
McPherson Street West (Floodvale Drain)	Council Site 22	No estuarine influence
Penrhyn Estuary	Council Site 23	Estuarine influence
Botany Golf Club	Council Site 24	No estuarine influence
Sir Joseph Banks Park	Council Site 25	No estuarine influence
Springvale Drain (Upper Reaches)	Council Site 26	No estuarine influence
Nant Street (Springvale Drain)	Council Site 27	No data available
McPherson Street (Springvale Drain)	Council Site 28	No data available
Wool Stores (u/s Mill Stream)	Council Site 30	Estuarine influence
FAC Mill Pond (u/s of SWSOOS)	Council Site 31	No estuarine influence

*Only those sites relevant to the Port Expansion Investigations are shown. Council has a number of other sites in catchments outside of the area of interest.

Samples were collected at the following times:-

- 1996 (January, March, April - two separate dates, May, June, December)
- 1997 (January, February, March, June, October)
- 1998 (February, May, September)
- 1999 (January, March, June, September, December)
- 2000 (May).

Sample analytes included:-

- pH
- Total Suspended Solids (TSS)
- Phosphorus reactive (RP)
- Total Phosphorus (TP)

- Conductivity (EC)
- Ammonia (NH_3)
- Dissolved Oxygen (DO)
- Biochemical Oxygen Demand (BOD)
- Faecal Coliforms (FC)
- Faecal Streptococci (FS)
- Nitrate (NO_3^-)
- Oxidised Nitrogen (NOx)
- Total Kjeldahl Nitrogen (TKN)
- Total Nitrogen (TN)
- Total Petroleum Hydrocarbons (TPH)
- Total Oil & Grease (TOG)
- Phenols
- Arsenic (As)
- Cadmium (Cd)
- Chromium (Cr)
- Copper (Cu)
- Lead (Pb)
- Mercury (Hg)
- Zinc (Zn).

Not all samples collected were analysed for all of these parameters.

A summary of all of the data for all of the relevant sites listed in Table 4.1 is shown in Table 4.2. The data indicate a range of observed conditions.

Table 4.2 Summary of All Data for Relevant Sites* from CBB Water Quality Monitoring Program

Analyte	Units	Minimum Observed	Maximum Observed
BOD	mg/L	1.6	110
Dissolved Oxygen	mg/L	9.73	10.47
Conductivity	mS/cm	0.047	54
pH	pH units	5.98	10.3
Total Suspended Solids	mg/L	0.9	290
Arsenic	mg/L	< 0.02	5
Cadmium	mg/L	0.0004	0.184
Chromium	mg/L	No data	No data
Copper	mg/L	< 0.001	0.31
Lead	mg/L	0.001	0.48
Mercury	mg/L	< 0.0001	0.0048
Zinc	mg/L	< 0.05	1.9
Faecal Coliforms	Cfu/100mL	1	120000
Faecal Streptococci	Cfu/100mL	1	18000
TPH	mg/L	0.1	28
Total Oil & Grease	mg/L	0	13
Phenol	mg/L	< 0.05	32
Nitrate	mg/L	< 0.01	2.6
Ammonia	mg/L	0.01	13
Oxidised Nitrogen	mg/L	< 0.005	0.97
TKN	mg/L	< 0.05	30
Total Nitrogen	mg/L	< 0.05	32
Total Phosphorus	mg/L	0.007	8.2
Phosphorus reactive	mg/L	< 0.05	0.97

** See Table 4.1 for site list*

A discussion of the data within the context of the all the data collated for this study is provided in Section 4.4.

EPA Harbourwatch

The NSW Environment Protection Authority (EPA) Harbourwatch program involves the sampling of a number of sites within Harbours in the greater metropolitan area, including Sydney Harbour, Pittwater and Botany Bay. The program involves the collection of samples on a six day cycle and analysis for faecal contamination indicator organisms (both faecal coliforms and Enterococci) (http://www.epa.nsw.gov.au).

In general, Enterococci are better indicators of the potential health risks of faecal contamination than faecal coliforms in marine and estuarine waters (ANZECC, 2000).

The most relevant site of this data collection program for this study is at Foreshore Beach (EPA Site 93). Other sites within the region include: -

- Yarra Bay (EPA Site 92)
- Frenchmans Bay (EPA Site 91)
- Congwong Bay (EPA Site 90)
- Kyeemagh Baths (EPA Site 94)
- Brighton Le Sands Baths (EPA Site 95)
- North Ramsgate (EPA Site 96)
- South Ramsgate (EPA Site 97)
- Dolls Point Baths (EPA Site 98)
- Sandringham Baths (EPA Site 99)
- Silver Beach (EPA Site 100).

All of these sites are shown in Figure 4.1. As a guide to the extent of the available data, a summary of the number of samples and some statistical analysis of the data is shown in Tables 4.3 and 4.4.

Table 4.3 Summary of Data for Foreshore Beach Site

Parameter	Value	
	Faecal Coliforms	Enterococci
Period of Data Considered	5 Jan 1995 - 24 Jun 2002	5 Jan 1995 - 24 Jun 2002
Frequency of Sampling	1 sample every 6 days	1 sample every 6 days
Number of Samples Collected	452	452
ANZECC Trigger Value (2000)	150 cfu/100 mL	35 cfu/100 mL
Minimum Value Recorded	0 cfu/100 mL	0 cfu/100 mL
Maximum Value Recorded (24^{th} April 1998)	42,000,000 cfu/100 mL	980,000 cfu/100 mL
Probability of Exceedence of Guidelines	19.4%	37%

Table 4.4 Statistical Details for Foreshore Beach Site* (after EPA)

Year	Season	Enterococci % Compliance with ANZECC (2000) Guideline	Faecal Coliforms % Compliance with ANZECC (2000) Guideline
1995	Winter	61.9	90.5
1995-96	Summer	53.1	87.5
1996	Winter	71.4	81.0

Year	Season	Enterococci % Compliance with ANZECC (2000) Guideline	Faecal Coliforms % Compliance with ANZECC (2000) Guideline
1996-97	Summer	90.3	100
1997	Winter	23.8	66.7
1997-98	Summer	87.1	87.1
1998	Winter	14.3	42.9
1998-99	Summer	56.3	78.1
1999	Winter	57.1	100
1999-00	Summer	48.4	61.3
Minimum	**NA**	**14.3**	**42.9**
Maximum	**NA**	**90.3**	**100**

* Available EPA data sets at the time of preparation of this report for compliance are reported only up to the summer period 1999 - 2000.

The data in Tables 4.3 and 4.4 show that: -

- The maximum recorded faecal coliform count was 42 million cfu/100mL. It should be noted that these data were collected after a prolonged rainfall period in April 1998 (with a total rainfall recorded from commencement of rainfall late on the 20th April to the end of the rainfall on the morning of the 24th April of 520.4 mm). It is suggested that significant sewer overflows probably occurred during this event and contributed to the elevated levels.

- Generally, compliance with the guidelines is variable with wet periods resulting in considerable non-compliance (e.g. Enterococci compliance of 14.3% for the period of winter 1998)

- Table 4.3 reports a probability of exceedence assessment of the available time series of data. In the case of faecal coliforms, the probability of exceedence of the ANZECC (2000) trigger value of 150 cfu/100 mL is 19.4%. Thus, approximately 20% of the time the waters are unsuitable for primary contact recreational use. Similarly, for Enterococci, the probability of exceedence of the ANZECC (2000) trigger value of 35 cells/100 mL is 37%. Thus, approximately 40% of the time the waters are unsuitable for primary contact recreational use using this measure of faecal contamination.

Further discussion of the data is provided in Section 4.4.

ORICA Voluntary Environmental Program

ORICA has collected data within the catchment and the estuary as part of various regulatory and voluntary monitoring programs to indicate the effectiveness of a remediation program for contaminated shallow groundwater (ORICA, 2002). This data was made available by ORICA to assist with this study.

Available data were acquired for water sampling undertaken between May 1999 and July 2001. Samples were collected at the following sites relevant to this project: -

- Springvale Drain Outlet (inflow point to Penrhyn Estuary) (SW031)

- Floodvale Drain Outlet (inflow point to Penrhyn Estuary) (SW029)
- Penrhyn Estuary at Old Boat Ramp (SW028)
- Penrhyn Estuary at New Boat Ramp (SW048)
- Within the ORICA facilities (stormwater pipe to Springvale Drain) (SW006)
- Within the ORICA facilities (Springvale Drain) (SW046)
- McPherson Street (Springvale Drain) (SW0005)
- McPherson Street (Floodvale Drain) (SW0053).

These sites are shown in Figure 4.1.

Analytes include: -

- Physico-chemical parameters (conductivity, temperature, pH, redox, Eh, dissolved oxygen)
- Volatile chlorinated hydrocarbons
- Semi-volatile hydrocarbons.

In general, surface samples were taken on a quarterly basis. However, in addition to this sampling, a series of samples were collected from the period 21 July 1999 through to 9 September 1999. Some samples were collected in areas affected by estuarine flows. A summary of the data is provided in Table 4.5.

Table 4.5 Summary of ORICA Data for All Sites

Analyte	Units	Minimum Observed	Maximum Observed
Electrical Conductivity	μ s/cm	293	47400
Temperature	deg C	10.4	20.6
pH	-	6.13	7.95
Redox	mV	-190	286
Electrical Potential	mV	40	520
Dissolved Oxygen	mg/L	0.65	6.7
Dissolved Oxygen	%	4	64
Total BTEX	mg/L	0	0.012
Total Chloromethanes	mg/L	0.02	2.02
Total Chloroethanes	mg/L	0.014	2.04
Total Chloroethenes	mg/L	0.041	3.8
EDC (Ethylene dichloride)	mg/L	0.083	265

A discussion of the data within the context of all the data collated for this study is provided in Section 4.4.

SACL Environmental Monitoring Program

As part of ongoing monitoring programs, the Sydney Airport Corporation Limited (SACL) monitors surface water quality at various sites within its area of operation. However, this data has not been able to be obtained for this report.

As a guide, the City of Botany Bay (2001) report that SACL monitor for cadmium, chromium, copper, iron, lead, manganese, zinc, total nitrogen, total phosphorus, hydrocarbons, ammonia and suspended solids. Available data assessed by the City of Botany Bay indicate that the concentration of all of these pollutants except iron and hydrocarbons in Airport surface runoff was found to be significantly less than the pollution levels generated from typical urban areas (as determined by the NSW EPA).

It is also reported (City of Botany Bay, 2001), that an assessment has been undertaken by SACL to determine whether the pollution in Airport surface runoff, particularly hydrocarbon pollution, has any noticeable impact on the ecology of the surrounding waters. This assessment concluded that it was unlikely that runoff from Sydney Airport would have any noticeable impact on local waterways, including Botany Bay.

Data Collected For Parallel Runway EIS

Studies associated with the preparation of the environmental impact statement for the Parallel Runway at Kingsford Smith Airport were conducted over a period of 1989 - 1993 when the EIS was submitted in draft form (Kinhill, 1990).

Investigations included: -

- Sampling of surface water quality from catchment areas (Mill Pond catchment) at 7 sites (November 1989)
- Sampling of groundwater quality in relevant parts of the Botany aquifer at 6 sites (November 1989)
- Sampling of surface water quality at 11 sites within Botany Bay (February - May 1990).

Sites sampled are shown in Figure 4.1. As indicated by the present shoreline configuration (i.e. with the constructed Parallel Runway, completed in 1994), some of the sampling sites have since been constructed-over.

Catchment surface water and groundwater sample analytes consisted of: -

- Calcium cation
- Magnesium cation
- Sodium cation
- Potassium cation
- Zinc cation
- Carbonate (HCO_3) anion
- Chlorine anion
- Sulphate (SO_4) anion
- Nitrate (NO_3) anion
- Phosphate (PO_4) anion
- Total Iron
- Molybdenum
- Zinc
- Lead
- Cadmium
- Arsenic
- Silicon
- Total coliform bacteria
- pH
- Water Temperature
- Conductivity

Water sample analytes in the Bay consisted of: -

- Faecal coliform bacteria
- Aluminium

- Suspended solids
- Total nitrogen
- Total phosphorus
- Chlorophyll a
- Total hydrocarbons
- PCBs
- Cadmium
- Total chromium
- Manganese
- Mercury
- Zinc

Table 4.6 Summary of Parallel Runway Data for Surface Waters

Analyte	Units	Minimum Observed	Maximum Observed
Faecal coliform bacteria	cfu/100 mL	0	1600000
Suspended solids	mg/L	<0.2	33.7
Total nitrogen	μg/L	10	5580
Total phosphorus	μg/L	30	1805
Chlorophyll A	mg/L	1.8	65.2
Total hydrocarbons	(mg/L)	<0.1	3.8
PCBs	mg/L	<0.5	0.9
Aluminium	μg/L	<100	500
Cadmium	μg/L	<100	200
Total chromium	μg/L	<100	100
Manganese	μg/L	<100	300
Mercury	μg/L	<1	3
Zinc	μg/L	<100	200
Total Fe	mg/L	<0.01	1.86
Mo	mg/L	<0.1	<0.1
Zn	mg/L	0.05	0.57
Pb	mg/L	<0.1	<0.1
Cd	mg/L	<0.01	<0.01
As	mg/L	<0.001	<0.01
Si	mg/L	<1	16
Eh	mV	-364	-213
pH	-	6.58	8.27
Water Temperature	(degrees C)	20	23
EC	μ S/cm 25 deg C	255	1017

A discussion of the data within the context of all the data collated for this study is provided in Section 4.4.

Data Collected by Sydney Water Corporation 1994 - 1995

Whist the current sites for ongoing monitoring are outlined in Section 2.4 and confined to areas outside of the specific study area, sampling was undertaken in 1994 and 1995 at a site along Foreshore Beach, near Penrhyn Estuary. The site is further east than the EPA Harbourwatch Site 92 (reported above and in Figure 4.1).

Data is reported in Hill and Ball (1994), Parkinson (1995) and Hill and Ball (1995).

The site was sampled on 36 occasions between April 1994 and March 1995. Parameters included:

- temperature
- conductivity
- dissolved oxygen
- pH
- faecal coliforms.

A summary of the data collected are shown in Table 4.7.

Table 4.7 Summary of Sydney Water Corporation Data 1994 - 1995

Analyte	Units	Minimum Observed	Maximum Observed
Temperature	deg C	13.1	22.2
Conductivity	μ S/m	4960	5460
DO	%	76	118
pH	-	7	8.5
Mean Faecal Coliforms	cfu/100 mL	2	19000

A discussion of the data within the context of all the data collated for this study is provided in Section 4.4.

Stormwater Management Plan

The Stormwater Management Plan (Willing and Partners, 1999) contains limited water quality data. Some relevant water quality indices are presented in Table 4.8.

Table 4.8: List of Water Quality Indices (adapted from Willing and Partners, 1999)

Parameter	Centennial Park	Botany Wetlands	Floodvale Drain	Botany Council	
				Average	Maximum
Total Suspended Solids (mg/L)	10	1 - 34	26 - 95	0.9	380
Total Phosphorus (mg/L)	0.05	0.22	NR	0.02	2.2
Total Nitrogen (mg/L)	0.5	4.3	NR	0.19	89
Biochemical Oxygen Demand (mg/L)	2.0	8.1	NR	1.6	110

NR - Not reported/no data.

There is no indication about the location and dates of the data collection from which these ranges were extracted. However, these indices show a broad picture of the pollution status in the catchment area.

A discussion of the data within the context of the all the data collated for this study is provided in Section 4.4.

Wider Area Programs, One-Off Programs and Miscellaneous Data

Other data collection programs identified through the process of the investigation are wider area programs (not specific to the area affected by the proposed port development), random or one-off samplings and other miscellaneous data. These sources include: -

- Sydney Water Corporation (sites in the Cooks and Georges River)
- van Senden et al, 1993 (turbidity, Secchi depths and suspended solids sampling over period April - July 1992)
- OZGREEN environmental network unpublished data (snapshot for March 2001 of faecal coliform counts from 24 sites indicating a range of between 0 - > 1,000,000 cfu/100 mL) (http://www.ozgreen.org.au/Botany.htm).

A data summary for the Bay is also reported in the Draft Healthy Rivers Commission report (2000). The summary indicates the following: -

- Pathogens - poor water quality in the northern part of the Bay (i.e. the study area)
- Nutrients and algae - generally good but exceeding guidelines for phosphorous
- Toxicants - aluminium and copper in high levels in water, most metals in low levels in sediments
- Physico-chemical - generally reasonable except for dissolved oxygen which may fall below guideline levels during daytime periods.

Whilst no additional data is reported, a summary of existing data is also reported by Smith (1998) entitled *State of the Bay.* This report was prepared by a team of environmental scientists working for the Bay councils of Botany Bay City, Hurstville, Kogarah, Randwick, Rockdale and Sutherland Shire, together with the Sutherland Shire Environment Centre. This report refers to the parameters of total nitrogen, suspended solids and lead in sediment for the Bay. The report concludes that: -

- Water quality decline has been evident for major rivers entering Botany Bay over several decades
- Total nitrogen exceeds the indicative national water quality guideline for nitrogen as nitrate or ammonia
- Suspended sediment level fluctuation has exceeded the national guidelines markedly
- Heavy metals are spread across the Bay in sediment.

4.1.2 Sediment Quality

Assessments of the quality of sediments for the area of interest and the wider Botany Bay area have been undertaken by a variety of researchers and for a variety of purposes.

They include: -

- Parallel Runway EIS (Kinhill, 1990) (23 sites, 20 grab samples, 3 core samples)
- Penrhyn Boat Ramp Studies (Johnstone Environmental Technology (JET), 1993)
- University of Sydney investigations (Teutsch, 1992, Birch, 1996 - a range of sites within the Bay)
- Morrisey et al (1994) (Kurnell and Yarra Bay only)
- University of New South Wales (Albani, *in progress*) (samples collected in January, 2002).

Details of relevant data collated as part of this investigation are outlined below. Details of the Morrisey et al (1994) and Albani (*in progress*) studies are not presented in this report. The Morrisey et al (1994) data is not relevant to the site and the Albani data was not available at the time of publication.

Data Collected For Parallel Runway EIS

The most accessible, publicly available published data for the Bay was found in Kinhill (1990). Sites are shown in Figures 4.1 and 4.2 (23 sites, 20 grab samples, 3 core samples). None of the sites were located within the Penrhyn Estuary area, nor on the Foreshore Beach area to coincide with the water quality sites assessed in Section 4.1.

In addition to identification of sediment type details, the following analytes were quantified:-

- Arsenic
- Cadmium
- Chromium
- Cobalt
- Copper
- Lead
- Mercury
- Tin
- Zinc
- Hexachlorobenzene
- alpha-BHC
- Total Petroleum Hydrocarbons
- Phosphorous
- Total Organic Carbon
- Organic Nitrogen

It should be noted that of the 23 sites assessed, sites S6, S11 and S10 showed the highest levels of metal contaminants from the available data. Sites S10 and S11 are located in the northern part of the Bay within the proposed port area, Site 6 is located off Lady Robinsons Beach to the south.

Whilst some sites are within or near the reclamation area for the proposed port (Sites S10 and S11) it is likely that the dredging works to win fill for the Parallel Runway mean that the results from these sites may no longer be valid for S10. Site S11 is located underneath the proposed reclamation and is the only site likely to be in a similar condition to that observed in the 1990 study.

A summary of the S11 data is shown in Table 4.9.

Table 4.9 Summary of Site 11 Data from Parallel Runway EIS

Analyte	Units	Observed
Zn	μ g/g dry weight	47.1
Cr	μ g/g dry weight	14.1
As	μ g/g dry weight	5.5
Hg	μ g/g dry weight	<0.2
Co	μ g/g dry weight	1
Pb	μ g/g dry weight	27.6
Cd	μ g/g dry weight	<0.2
Cu	μ g/g dry weight	10.8
Sn	μ g/g dry weight	0.4

Analyte	Units	Observed
HCB	μ g/g dry weight	0.02
alpha-BHC	μ g/g dry weight	<.008
TPH	μ g/g dry weight	748
P	μ g/g dry weight	235
TOC	mg/g dry weight	5
ON	mg/g dry weight	<0.1

A discussion of the data within the context of the all the data collated for this study is provided in Section 4.4.

Data Collected For Penrhyn Road Boat Ramp Studies

Other useful data specifically within Penrhyn estuary is published by JET (1993). This study for the replacement of the Penrhyn Road Boat Ramp involved the collection of 25 sediment samples from a number of sites in October 1993. These sites are shown in Figure 4.2 and included:

- Push tubes from a boat @ 5 locations (polycarbonate tubes)
- Surface sediment samples using clam shell grab @ 5 locations
- Hand auger samples at low tide (4 locations).

In addition to grain size analysis, core sections and grab samples were analysed for the following: -

- Mercury
- Chromium
- Chromium VI
- Hexachlorobenzene.

A summary of the analysis of surface sediment samples is provided in Table 4.10.

Table 4.10 Summary of Surface Sample Results

Analyte	Units	Minimum Observed	Maximum Observed
Hg	mg/kg	<0.05	26.7
Cr	mg/kg	<2	223
Cr VI	mg/kg	2.8	2.8
HCB	mg/kg	<0.06	4.2

A discussion of the data within the context of the all the data collated for this study is provided in Section 4.4.

Data Collected By Sydney University

Students and staff of Sydney University have undertaken a number of investigations with regard to sediment contaminants over a period of time. Undergraduate honours theses have been prepared (e.g. Teutsch, 1992) and papers published on the various findings (e.g. Birch, 1996).

Relevant information from Birch (1996) has been utilised for the purposes of providing background information on the baseline conditions of the Bay sediments. Birch (1996) details investigations including: -

- Samples collected by geological divers using push cores (196 surface samples from the Botany Bay/Georges River system) some of these samples were collected in triplicate
- Approximately 8 sites of interest were sampled along the northern part of the Bay, north-east of the runway, relevant to this study
- Analytes include copper, zinc, nickel and lead.

Sampling was undertaken prior to the construction of the Parallel Runway in 1992.

The mapping published in Birch (1996) indicates that:

- copper concentrations in sediment ranges from 50 -100 μ g/g in the mud fraction in the study area
- zinc concentrations in sediment ranges from 200 - 500 μ g/g in the mud fraction in the study area
- nickel concentrations in sediment ranges from 20 - 40 μ g/g in the mud fraction in the study area
- lead concentrations in sediment ranges from 100 - 200 μ g/g in the mud fraction in the study area.

A discussion of the data within the context of all the data collated for this study is provided in Section 4.4.

4.2 BASELINE DATA ASSESSMENT METHODOLOGY

4.2.1 Spatial Units Assessed

Based on the available data reported in Section 4.1 and the nature of the systems considered, four spatial units have been assessed with regard to water quality:-

- Catchments (freshwater) (catchments considered included Springvale Drain, Floodvale Drain, Foreshore Beach Drains and the Mill Pond)
- Mill Stream (upstream of SWSOOS) (fresh water)
- Penrhyn Estuary (estuarine)
- Foreshore Beach (Botany Bay) (estuarine/marine).

Similarly, two spatial units were considered with regard to sediment quality:-

- Penrhyn Estuary
- Botany Bay.

The selection of spatial units was undertaken based on the available monitoring sites (Figure 4.1), the type of environment (freshwater, estuarine or marine) and the location of the proposed port expansion (Appendix A).

Data identified was then incorporated into one of these spatial units and reported as a range of observed values in Tables 4.12 and 4.13. Tables 4.12 and 4.13 make reference to water and sediment quality 'trigger' values. These are discussed in detail in Section 4.3.

4.2.2 Analyte Selection

A detailed overview of the analytes selected as part of the baseline assessment and a brief comment on their likely impacts is provided in Table 4.11.

4.2.3 Data Quality

Where reported data have not been collected or analysed in accordance with appropriate standards (e.g. Australian Standards or recognised laboratory analysis methods), no attempt has been made to review laboratory quality control as this information was unavailable. In general, the data included in the compiled data are within reported ranges for surface waters and therefore have been considered as reasonably representative of the likely conditions.

The majority of presented water quality data were collected after the construction of the Parallel Runway, thus no attempt has been made in this report to differentiate between data collected before and after runway construction.

The majority of presented sediment quality data were collected prior to the construction of the Parallel Runway. Data collected recently (Section 4.1.2) will resolve any changes and provide a new dataset once available.

4.2.4 Data Gaps

Tables 4.12 and 4.13 highlight a number of gaps in the available data for the area of interest.

For example, whilst grab samples have been collected or probes deployed from time to time to determine the levels of physico-chemical parameters at a point in time (such as pH, temperature, dissolved oxygen), the diurnal variability in these physico-chemical parameters was unknown.

Additionally, there have been no wet weather events sampled from the catchment, nor the effects of wet weather flows measured within the estuary areas.

To resolve these data gaps, a program of data collection was devised and implemented. This is discussed in detail in Section 5. Data gaps for sediment quality are currently being resolved through investigations by the University of New South Wales (Albani) (Section 4.1.2).

A number of data gaps could not be resolved during the timeframe of this assessment. The principal gaps are the lack of long-term, detailed site specific data such as:

- time series or regular analysis of chlorophyll-a concentrations,
- identification of algal species and counts of species over seasonal and inter-annual periods,
- measurements of light penetration into the water column,
- benthic nutrient flux data, and
- other site specific data to aid the analysis of nutrient dynamics that could be utilised to calibrate complex numerical process models for the area of interest.

As such, modelling of the estuary to assess the impact of the proposed port expansion was undertaken given these limitations. Details of the modelling are provided in Section 7.

4.3 SELECTION OF WATER AND SEDIMENT QUALITY GUIDELINES

To make a determination on the current status of both the water and sediment quality of the area of interest, a comparison with recommended water and sediment quality guidelines has been undertaken. Current practice in Australia involves the use of the ANZECC (2000) water and sediment quality guidelines in the absence of locally determined guidelines.

The selection of appropriate water and sediment quality guidelines is dependent on the values or protection criteria assigned to a particular waterway. The Healthy Rivers Commission's Inquiry for Botany Bay (HRC, 2001) identified the following protection criteria for the area of interest:

- Protection of visual character
- Protection of aquatic and riparian ecosystems
- Protection of human consumers of cooked fish, shellfish and crustaceans
- Protection of primary contact recreation
- Protection of secondary contact recreation.

The guidelines associated with the protection of aquatic and riparian ecosystems, and primary contact recreation are generally the most stringent. As such, these guidelines have been used for the purposes of comparison with available data. It should be noted that the aquaculture and human consumption of aquatic foods ANZECC (2000) guidelines are not applicable to the area of interest. ANZECC (2000) state that the '*guidelines for protecting the health of commercial fish species do not apply to recreational and commercial fisheries based on wild populations of aquatic organisms. Wild fish stocks are dependent on healthy ecosystems to support them throughout their life cycle. Hence, for the protection of wild fish stocks it is best to apply the water quality guidelines for managing aquatic ecosystems'*.

To supplement the protection criteria outlined above, HRC (2001) identified that:-

- Northern Botany Bay area is a 'highly modified' system and the desired outcome for this area is the restoration of the ability of this area to sustain chosen values/uses. The management goal for this area is the rehabilitation of key elements.
- Objective RHO 4 recommends that the guideline trigger values contained in ANZECC (2000) should be adopted and used as indicative values for the initial phases of an adaptive approach to water quality and ecosystem management.
- Objective RHO 4 also indicates that the trigger values provided for nutrients in the ANZECC (2000) guidelines may not be appropriate for parts of the system. Site specific studies are recommended to be undertaken in cases where any trigger values are to form the basis of any regulatory program or nutrient trading scheme.

Adopted single guideline trigger values are presented against observed values in Tables 4.12 and 4.13. The 'trigger value' is the recommended threshold above which further investigation should be undertaken (rather than an absolute compliance level).

Where quoted, the 95% level of protection is adopted (being the ANZECC (2000) recommended level for a slightly to moderately disturbed systems). However, in the case of chemicals which bio-accumulate, the recommended protection level of 99% is quoted.

ANZECC (2000) indicates that trigger values are for 'ambient' water quality conditions. The ANZECC (2000) guidelines state *'they have not been designed for direct application in activities such as discharge consents, recycled water quality or stormwater quality, nor should they be used in this way. (The exception to this may be water quality in stormwater systems that are regarded as having some conservation value). They have been derived to apply to the ambient waters that receive effluent or stormwater discharges, and protect the environmental values they support. In this respect, the Guidelines have not been designed to deal with mixing zones*,' these being *'explicitly defined areas around an effluent discharge where the water quality may still be below that required to protect the designated environmental values'.*

As such, trigger levels should therefore only generally apply to dry weather water quality observations and areas away from stormwater or effluent discharge points. However, some of the data included in Table 4.12 are from wet weather events, mixing zone areas or highly modified systems with limited conservation value (such as concrete lined channels). Therefore the trigger levels may not be appropriate for the full range of conditions observed. These considerations have been conservatively omitted from the assessment and thus it provides a worst case comparison.

For estuarine systems, where no estuarine guidelines are available for an analyte, the marine guideline has been adopted.

4.4 BASELINE DATA ASSESSMENT RESULTS

Table 4.12 presents a summary of available water quality data. For each spatial unit the analyte and the available data are presented as an observed range, along with the corresponding ANZECC (2000) trigger value. Where appropriate, the ANZECC recommended level of protection associated with the trigger value is also noted (parenthesised). This table also includes summary data from in-situ measurement field work reported in Section 5.

In the same manner, Table 4.13 presents a summary of the available sediment quality data.

In the absence of numerical guidelines that have been specifically locally developed, the following section describes water and sediment quality in terms of a comparison with ANZECC (2000) guidelines (Section 4.3). Environmental impacts and human health risks associated with elevated levels of contaminants in the project area are to be addressed by The Ecology Lab and URS in separate reports.

4.4.1 Water Quality

This section provides a bullet point summary of existing water quality reported in Table 4.12 and highlights instances where observed analyte levels have exceeded recommended ANZECC (2000) trigger levels.

Catchments (Freshwater)

- pH range for catchment areas can be slightly above or below the trigger level range
- Catchment areas show elevated BOD levels
- A variety of sites show considerably low dissolved oxygen concentrations, almost to anoxic levels
- Reducing conditions have been observed at times – these conditions have implications for the speciation of nutrients and heavy metals
- Elevated NOx concentrations observed well above guideline trigger values
- Total Nitrogen (TN) can vary between one and two orders of magnitude above the trigger value
- Total Phosphorous (TP) values are elevated by up to two orders of magnitude above trigger values, but ortho-phosphate (which is the bioavailable component of total phosphorous), is within the lower bound of the trigger values
- Total Petroleum Hydrocarbons (TPH) ranges are elevated – the observed values are well in excess of trigger values which is expected given the considerable hydrocarbon sources within the catchments and groundwater.

Limited data indicate the following analytes may also substantially exceed ANZECC (2000) trigger levels at some locations and for some times:

- 1,2-Dichloroethane (also known as EDC)
- Cadmium
- Copper
- Lead

- Mercury
- Zinc
- Faecal Coliforms.

Penrhyn Estuary (Estuarine)

- Penrhyn Estuary can show elevated turbidity levels
- Reducing conditions have been observed at times – these conditions have implications for the speciation of nutrients and heavy metals
- Elevated NOx concentrations observed well above trigger levels
- Total Nitrogen can vary between one and two orders of magnitude above trigger levels
- Total Phosphorous values are elevated above trigger values, but ortho-phosphate (which is the bioavailable component of total phosphorous), is within the lower bound of the trigger values and therefore less problematic
- Chlorophyll-a levels can exceed trigger values by as much as 5 times
- Total Petroleum Hydrocarbons (TPH) ranges are elevated – the observed values are well in excess of trigger values which is expected given the considerable hydrocarbon sources within the catchments and groundwater.

Limited data indicate the following analytes may also substantially exceed ANZECC (2000) trigger levels at some times:

- Carbon tetrachloride
- Chloroform
- 1,1,2-Trichloroethane
- 1,2-Dichloroethane
- Hexachlorobenzene
- Hexachlorobutadiene
- Aluminium
- Arsenic
- Cadmium
- Copper
- Lead
- Manganese
- Zinc
- Faecal Coliforms.

This would be expected, as Penrhyn Estuary is the receiving water for the catchments.

Mill Stream (u/s of SWSOOS)

- pH range for catchment areas can be slightly above or below the trigger level range
- A variety of sites show low dissolved oxygen levels
- Total Nitrogen can exceed trigger levels by up to one order of magnitude

- Total Phosphorous values can exceed trigger levels by two orders of magnitude, but ortho-phosphate (which is the bioavailable component of total phosphorous), is within the lower bound of the trigger levels and therefore less problematic.

There was no available data for hydrocarbons and few data generally available for metals, however, limited data indicate the following analytes may also substantially exceed ANZECC (2000) trigger levels:

- Cadmium
- Copper
- Iron
- Lead
- Zinc
- Faecal Coliforms.

Botany Bay (just off Foreshore Beach)

- Total Phosphorous values can slightly exceed trigger values
- Chlorophyll-a levels can exceed trigger values
- Total Petroleum Hydrocarbons (TPH) ranges are well in excess of trigger levels (more than three orders of magnitude)
- Faecal indicator organisms can considerably exceed guidelines. Trigger values are likely to be exceeded 20 – 40% of the time.

There was no available data for specific hydrocarbons and few data generally available for metals, however, limited data indicate the following analytes may also substantially exceed ANZECC (2000) trigger levels:

- Aluminium
- Cadmium
- Chromium
- Mercury.

4.4.2 Sediment Quality

In the same way as the water quality assessment is presented (Section 4.4.1), this section provides a bullet point summary of existing sediment quality reported in Table 4.13 and highlights instances where observed analyte levels have exceeded recommended ANZECC (2000) trigger levels.

More detailed analyses of contaminated sediments and the implications for the proposed port expansion can be found within the volumes of the Environmental Impact Statement (URS, 2003).

Penrhyn Estuary

Data were only available for Chromium, Mercury and Hexochlorobenze (HCB) concentrations. Of these, Chromium levels have been found to exceed the lower extent of the ANZECC trigger range, whilst Mercury has been found to exceed the upper trigger range level. There are no ANZECC (2000) guideline trigger levels for HCB.

Botany Bay (Northern Part in the Vicinity of the Proposed Port Expansion)

Whilst there was more data for the Bay than for Penrhyn Estuary, including metal, hydrocarbon and nutrient data, ANZECC (2000) only gives sediment trigger guidelines for metals.

For available data, most metal levels were below ANZECC (2000) trigger levels. In the case of Arsenic and Cadmium the maximum, recorded levels were close to the lower ANZECC (2000) trigger range level. Lead has been recorded at levels exceeding the lower ANZECC (2000) trigger range level for this analyte.

Table 4.11 Water Quality Analyte Overview

Analyte	Likely Variability and/or Definition and/or Source Details derived from ANZECC (2000)	Example(s) of Impact of Elevated Levels	ANZECC - Aquatic Ecosystem Protection Guidelines (AEPG) or Recreational Contact Guidelines (RCG) or No Guideline (NG)	Comment
Physico-chemical				
Conductivity	Estuarine areas will see significant tidal variation	May result in changes to aquatic flora and riparian vegetation type.	AEPG - Actual Guideline Provided	-
pH	Can be impacted by acid sulfate soils (low levels) and industrial discharges (high levels)	Direct toxicity to biota	AEPG - Actual Guideline Provided	-
Turbidity	Likely to see surge in levels due to freshwater inflows and sewer overflows. EPA Licenced premises in the catchment (Section 2.3)	May reduce light penetration and have impacts on aquatic flora and fauna.	AEPG - Actual Guideline Provided	Key Aquatic Ecosystem Protection Indicator.
Suspended Particulate Material (SS)	Likely to see surge in levels due to freshwater inflows and sewer overflows. Alternate measure to turbidity for the purposes of comparison with other reported data, EPA Licenced premises in the catchment (Section 2.3)	May reduce light penetration and have impacts on aquatic flora and fauna.	NG	-
BOD (Ultimate)	Catchment (e.g. Sewer overflows), EPA Licenced premises in the catchment (Section 2.3)	Depletion of dissolved oxygen levels	NG	Required to assist with DO/BOD modelling.
DO	Likely to vary considerably over a daily cycle	Reduced levels have impact on biota	AEPG - Actual Guideline Provided	-
Redox	Likely to vary considerably with salinity	-	NG	-
Temperature	Likely to vary considerably with atmospheric temperature and season	Variation may have impacts on biota	AEPG Guideline is comparative for change in temperature over time.	-
Nutrients				**-**
Nitrate	Likely to see surge in levels due to freshwater inflows and sewer overflows	-	NG	-

Analyte	Likely Variability and/or Definition and/or Source Details derived from ANZECC (2000)	Example(s) of Impact of Elevated Levels	ANZECC - Aquatic Ecosystem Protection Guidelines (AEPG) or Recreational Contact Guidelines (RCG) or No Guideline (NG)	Comment
NOx	Likely to see surge in levels due to freshwater inflows and sewer overflows		AEPG – Actual Guideline Provided, RCG - Actual Guideline Provided	Provides an improved understanding of nitrogen speciation and availability
Ammonia (NH_3)	Likely to see surge in levels due to freshwater inflows and sewer overflows	Direct toxicity to biota	AEPG – Actual Guideline Provided, RCG - Actual Guideline Provided	Provides an improved understanding of nitrogen speciation and availability
Total Nitrogen	Likely to see surge in levels due to freshwater inflows and sewer overflows, EPA Licenced premises in the catchment (Section 2.3)	Excess levels may result in nuisance growth of aquatic plants	AEPG - Actual Guideline Provided	Key Aquatic Ecosystem Protection Indicator. Catchment and Estuary, EPA Licenced Premises
FRP (PO_4-P)	Likely to see surge in levels due to freshwater inflows and sewer overflows	Excess levels may result in nuisance growth of aquatic plants	AEPG – Actual Guideline Provided	Provides an improved understanding of phosphorous speciation and availability to biota
Total Phosphorous	Likely to see surge in levels due to freshwater inflows and sewer overflows	Excess levels may result in nuisance growth of aquatic plants	AEPG - Actual Guideline Provided	Key Aquatic Ecosystem Protection Indicator. Catchment (e.g. garden fertiliser application, road runoff) and Estuary
Chlorophyll a (chla)	Indicative of overall estuarine health (eutrophication), often used to indicate likelihood of algal bloom	Excess levels may result in nuisance growth of aquatic plants,	AEPG - Actual Guideline Provided	Key Aquatic Ecosystem Protection Indicator.
Hydrocarbons				
Total Petroleum Hydrocarbons (TPH)	Catchment and Estuary (past and present industry) sources.	Surface film can prevent gas exchange with atmosphere. Can be toxic to biota.	No guideline specified	An indicator of all petroleum hydrocarbon sources.
Oil and Grease	Catchment and Estuary (past and present industry) sources, EPA Licenced premises in the catchment (Section 2.3)	Surface film can prevent gas exchange with atmosphere. Can be toxic to biota.	RCG – Actual Guideline Provided	Likely to be present as a result of past and present industry in the catchment, EPA Licenced Premises
Aromatic Hydrocarbons				

Analyte	Likely Variability and/or Definition and/or Source Details derived from ANZECC (2000)	Example(s) of Impact of Elevated Levels	ANZECC - Aquatic Ecosystem Protection Guidelines (AEPG) or Recreational Contact Guidelines (RCG) or No Guideline (NG)	Comment
Monoaromatic hydrocarbons	Benzene, Ethyl benzene, Toluene and Xylene- the high volatility and relatively low water solubility of these chemicals indicates that they would be rapidly lost to atmosphere from a water body, with half-lives for evaporation <=5 hours at 20°C	Can be toxic to biota.	AEPG - Actual Guideline Provided	Catchment sources dominant.
Chloromethanes				
Chloromethane, Carbon Tetrachloride	Chlorinated methanes (of which Chloromethane and Carbon Tetrachloride are examples) are commonly used solvents for adhesives, pesticides, fats, oils, rubbers, alkaloids, waxes, resins and for specialty chemicals and as a cleansing agent such as in dry cleaning. Some are used in paint strippers, for manufacture of fluorocarbon refrigerants and in the past in fire extinguishers.	Can be toxic to biota.	AEPG - Actual Guideline Provided	Catchment sources dominant.
Chloroethanes				
Trichoroethane	Chlorinated ethanes (of which Trichloroethane is an example) are commonly used as industrial solvents, dry-cleaning agents, anaesthetics, and in the production of other organochlorines, textiles, tetraethyl lead fuel additives and plastics, particularly polyvinyl chloride, as well as in many household products such as detergents, fumigants, correction fluid, varnishes and rust removers	Can be toxic to biota.	AEPG - Actual Guideline Provided	Catchment sources dominant.
Chloroethenes				
Tetrachloroethene	Chlorinated Ethenes (of which Tetrachloroethene, Trichloroethene, cis-	Can be toxic to biota	NG	Catchment sources dominant

Analyte	Likely Variability and/or Definition and/or Source Details derived from ANZECC (2000)	Example(s) of Impact of Elevated Levels	ANZECC - Aquatic Ecosystem Protection Guidelines (AEPG) or Recreational Contact Guidelines (RCG) or No Guideline (NG)	Comment
	1,2-Dichloroethene, trans-1,2-Dichloroethene, 1,1-Dichloroethene are examples) have been sampled in the waters of Penrhyn Estuary. There are no trigger values for these analytes in ANZECC (2000). In terms of sources, tetrachloroethene for example has been used primarily as a solvent in dry-cleaning industries and to a lesser extent as a degreasing solvent. The highest environmental levels of tetrachloroethene are found in the commercial dry-cleaning and metal-degreasing industries.			
Chlorobenzenes				
Chlorobenzene	Chlorinated benzenes are used as industrial solvents for waxes, gums, resins, rubbers, oil, asphalt and general degreasing, as chemical intermediates for nitrochlorobenzenes, chlorophenols, chloroanilines, pesticides, herbicides and fungicides, and as insecticides for termites and borers. 1,4-Dichlorobenzene is used mainly as an air deodorant and insecticide. Hexachlorobenzene is used for organic synthesis, for synthetic rubber and as a rubber additive, as a plasticiser for PVC, an intermediate in dye manufacture, in manufacture of electrodes, and previously as a fungicide, particularly for wheat seed treatment against bunt. Chlorination of effluents containing traces of aromatic chemicals	Can be toxic to biota.	AEPG - Actual Guideline Provided	Catchment sources dominant.

Analyte	Likely Variability and/or Definition and/or Source Details derived from ANZECC (2000)	Example(s) of Impact of Elevated Levels	ANZECC - Aquatic Ecosystem Protection Guidelines (AEPG) or Recreational Contact Guidelines (RCG) or No Guideline (NG)	Comment
	can result in formation of chlorobenzenes.			
Miscellaneous Industrial Chemicals				
Hexachlorobutadiene	Hexachlorobutadiene is a by-product of the production of chlorinated hydrocarbons. It is used as a solvent in chemical industries and as a heat transfer fluid in electrical transformers. The presence of hexachlorobutadiene in the environment results from anthropogenic sources such as volatilisation and from industrial wastes.	Can be toxic to biota.	AEPG - Actual Guideline Provided	Catchment sources dominant.
Polychlorinated Biphenyls (PCBs)				
Polychlorinated Biphenyls (PCBs)	ANZECC (2000) states that PCBs have been widely used as dielectric fluids for capacitors and transformers, as heat transfer fluids, plasticisers, lubricant inks, fire retardants, organic chemical solvents, paint additives, immersion oils, sealing liquids, adhesives, laminating agents, waxes and dust removers. PCBs commonly are highly lipophilic (increases with increasing chlorine substitution) and high stability under normal or extreme conditions. Hence they tend to bioaccumulate in terrestrial and aquatic organisms and, along with DDT residues, are globally distributed.	Bioaccumulator causing secondary toxic effects to biota	NG	Likely to be present as a result of Catchment and Estuary sources.
Metals				
$CaCO_3$	-	Used for interpretation of	RCG – Actual Guideline	Used for interpretation of metal toxicity

Analyte	Likely Variability and/or Definition and/or Source Details derived from ANZECC (2000)	Example(s) of Impact of Elevated Levels	ANZECC - Aquatic Ecosystem Protection Guidelines (AEPG) or Recreational Contact Guidelines (RCG) or No Guideline (NG)	Comment
		metal toxicity	Provided	
Arsenic	ANZECC (2000) states that arsenic is released naturally by the weathering of rocks containing arsenic. The Arsenic released due to human activities is about twice as much as natural sources.	Direct toxicity to biota	AEPG - Actual Guideline Provided, RCG - Actual Guideline Provided	Likely to be present as a result of Catchment and Estuary (past and present industry) sources
Cadmium	Human derived cadmium emissions are generally from phosphate fertilisers, non-ferrous metals production, and the iron and steel industry.	Direct toxicity to biota	AEPG - Actual Guideline Provided, RCG - Actual Guideline Provided	Likely to be present as a result of Catchment and Estuary (past and present industry) sources
Copper	Copper is an essential trace element found in most natural waters, but in higher doses can have a toxicity effect.	Direct toxicity to biota	AEPG - Actual Guideline Provided, RCG - Actual Guideline Provided	Likely to be present as a result of Catchment and Estuary (past and present industry) sources
Total Chromium	Chromium is commonly used in the production of alloys (such as stainless steel), pigments (such as in paints and cements) and as a wood preservative.	Direct toxicity to biota	AEPG - Actual Guideline Provided, RCG - Actual Guideline Provided	Likely to be present as a result of Catchment and Estuary (past and present industry) sources
Iron	The level of naturally occurring iron in water is dependent on the geology of the area as well as other chemical components in the waterway.	Direct toxicity to biota	AEPG – Inferred Guideline Provided, RCG - Actual Guideline Provided	Likely to be present as a result of Catchment and Estuary (past and present industry) sources
Lead	ANZECC (2000) states that the human sources of lead far outweigh the natural sources. The most common sources being "precipitation, fall-out of lead dust, street runoff and industrial and municipal wastewater discharges"	Direct toxicity to biota	AEPG - Actual Guideline Provided, RCG - Actual Guideline Provided	Likely to be present as a result of Catchment and Estuary (past and present industry) sources
Manganese	There are a variety of sources of Manganese. ANZECC (2000) states that manganese is commonly used in "steel alloys and dry cell batteries as well as in	Direct toxicity to biota	AEPG – Inferred Guideline Provided, RCG - Actual Guideline Provided	Likely to be present as a result of Catchment and Estuary (past and present industry) sources

Analyte	Likely Variability and/or Definition and/or Source Details derived from ANZECC (2000)	Example(s) of Impact of Elevated Levels	ANZECC - Aquatic Ecosystem Protection Guidelines (AEPG) or Recreational Contact Guidelines (RCG) or No Guideline (NG)	Comment
	paints, inks, glass, ceramics, fireworks and fertilisers".			
Mercury (inorganic)	Most of the mercury in the environment is a result of human activities, such as burning coal for energy production, mining and deforestation.	Bioaccumulator causing secondary toxic effects to biota	AEPG - Actual Guideline Provided, RCG - Actual Guideline Provided	Likely to be present as a result of Catchment and Estuary (past and present industry) sources
Zinc	Zinc can enter the environment through natural and human activities. ANZECC (2000) states that natural sources can include "weathering and erosion" while human sources can include "zinc production, waste incineration and urban runoff", EPA Licenced premises in the catchment (Section 2.3).	Direct toxicity to biota	AEPG – Actual Guideline Provided, RCG - Actual Guideline Provided	Likely to be present as a result of Catchment and Estuary (past and present industry) sources
Biological				
Faecal Coliforms	Indicator of faecal pollution. Diffuse source over catchment and sewer overflows	Illness due to primary or secondary human contact	RCG - Actual Guideline Provided	Key recreational contact guideline. Directly comparable with long-term Harbourwatch data (EPA)
Faecal Streptococci	Indicator of faecal pollution. Diffuse source over catchment and sewer overflows	Illness due to primary or secondary human contact	NG	-
Enterococci	Indicator of faecal pollution - a better indicator for marine and estuarine sites. Diffuse source over catchment and sewer overflows	Illness due to primary or secondary human contact	RCG - Actual Guideline Provided	Key recreational contact guideline. Directly comparable with long-term Harbourwatch data (EPA)

Table 4.12 Summary of Water Quality for Areas of Interest from All Available Sources

Analyte	Catchments (Freshwater)	Penrhyn Estuary (Estuarine)	Mill Stream (u/s of SWSOOS)	Bay (just off Foreshore Beach)
Physico-chemical				
Conductivity (mS/cm)	Observed Range: 0.2 - 4.1 Trigger Level: 0.125 - 2.2	Observed Range: 0.337 - 54 Trigger Level: NA	Observed Range: 0.18 - 24 Trigger Level: 0.125 - 2.2	Observed Range: 49.6 - 54.6 Trigger Level: NA
pH	Observed Range: 6.13 - 9.4 Trigger Level: 6.5 - 8.5	Observed Range: 6.61 – 8.2 Trigger Level: 7 - 8.5	Observed Range: 6.32 - 8.8 Trigger Level: 6.5 - 8.5	Observed Range: 7 - 8.5 Trigger Level: 7 - 8.5
Total Suspended Solids (mg/L)	Observed Range: <1 - 150 Trigger Level: NA	Observed Range: 3 – 220 Trigger Level: NA	Observed Range: < 1 - 28 Trigger Level: NA	Observed Range: < 1 - 12 Trigger Level: NA
Turbidity (NTU)	Observed Range: 0 - 50 Trigger Level: 6 - 50	Observed Range: 0.5 – 10 Trigger Level: 0.5 – 10	Observed Range: NA Trigger Level: 0.5 - 10	Observed Range: 0.1 - 14 Trigger Level: 0.5 - 10
Biochemical Oxygen Demand (mg/L)	Observed Range: 2 - 110 Trigger Level: NA	Observed Range: 2 – 48 Trigger Level: NA	Observed Range: 1.6 - 16 Trigger Level: NA	Observed Range: NA Trigger Level: NA
Dissolved Oxygen (mg/L or % Saturation)	Observed Range: 0.56 - 5.7 mg/L Observed Range: 5.3 - 53.7% Trigger Level: Only as % Saturation - 85 - 110%	Observed Range: 1.7 - 7.2 mg/L Observed Range: 82.5 – 91.5% Trigger Level: Only as % Saturation - 80 - 110%	Observed Range: 4.5 - 6.2 mg/L Observed Range: 43.7 - 60% Trigger Level: Only as % Saturation - 85 - 110%	Observed Range: NA Observed Range: 76 - 118% Trigger Level: Only as % Saturation - 80 - 110%
Redox (mV)	Observed Range: -183 - 223 Trigger Level:NA	Observed Range: -190 – 286 Trigger Level: NA	Observed Range: 319 - 610 Trigger Level: NA	Observed Range: NA Trigger Level: NA
Temperature (°C)	Observed Range: 10.4 - 20.1 Trigger Level: No specific value, based on change from observed range.	Observed Range: 15.71 - 16.3 Trigger Level: As for catchment.	Observed Range: 13.82 - 14.42 Trigger Level: As for catchment.	Observed Range: 13.1 - 22.2 Trigger Level: As for catchment.
Nutrients				
Nitrate (mg/L)	Observed Range: <0.01 - 2.6 Trigger Level: 0.7 (95%)	Observed Range: < 0.01 - 0.36 Trigger Level: NA	Observed Range: < 0.01 - 0.48 Trigger Level: 0.7 (95%)	Observed Range: NA Trigger Level: NA
Oxidised Nitrogen (or NOx) (mg/L)	Observed Range: 0.02 - 0.85 Trigger Level: 0.04	Observed Range: 0.08 – 0.2 Trigger Level: 0.015	Observed Range: NA Trigger Level: 0.04	Observed Range: NA Trigger Level: 0.015
Ammonia (mg/L)	Observed Range: 0.03 - 13 Trigger Level: 0.9 (95%)	Observed Range: 0.03 – 0.64 Trigger Level: 0.91 (95%)	Observed Range: < 0.01 - 0.55 Trigger Level: 0.9 (95%)	Observed Range: NA Trigger Level: 0.91 (95%)
Total Kjeldahl Nitrogen (mg/L)	Observed Range: 0.2 - 23 Trigger Level: NA	Observed Range: 0.05 – 0.74 Trigger Level: NA	Observed Range: 0.09 - 1.4 Trigger Level: NA	Observed Range: NA Trigger Level: NA
Total Nitrogen (mg/L)	Observed Range: 0.6 - 32 Trigger Level: 0.5	Observed Range: < 0.05 - 5.58 Trigger Level: 0.3	Observed Range: 0.3 - 7 Trigger Level: 0.5	Observed Range: 0.06 - 0.27 Trigger Level: 0.3
Ortho-phosphorous (mg/L) Trigger value provided is for 'filterable reactive phosphate'	Observed Range: 0.05 - 0.07 Trigger Level: 0.02	Observed Range: < 0.05 - 0.05 Trigger Level: 0.005	Observed Range: < 0.05 Trigger Level: 0.02	Observed Range: NA Trigger Level: 0.005
Total Phosphorus (mg/L)	Observed Range: <0.05 - 5.8	Observed Range: < 0.05 - 8.2	Observed Range: < 0.05 - 5.1	Observed Range: 0.022 - 0.05

Analyte	Catchments (Freshwater)	Penrhyn Estuary (Estuarine)	Mill Stream (u/s of SWSOOS)	Bay (just off Foreshore Beach)
	Trigger Level: 0.05	Trigger Level: 0.03	Trigger Level: 0.05	Trigger Level: 0.03
Silicon (mg/L)	Observed Range: NA Trigger Level: NA	Observed Range: NA Trigger Level: NA	Observed Range: < 1 - 16 Trigger Level: NA	Observed Range: NA Trigger Level: NA
Chlorophyll-a (μ g/L)	Observed Range: NA Trigger Level: 5	Observed Range: 1.5 – 20.5 Trigger Level:4	Observed Range: NA Trigger Level: 4	Observed Range: 5.1 - 12.3 Trigger Level: 5
Hydrocarbons				
Total Petroleum Hydrocarbons (mg/L)	Observed Range: < 0.1 - 28 Trigger Level: 0.007	Observed Range: 0.4 - 2.5 Trigger Level: 0.007	Observed Range: NA Trigger Level: 0.007	Observed Range: < 1 - 2 Trigger Level: 0.007
Total Oil and Grease (mg/L)	Observed Range: 8 - 11 Trigger Level: NA	Observed Range: NA Trigger Level: NA	Observed Range: NA Trigger Level: NA	Observed Range: NA Trigger Level: NA
Aromatic Hydrocarbons*				
Benzene (mg/L)	Observed Range: NA Trigger Level: 0.95 (95%)	Observed Range: < 0.001 - 0.02 Trigger Level: 0.5 (95%)	Observed Range: NA Trigger Level: 0.95 (95%)	Observed Range: NA Trigger Level: 0.5 (95%)
Toluene (mg/L)	Observed Range: NA Trigger Level: 0.18 (95%)	Observed Range: < 0.001 - 0.002 Trigger Level: 0.18 (95%)	Observed Range: NA Trigger Level: 0.18 (95%)	Observed Range: NA Trigger Level: 0.18 (95%)
Ethyl benzene (mg/L)	Observed Range: NA Trigger Level: 0.08 (95%)	Observed Range: < 0.001 - 0.001 Trigger Level: 0.08 (95%)	Observed Range: NA Trigger Level: 0.08 (95%)	Observed Range: NA Trigger Level: 0.08 (95%)
p,m-Xylenes (mg/L)	Observed Range: NA Trigger Level: NA	Observed Range: < 0.001 - 0.001 Trigger Level: NA	Observed Range: NA Trigger Level: NA	Observed Range: NA Trigger Level: NA
o-Xylene (mg/L)	Observed Range: NA Trigger Level: 0.35 (95%)	Observed Range: < 0.001 - 0.001 Trigger Level: 0.35 (95%)	Observed Range: NA Trigger Level: 0.35 (95%)	Observed Range: NA Trigger Level: 0.35 (95%)
Total BTEX (mg/L) (Benzene, Toluene, Ethyl benzene and Xylene)	Observed Range: NA Trigger Level: NA	Observed Range: 0 - 0.012 Trigger Level: NA	Observed Range: NA Trigger Level: NA	Observed Range: NA Trigger Level: NA
Choromethanes*				
Carbon tetrachloride (mg/L)	Observed Range: NA Trigger Level:0.24 (95%)	Observed Range: 0.01 – 1 Trigger Level: 0.24 (95%)	Observed Range: NA Trigger Level:0.24 (95%)	Observed Range: NA Trigger Level: 0.24 (95%)
Chloroform (mg/L)	Observed Range: NA Trigger Level: 0.37 (99%)	Observed Range: 0.01 – 1 Trigger Level: 0.37 (99%)	Observed Range: NA Trigger Level: 0.37 (99%)	Observed Range: NA Trigger Level: 0.37 (99%)
Dichloromethane (mg/L)	Observed Range: NA Trigger Level: 4 (95%)	Observed Range: < 0.005 - 0.02 Trigger Level: 4 (95%)	Observed Range: NA Trigger Level: 4 (95%)	Observed Range: NA Trigger Level: 4 (95%)
Total Chloromethanes (mg/L)	Observed Range: NA Trigger Level: NA	Observed Range: 0.02 – 2.02 Trigger Level: NA	Observed Range: NA Trigger Level: NA	Observed Range: NA Trigger Level: NA
Chloroethanes*				
1,1,1-Trichloroethane (mg/L)	Observed Range: NA Trigger Level: 0.27 (95%)	Observed Range: < 0.001 - 0.002 Trigger Level: 0.27 (95%)	Observed Range: NA Trigger Level: 0.27 (95%)	Observed Range: NA Trigger Level: 0.27 (95%)
1,1,2-Trichloroethane (mg/L)	Observed Range: NA Trigger Level: 6.5 (95%)	Observed Range: 0.004 - 0.2 Trigger Level: 1.9 (95%)	Observed Range: NA Trigger Level: 6.5 (95%)	Observed Range: NA Trigger Level: 1.9 (95%)
1,2-Dichloroethane (mg/L) (aka EDC, Ethylene dichloride)	Observed Range: 0.66 - 265 Trigger Level: 1.9 (95%)	Observed Range: <0.001 - 76.2 Trigger Level: 1.9 (95%)	Observed Range: NA Trigger Level: 1.9 (95%)	Observed Range: NA Trigger Level: 1.9 (95%)

Analyte	Catchments (Freshwater)	Penrhyn Estuary (Estuarine)	Mill Stream (u/s of SWSOOS)	Bay (just off Foreshore Beach)
Hexachloroethane (mg/L)	Observed Range: NA Trigger Level: 0.29 (99%)	Observed Range: < 0.0001 Trigger Level: 0.29 (99%)	Observed Range: NA Trigger Level: 0.29 (99%)	Observed Range: NA Trigger Level: 0.29 (99%)
Total Chloroethanes (mg/L)	Observed Range: NA Trigger Level: NA	Observed Range: 0.014 - 2.04 Trigger Level: NA	Observed Range: NA Trigger Level: NA	Observed Range: NA Trigger Level: NA
Chloroethenes**				
Tetrachloroethene (mg/L)	Observed Range: NA Trigger Level: NA	Observed Range: 0.005 - 0.2 Trigger Level: NA	Observed Range: NA Trigger Level: NA	Observed Range: NA Trigger Level: NA
Trichloroethene (mg/L)	Observed Range: NA Trigger Level: NA	Observed Range: 0.02 – 2 Trigger Level: NA	Observed Range: NA Trigger Level: NA	Observed Range: NA Trigger Level: NA
cis-1,2-Dichloroethene (mg/L)	Observed Range: NA Trigger Level: NA	Observed Range: 0.01 – 1 Trigger Level:NA	Observed Range: NA Trigger Level: NA	Observed Range: NA Trigger Level: NA
trans-1,2-Dichloroethene (mg/L)	Observed Range: NA Trigger Level: NA	Observed Range: 0.002 - 0.2 Trigger Level: NA	Observed Range: NA Trigger Level: NA	Observed Range: NA Trigger Level: NA
1,1-Dichloroethene (mg/L)	Observed Range: NA Trigger Level: NA	Observed Range: 0.001 - 0.1 Trigger Level: NA	Observed Range: NA Trigger Level: NA	Observed Range: NA Trigger Level: NA
Total Chloroethenes (mg/L)	Observed Range: NA Trigger Level: NA	Observed Range: 0.041 - 3.8 Trigger Level: NA	Observed Range: NA Trigger Level: NA	Observed Range: NA Trigger Level: NA
Chlorobenzenes**				
1,2-Dichlorobenzene (mg/L)	Observed Range: NA Trigger Level: 0.16 (95%)	Observed Range: < 0.0001 - 0.0002 Trigger Level: NA	Observed Range: NA Trigger Level: 0.16 (95%)	Observed Range: NA Trigger Level: NA
1,3-Dichlorobenzene (mg/L)	Observed Range: NA Trigger Level: 0.26 (95%)	Observed Range: < 0.0001 Trigger Level: NA	Observed Range: NA Trigger Level: 0.26 (95%)	Observed Range: NA Trigger Level: NA
1,4-Dichlorobenzene (mg/L)	Observed Range: NA Trigger Level: 0.06 (95%)	Observed Range:<0.0001-0.0003 Trigger Level: NA	Observed Range: NA Trigger Level: 0.06 (95%)	Observed Range: NA Trigger Level: NA
1,3,5-Trichlorobenzene (mg/L)	Observed Range: Trigger Level: 0.008 (99%)	Observed Range: < 0.0001 - 0.0001 Trigger Level: 0.008 (99%)	Observed Range: NA Trigger Level: 0.008 (99%)	Observed Range: NA Trigger Level: 0.008 (99%)
1,2,4-Trichlorobenzene (mg/L)	Observed Range: NA Trigger Level: 0.085 (99%)	Observed Range: < 0.0001 Trigger Level: 0.02 (99%)	Observed Range: NA Trigger Level: 0.085 (99%)	Observed Range: NA Trigger Level: 0.02 (99%)
Pentachlorobenzene (mg/L)	Observed Range: NA Trigger Level: 0.0015 (99%)	Observed Range: < 0.0001 Trigger Level: 0.0015 (99%)	Observed Range: NA Trigger Level: 0.0015 (99%)	Observed Range: NA Trigger Level: 0.0015 (99%)
Hexachlorobenzene	Observed Range: NA Trigger Level: 0.00005 (99%)	Observed Range: < 0.0001 Trigger Level: 0.00005 (99%)	Observed Range: NA Trigger Level: 0.00005 (99%)	Observed Range: NA Trigger Level: 0.00005 (99%)
Miscellaneous Industrial Chemicals				
Hexachlorobutadiene (mg/L)	Observed Range: NA Trigger Level: 0.00004	Observed Range: < 0.0001 - 0.0001 Trigger Level: 0.00003	Observed Range: NA Trigger Level: 0.00004	Observed Range: NA Trigger Level: 0.00003

Analyte	Catchments (Freshwater)	Penrhyn Estuary (Estuarine)	Mill Stream (u/s of SWSOOS)	Bay (just off Foreshore Beach)
Phenols				
Phenol (mg/L)	Observed Range: < 0.05 Trigger Level: 0.32 (95%)	Observed Range: NA Trigger Level: 0.4 (95%)	Observed Range: NA Trigger Level: 0.32 (95%)	Observed Range: NA Trigger Level: 0.4 (95%)
Polychlorinated Biphenyls (PCBs)				
PCBs (μ g/L)	Observed Range: NA Trigger Level: NA	Observed Range: < 0.5 Trigger Level: NA	Observed Range: NA Trigger Level: NA	Observed Range: < 0.5 Trigger Level: NA
Metals *(none have been adjusted for hardness as no data available)*				
Aluminium (μ g/L) (pH generally > 6.5)	Observed Range: NA Trigger Level: 55 (95%)	Observed Range: < 100 –300 Trigger Level: NA	Observed Range: Trigger Level: 55 (95%)	Observed Range: < 100 - 100 Trigger Level: NA
Arsenic (μ g/L)	Observed Range: <0.02 Trigger Level: NA	Observed Range: <0.02 Trigger Level: 1 - 3.3	Observed Range: < 0.02 Trigger Level:NA	Observed Range: NA Trigger Level: 1 - 33.
Cadmium (μ g/L)	Observed Range: <0.4 - 110 Trigger Level: 0.2 (95%)	Observed Range: 0.4 – 184 Trigger Level: 0.7 (99%)	Observed Range: < 0.4 - 2 Trigger Level: 0.2 (95%)	Observed Range: < 100 - 200 Trigger Level: 0.7 (99%)
Copper (μ g/L)	Observed Range: 10 - 80 Trigger Level: 1.4 (95%)	Observed Range: 3 – 160 Trigger Level: 1.3 (95%)	Observed Range: 5 - 250 Trigger Level: 1.4 (95%)	Observed Range: NA Trigger Level: 1.3 (95%)
Total Chromium (μ g/L)	Observed Range: NA Trigger Level: NA	Observed Range: < 100 Trigger Level: 0.01 – 0.1	Observed Range: NA Trigger Level: NA	Observed Range: < 100 - 100 Trigger Level: 0.01 - 0.1
Iron (Total) (μ g/L)	Observed Range: NA Trigger Level: 300	Observed Range: NA Trigger Level: 300	Observed Range: < 10 - 1860 Trigger Level: 300	Observed Range: NA Trigger Level: 300
Lead (μ g/L)	Observed Range: < 1 - 310 Trigger Level: 3.4 (95%)	Observed Range: < 1 – 480 Trigger Level: 4.4 (95%)	Observed Range: 4 - 50 Trigger Level: 3.4 (95%)	Observed Range: NA Trigger Level: 4.4 (95%)
Manganese (μ g/L)	Observed Range: NA Trigger Level: 1900 (95%)	Observed Range: 100 –300 Trigger Level: 80 (95%)	Observed Range: NA Trigger Level: 1900 (95%)	Observed Range: < 100 Trigger Level: 80 (95%)
Mercury (μ g/L)	Observed Range: 0.1 - 4.8 Trigger Level: 0.01	Observed Range: < 1 Trigger Level: 0.0017	Observed Range: NA Trigger Level: 0.01.	Observed Range: < 1 - 1 Trigger Level: 0.0017
Molybdenum (μ g/L)	Observed Range: NA Trigger Level: 34	Observed Range: NA Trigger Level: 23	Observed Range: <100 Trigger Level: 34	Observed Range: NA Trigger Level: 23
Zinc (μ g/L)	Observed Range: <50 - 1400 Trigger Level: 8 (95%)	Observed Range: < 50 – 1300 Trigger Level: 15 (95%)	Observed Range: < 50 - 570 Trigger Level: 8 (95%)	Observed Range: < 100 Trigger Level: 15 (95%)
Biological				
Faecal Coliforms (cfu/100 mL)	Observed Range: <1 - 120,000 Trigger Level: 150	Observed Range: <10 - 11,800 Trigger Level: 150	Observed Range: < 1 - 120,000 Trigger Level: 150	Observed Range: 0 - 42,000,000 Trigger Level: 150
Faecal Streptococci (cfu/100 mL)	Observed Range: < 1 - 18,000 Trigger Level: NA	Observed Range: < 2 – 500 Trigger Level: NA	Observed Range: 2 - 3000 Trigger Level: NA	Observed Range: NA Trigger Level: NA
Enterococci (cfu/100 mL)	Observed Range: NA Trigger Level: 35	Observed Range: NA Trigger Level: 35	Observed Range: NA Trigger Level: 35	Observed Range: 0 - 980,000 Trigger Level: 35

'Catchments' is a summary of all City of Botany Bay Council, ORICA (1996 - 2001), recent ambient conditions physico-chemical monitoring for this project (Section 5) and data for catchment sources where the site is not influenced by estuarine waters. Catchment data is generally dominated by Council data which is dry weather (or ambient conditions) data.

'Penrhyn Estuary' is a summary of Council data, recent ambient conditions physico-chemical monitoring for this project (Section 5), Parallel Runway EIS data (collected in February 1990), ORICA Sites SW028, SW029, SW031, SW048 sampled between 1999 and 2001.

'Mill Stream' is a summary of Council data for a site upstream of the SWSOOS and data from 1989 reported in Unisearch (1990) and later in Kinhill (1990) for heavy metals.

'Botany Bay' is a summary of Parallel Runway EIS data (pre Parallel Runway) for the Foreshore Beach area, NSW EPA Harbourwatch data and a summary of data for the entire bay area for samples collected in 1992 (van Senden et al, 1993). Mixture of wet and dry sampling periods is unknown.

ANZECC guidelines for analytes are generally for the protection of aquatic ecosystems. Primary contact recreational guidelines are applied for bacteriological parameters such as faecal coliforms. The 95% protection level is generally used as the system is slightly to moderately disturbed. Where chemicals are known to bioaccumulate the 99% level of protection is applied, and the protection level is parenthesised next to the trigger level.

** No estuarine guidelines are provided by ANZECC, so the marine guideline has been quoted.

Table 4.13 Summary of Sediment Quality for Areas of Interest from All Available Sources

Analyte	Penrhyn Estuary	Botany Bay
Metals and Metalloids		
Arsenic (μ g/g)	Observed Range: NA Trigger Level: 20 - 70	Observed Range: 0.5 - 16.3 Trigger Level: 20 - 70
Cadmium (μ g/g)	Observed Range: NA Trigger Level: 1.5 – 10	Observed Range: < 0.2 - 1 Trigger Level: 1.5 - 10
Cobalt (μ g/g)	Observed Range: NA Trigger Level: NA	Observed Range: 0.1 - 5 Trigger Level: NA.
Copper (μ g/g)	Observed Range: NA Trigger Level: 65 - 270	Observed Range: 0.1 - 19.3 (Birch reports 50 - 100 in mud fraction) Trigger Level: 65 - 270
Chromium (μ g/g)	Observed Range: < 2 – 223 Trigger Level: 80 - 370	Observed Range: 0.8 - 27.4 Trigger Level: 80 - 370
Chromium VI (μ g/g)	Observed Range: 1.4 – 2.8 Trigger Level: NA	Observed Range: NA Trigger Level: NA
Tin (μ g/g)	Observed Range: NA Trigger Level: NA	Observed Range: 0 - 0.8 Trigger Level: NA
Lead (μ g/g)	Observed Range: NA Trigger Level: 50 – 220	Observed Range: 1.3 - 56.4 (Birch reports 100 - 200 in mud fraction) Trigger Level: 50 - 220
Mercury (μ g/g)	Observed Range: <0.05 - 36.2 Trigger Level: 0.15 - 1	Observed Range: < 0.3 Trigger Level: 0.15 - 1
Nickel (μ g/g)	Observed Range: NA Trigger Level: 21 – 52	Observed Range: NA (Birch reports 20 - 40 in mud fraction) Trigger Level: 21 - 52
Zinc (μ g/g)	Observed Range: NA Trigger Level: 200 - 410	Observed Range: 3 - 151 (Birch reports 200 - 500 in mud fraction) Trigger Level: 200 - 410
Hydrocarbons		
HCB (μ g/g)	Observed Range: < 0.06 - 4.2 Trigger Level: NA	Observed Range: < 0.004 - 0.1 Trigger Level: NA
alpha-BHC (μ g/g)	Observed Range: NA Trigger Level: NA	Observed Range: < 0.004 - 0.031 Trigger Level: NA
TPH (μ g/g)	Observed Range: NA Trigger Level: NA	Observed Range: < 22 - 1103 Trigger Level: NA
Nutrients		
Phosphorous (μ g/g)	Observed Range: NA Trigger Level: NA	Observed Range: 145 - 970 Trigger Level: NA
Total Organic Carbon (μ g/g)	Observed Range: NA Trigger Level: NA	Observed Range: 0.3 - 22.1 Trigger Level: NA
Organic Nitrogen (μ g/g)	Observed Range: NA Trigger Level: NA	Observed Range: < 0.1 - 19 Trigger Level: NA

'Penrhyn Estuary' is a summary of results from the Penrhyn Road Boat Ramp Studies (Johnstone Environmental Technology, 1993).

'Botany Bay' is a summary of Parallel Runway EIS data (pre Parallel Runway) and Birch, 1996.

Trigger levels are Interim Sediment Quality Guidelines from ANZECC (2000), hence a low – high range is given.

5. FIELD DATA COLLECTION

A field exercise was undertaken as part of the investigations to supplement the available data outlined in Section 4.

5.1 METHODOLOGY

5.1.1 Sampling Rationale

The objective for undertaking sampling during dry weather is to fill a data gap identified during the early stages of this study. Whilst sampling has been undertaken at various sites over various times, no assessment of the diurnal variability of specific analytes had been undertaken prior to this study (Section 4.2.4).

The collection of such information is invaluable and aids the description of existing conditions and contributes to the baseline data set.

The rationale for site selection was twofold:

- to determine diurnal variability of incoming flows from the catchments to the proposed port area under dry weather conditions for the purposes of modelling (See Section 7)
- to establish a baseline of dry weather diurnal variability of estuarine waters which are likely to be affected by the proposed port expansion.

As such sites were selected based on accessibility and being representative of incoming flows to receiving waters in the vicinity of the proposed port.

Table 5.1 presents the parameter selection criteria.

Table 5.1 Water Quality Parameter Selection Rationale, In-Situ Measurements

Parameter	Likely Variability and/or Definition and/or Source Details derived from ANZECC (2000)	Likely Impact	Reason for Selection for Port Botany Monitoring Exercise
pH	Likely to show some variation in upper reaches of inflows (as a result of sandy soils) trending to higher values downstream. Low readings (< 4) indicative of acid sulphate soil conditions.	Variance can result in direct toxic impacts on some biota	Existing pH could potentially change as a result of new port layout. Baseline data required. EPA Licenced Premises with pH issues.
Dissolved Oxygen	Likely to show natural variation with depth (higher at surface and lower at depth) which will vary on a daily basis due to atmospheric temperature change, insitu biological demand (bio-uptake which is highest at night), tidal movements and the introduction of biological oxygen demand as a result of wet weather flows (following rain events and sewer overflows)	Low levels will result in direct impact on some biota	Existing DO could potentially change as a result of new port layout. Baseline data required as part of BACI type approach (Before After Control Impact). This is generally the case for all. Also required to assist with establishing acceptable limits for DO/BOD modelling.
Temperature	Likely to show variation with depth likely to vary on a daily basis due to atmospheric temperature change and tidal movements	Variance can result in direct impacts on some biota	Existing temperature could potentially change as a result of new port layout. Baseline data required.
Salinity/ Conductivity	Likely to show variation with depth which will vary on a daily basis due to tidal movements and fresh water inflow	Variance can result in direct impacts on some organisms	Existing salinity regime could potentially change as a result of new port layout. Baseline data required.
Turbidity	Likely to show variation as a result of wet weather flows	High levels will result in impairment of light penetration and associated impacts on biota (e.g. seagrass)	Existing turbidity could potentially change as a result of new port layout. Baseline data required. Sources in catchment including EPA Licenced Premises and port movements
Redox	Likely to show variation with salinity and temperature	NA	Required for interpretation of other results

5.1.2 Field Exercise, June 2002

To aid the understanding of the dry weather diurnal processes within the inflow tributaries and the Bay areas around Foreshore Beach, a one-day field exercise was undertaken to assess physico-chemical parameters.

The in-situ measurements were undertaken on 6 June 2002. During the survey, weather conditions were fine, and the maximum recorded air temperature during the day was 19.4°C (Sydney Airport, Bureau of Meteorology). Daily rainfall recorded in the study area for 16 days prior to the field exercise is shown in Table 5.2.

Table 5.2 Daily Rainfall Totals Prior to 6 June 2002 (J. Evans, BoM, pers comm)

Date	Total Rainfall (mm)
03/06/2002	1.4
02/06/2002	3
31/05/2002	3.4
30/05/2002	5.4
29/05/2002	10.2
26/05/2002	9.4
25/05/2002	6.8
24/05/2002	8.4
21/05/2002	2.4

Data were collected using a Hydrolab Datasonde 4a (Hydrolab, 1997). For Occupational Health and Safety purposes, sampling was conducted only during daylight hours. As such, sampling commenced at 7:18 am and was completed at 5:04 pm. In general, the time between each sampling was of the order of 1.75 hours.

Data collection involved sampling at each of seven sites in a circuit fashion in order to assess the variation in the parameters over the day.

The seven sites were:-

1. Mill Stream at Engine Pond (just upstream of weir)
2. Mill Stream at Foreshore Road (upstream side)
3. Stormwater channel at Sir Joseph Banks Road
4. Floodvale Drain at Botany Road upstream of Golf Course
5. Springvale Drain at McPherson Street (upstream side)
6. Springvale Drain at Caltex Carpark just upstream of Penrhyn Estuary
7. Penrhyn Road Boat Ramp (Penrhyn Estuary).

The sampling site locations are presented in Figure 5.1.

5.2 RESULTS

Table 5.3 provides a summary of the results. It should be noted that these data were collated with data from literature and included in Table 4.12.

Table 5.3 Data Summary from Field Data Collection 6 June 2002

Parameter		Site						
		1	2	3	4	5	6	7
pH	Minimum	6.32	6.68	7.46	6.72	6.22	6.80	7.64
	Maximum	6.93	7.25	7.80	6.83	6.35	7.00	7.76
	No. Samples	6	6	6	6	5	6	6
	Average	6.74	6.94	7.66	6.79	6.29	6.90	7.71
Dissolved Oxygen (% Saturation)	Minimum	43.70	2.20	83.50	38.00	5.30	35.50	82.50
	Maximum	60.20	71.00	104.60	53.70	11.10	46.80	91.50
	No. Samples	6	6	6	6	5	6	6
	Average	54.42	24.03	97.03	47.62	8.04	43.23	87.87
Dissolved Oxygen (mg/L)	Minimum	4.51	0.17	8.21	3.60	0.56	3.49	6.61
	Maximum	6.14	7.18	10.23	5.27	1.12	4.68	7.23
	No. Samples	6	6	6	6	5	6	6
	Average	5.58	2.28	9.61	4.60	0.83	4.34	6.99
Temperature (°C)	Minimum	13.82	14.62	15.31	15.88	12.40	13.95	15.71
	Maximum	14.43	17.90	16.36	17.82	14.69	15.99	16.30
	No. Samples	6	6	5	6	5	6	6
	Average	14.10	16.55	15.97	16.92	13.62	14.95	15.96
Salinity (ppt)	Minimum	0.08	0.36	0.17	0.40	1.03	-0.01	34.30
	Maximum	0.08	32.76	0.18	0.41	1.33	0.95	34.86
	No. Samples	6	6	5	6	5	6	6
	Average	0.08	18.97	0.17	0.41	1.16	0.72	34.65
Conductivity (mS/cm)	Minimum	0.18	0.70	0.35	0.78	1.93	0.00	52.01
	Maximum	0.18	49.91	0.36	0.80	2.48	1.77	52.77
	No. Samples	6	6	5	6	5	6	6
	Average	0.18	29.78	0.36	0.78	2.16	1.35	52.48
Turbidity (NTU)	Minimum	6.20	0.00	0.00	0.00	28.80	32.60	1.10
	Maximum	8.70	50.50	9.00	22.00	59.60	68.30	9.70
	No. Samples	6	6	5	6	5	6	6
	Average	7.52	14.27	5.06	14.15	42.94	51.53	4.03
Redox (mV)	Minimum	319	-25	247	137	129	112	220
	Maximum	610	353	367	223	196	210	403
	No. Samples	6	6	5	6	5	6	6
	Average	407	235.33	300	171.33	156.40	155.33	339.33

The in-situ measurements indicate that there are three parameters that exceeded guideline values or, where guidelines were not available, generally accepted ranges reported for healthy aquatic ecosystems. These were: -

- Dissolved oxygen at all sites except Site 3 and Site 7 (ANZECC, 2000 generally reports an acceptable range of 80 - 100% Saturation)
- Oxidation-reduction potential (Redox) (no ANZECC guidelines are available)
- Turbidity at Sites 5 and 6 (ANZECC, 2000 generally reports a range of 0.5 - 50 NTU for estuaries and lowland river systems).

As a guide, the dissolved oxygen concentration in a waterbody is dependent on temperature, salinity, biological activity (microbial, primary production) and the rate of transfer from the atmosphere (ANZECC, 2000). Exchange from the atmosphere is the main source of oxygen into an ecosystem, with this exchange increased under turbulent conditions. Aquatic plants also produce oxygen when they photosynthesise during the day, however, they also use oxygen when they respire (breakdown carbohydrates, fats and proteins and expel CO_2) at night, so that their net effect on oxygen input to ecosystems is often quite small. Under natural conditions, DO concentrations may change considerably over a daily (or diurnal) period. In highly productive systems (e.g. estuaries and eutrophic waterbodies), severe DO depletion can occur, particularly when these systems are stratified (ANZECC, 2000). As such, the extreme ranges observed may not be a cause for concern in estuarine areas (e.g. Site 2). Further details of ANZECC (2000) guidelines for healthy ecosystems and other reported data for the area of interest can be found in Table 4.12.

The recorded redox potential ranges from strongly reducing conditions (-25 mV) to oxidising conditions (610 mV). Redox can be a sensitive parameter, as a result the deployment of the instrument was such that the level were established by allowing the instrument output to stabilise to an equilibrium before any measurements were recorded. Redox potential can be utilised to establish the likely speciation of a parameter in the absence of other data. For example, the speciation of nitrogen is controlled by pH and redox and moves from various forms such as NH_4^+, NO_3^- and NO_2^- (where NH_4^+ is the more bioavailable form and can be toxic to organisms in elevated concentrations). For example, it is likely that during the course of the day on the 6 June 2002 that at Sites 1 and 7 the speciation of Nitrogen varied from NO_3^-in the morning through to NH_4^+ in the early afternoon.

Turbidity can be highly erratic during in-situ measurement and is dependent on careful probe deployment. Levels of turbidity recorded, whilst in excess of ANZECC (2000) guidelines are not un-representative of an urban system. Further details of ANZECC (2000) guidelines for healthy ecosystems and other reported data for the area of interest can be found in Table 4.12.

6. CATCHMENT MODELLING - EXISTING CONDITIONS

The purpose of catchment modelling was to generate some of the water quality inputs to the Bay to be used by the Delft3d model for investigation of estuarine water quality within the area of interest (Sections 7 and 8). A water quality model, *model for urban stormwater improvement conceptualisation* (MUSIC) (CRC for Catchment Hydrology, 2001) was developed for this purpose.

Catchment modelling is a complex task and the development of modelling tools for the purpose has been the topic of ongoing research in Australia for a number of years. The wide variability in catchment behaviour and the high costs associated with the collection and analysis of samples has led to a focus in this assessment on key parameters - generally nutrients and suspended sediments. As such, whilst the data in Section 4 indicate that there are an extensive range of contaminants derived from the catchment, the catchment modelling has been undertaken within the limits of those parameters for which published research on their behaviour is available.

6.1 MODEL DESCRIPTION

MUSIC is a catchment modelling tool (CRC for Catchment Hydrology, 2001) and is an appropriate application for the level of calibration data that is available for the area. The model does not contain complex algorithms for runoff routing modelling, catchment contaminant build-up and wash-off processes. Nevertheless, it is the result of a comprehensive research program and is a suitable tool to generate representative flows, concentrations and loads from the various catchment areas of interest for receiving water quality assessment.

MUSIC has three types of source nodes for runoff and pollutant generation. These are urban, agricultural and forest source nodes. The only difference amongst the source nodes is the use of different default parameters. These nodes can thus be used to represent other types of landuse, including industrial areas and parklands if the appropriate parameters for such sources can be identified. In the current study, industrial land uses and grassed land uses (e.g. golf courses, racecourse and parks) have been implemented in the model framework along with urban residential areas.

MUSIC can accommodate three pollutants explicitly. They are: -

- Total suspended solids (TSS)
- Total phosphorous (TP)
- Total nitrogen (TN).

Other pollutants can also be represented in the model for simulation if appropriate parameter values for the designated pollutants can be assigned. In the case of this study, no further parameters were available to describe other pollutants. Means of generating time series of other pollutants for use in Delft3D modelling are described in the relevant portions of Chapter 7.

Runoff and pollutants generated from source nodes can be “treated” by the use of treatment nodes. The version of MUSIC used for this study has seven types of treatment nodes, including swales, buffer areas, wetlands, infiltration systems, gross pollutant traps (GPT) and ponds. Thus a source node can be linked to a series of treatment nodes to create a ‘treatment train’. The connection is made by the use of a ‘drainage link’.

MUSIC has a ‘receiving node’ that receives outflows from different branches or subcatchments. This gives users flexibility to model several catchments together.

The input data for MUSIC can be categorised into three types. They are: -

- Meteorological data (rainfall and evaporation time series)
- Topographic data (pervious and impervious ratio, deep soil and shallow soil ratio, field capacity, infiltration parameters, groundwater recharge rate, and groundwater drainage rate)
- Water quality data (mean and standard deviation of pollutant concentration in stormwater, mean and standard deviation of pollutant concentration in baseflow).

The validation data to aid comparison of the results of MUSIC include:

- Streamflow data
- Water quality data.

6.2 MODEL INPUT DATA

6.2.1 Meteorological Data

These include the intensity-frequency-duration (IFD) data from AR&R (1987), the daily and hourly rainfall from the Bureau of Meteorology's (BoM) National Climate Centre for the locations and durations listed in Table 6.1 below, and the evaporation data for Sydney Airport, also from the National Climate Centre.

Table 6.1: Rainfall Gauges in the Vicinity of the Catchment and Bay

Name	BoM Code	Remark
Sydney Airport AMO	66037	Hourly rainfall
Rockdale Bowling Club	66074	Daily rainfall
Maroubra RSL Bowling Club	66122	Daily rainfall
Marrickville	66036	Daily rainfall

The basic IFD parameters for the study area are shown in Table 6.2.

Table 6.2: IFD Parameters from AR&R (Volume 2, 1987) for Lower Region of Catchments

Storm Duration	2 year ARI Intensity (mm/hr)	50 year ARI Intensity (mm/hr)
1 hour	41.9	87
12 hour	8.27	16.8
72 hour	2.55	5.19

6.2.2 Topographic Data

These include aerial photos of eastern Sydney (LPINSW, 2000) the 1:2000 and 1:4000 orthophoto maps (LIC), the 1:25000 Topographic Map (LIC), and the Geological Series Sheet No 9130 (NSW Mineral Resources, 1983).

Topographical data also include information on existing drains, ponds and hydraulic control structures from a variety of sources:-

- Information on the volume, depth, surface area and related details of the Centennial Park ponds is available in Brown et al (1999) and is summarised in Table 6.3. The total surface area of the 10 ponds is approximately 24 ha.
- Detailed dimensions on the hydraulic control structures of Willow, Duck, Randwick and Kensington ponds are available in SMEC (1992).
- Information on the volume, depth, surface area etc of the cascade of ponds in the Botany Wetlands was not directly available. However, more than one hundred surveyed cross sections and details of the hydraulic control structures of Botany Wetlands are available in SMEC (1992). Based on the surveyed cross sections and the aerial photos, it was possible to estimate the surface area, depth and volume of the ponds in the Botany Wetlands.

Table 6.3 Centennial Park Pond Dimensions (after Brown et al, 1999)

Pond	Max Depth (m)	Mean Depth (m)	Area (m^2)	Volume (m^3)	Inflow Sources
Model Yacht	2.25	0.97	12700	12261	1 major, 2-3 minor
Fly Casting	2.45	1.03	11600	11941	from Model Yacht
Musgrave	1.00	0.25	4600	1170	1 Major
One More Shot	2.30	0.93	3800	3520	from Musgrave, 2 minor
Willow	2.92	1.40	29700	41622	from one more shot & fly casting, runoff from horse track
Duck	4.45	1.01	57400	58123	from Willow, runoff from horse track
Randwick	2.96	0.55	28700	15789	1 major, from Duck
Busbys	2.53	0.58	42300	24579	1 major, 2 minor
Lily	1.22	0.45	7000	3140	Groundwater upwelling from Lachlan swamp
Kensington	N/A	0.675	40000	27000	2 major, and a channel from Busbys & Randwick

Information on existing drains (e.g. location, type, and size, for Springvale Drain, Floodvale Drain and the Foreshore Beach drains) is available in Lawson and Treloar (2003a), Willing and Partners (1999), Sinclair Knight (1992), Sinclair Knight Merz (1996) and Water Research Laboratory (1990).

6.2.3 Water Quality Data

A full description of available water quality data is described in Sections 4 and 5. No storm event monitoring has been undertaken in the catchment to assist with determining storm event pollutant concentrations. However, dry weather monitoring of various parameters has been undertaken. This data is of assistance in the determination of baseflow or dry weather pollutant concentrations.

6.2.4 Streamflow Data

A review of available publications and discussions with City of Botany Bay Council representatives indicates that there are no stream gauges within the catchments of interest. In the absence of this information, design event information from other studies was compiled to assist with flow comparisons.

For the Mill Pond catchment, Table 6.4 shows the 10 year ARI peak flows under existing conditions estimated by MIKE-11 (a one-dimensional hydraulic model) at three locations within the Botany Wetlands.

Table 6.4: Mill Pond 10 year ARI Peak Discharges at Salient Locations (after SMEC, 1992)

Location	Q (m^3/s)	Remark
Outlet of Pond No 6	19.9	At the second bridge downstream of Gardeners Road
Outlet of Pond No 3A	24.1	At the culvert under Wentworth Avenue
Outlet of Engine Pond	26.9	At the concrete weir and SWSOOS

For Springvale Drain, Floodvale Drain and the Foreshore Beach drains, the RAFTS model established for flood modelling (Lawson and Treloar, 2003a) was run with the same rainfall inputs for an event within the period of record considered by MUSIC (Section 6.3). Details of the comparison of results are provided in Section 6.4. Full details of the setup of the RAFTS model can be found in Lawson and Treloar (2003a).

6.3 MODEL ESTABLISHMENT

Two MUSIC models were developed in this study: one for the Mill Pond catchment, and the other for the Springvale Drain, Floodvale Drain and the Foreshore Beach catchments. These two models were not combined due to the complexity in model structure and potentially lengthy execution time.

Both models use the same meteorological data from Sydney Airport (BoM, 66037). Available 1-hour pluviograph data covers the period of July 6, 1962 to March 31 2001. However, due to gaps in the data set, a suitable period of continuous data was sought within the record for modelling, to avoid having to synthesise data. As such, a relatively continuous period of record available from July 1, 1998 to January 31, 2000 was selected for use in the model. This period was also consistent with the available water quality data collected in the catchment by the City of Botany Bay Council (see Section 4) for the purposes of calibration. The concurrent daily evaporation time series was also used.

As a guide to the nature of the period selected, the total annual recorded rainfall for the 1999 calendar year was 1302 mm. In comparison with the long-term average of 1100 mm, this indicates that 1999 was a slightly wetter than average rainfall year.

6.3.1 The Mill Pond Model

The delineation of the Mill Pond catchment was carried out using the MAPINFO GIS package based upon the 2-m contour lines on the 1:2000 and 1:4000 orthophoto maps (which were scanned and ortho-rectified), in conjunction with available aerial photographs (see Section 6.2.2). Landuse types were identified from the aerial photographs, which were representative of the current land use. The main landuse types included residential areas, parks, golf courses, industrial areas, ponds, wetlands and racecourse.

Based on the landuse types, the catchment was subdivided into 46 subcatchments as shown in Figure 6.1. Details such as subcatchment areas and pervious and impervious ratios are presented in Appendix C. The size of the subcatchments ranges from 4.55 ha to 98.73 ha.

Two of the most important features of the Mill Pond MUSIC model are the presence of the Centennial Park ponds and the cascade of ponds in the Botany Wetlands. These features provide a considerable natural flow and pollutant load attenuation function. The capacities and depths of the Centennial Park ponds were adopted from Brown et al (1999) and Brown (1997). The weir and outlet dimensions of these ponds were adopted from SMEC (1992). Data for the downstream ponds were collated and interpreted based on the surveyed cross sections and hydraulic structures, also from SMEC (1992).

The 46 subcatchments were represented as 46 separate source nodes in the Mill Pond model. These source nodes were systematically linked to represent the natural stormwater flow paths and attenuation processes. Some source nodes were linked with GPTs, ponds and/or swales where such treatment devices/features are installed. Information on GPTs was derived from Willing and Partners (1999). The size of the swales was determined using topographic information.

The model layout for the Mill Pond catchment is presented in Figure 6.2.

6.3.2 Springvale, Floodvale and the Foreshore Beach Stormwater Drains

The delineation of the Springvale Drain, Floodvale Drain and the Foreshore Beach catchments was carried out in a similar manner to that for the Mill Pond catchment.

Based on the landuse types, the catchments were subdivided into 54 subcatchments as shown in Figure 6.1.

Details of subcatchment areas, pervious and impervious ratios etc, are presented in Appendix C. The size of the subcatchments ranges from 1.6 ha to 28.9 ha.

The 54 subcatchments are represented as source nodes in the MUSIC model. These source nodes were linked in a way such that the existing stormwater drainage system could be represented. The model layout for the Springvale, Floodvale and Foreshore Beach catchments is presented in Figure 6.3. The receiving node shown in Figure 6.3 is indicative of the Bay for modelling purposes only.

6.4 MODEL VALIDATION PROCESS AND RESULTS

6.4.1 Flows

In the absence of any streamflow data to check the model results against (Section 6.2.4), a check of the MUSIC model flows was made against two alternate methods. The first method used was a check against reported results from other hydrological models (e.g. RAFTS) for comparable rainfall events. The second method was a comparison with the Probabilistic Rational Method (ARR, 1999) for comparable rainfall events. Due to the nature of the Mill Pond catchment, with considerable storages of the Centennial Park ponds and the Botany wetlands, this second method does not provide a suitable comparison. Engineering judgement was also used to consider model results in comparison to observations during field inspections.

An assessment of the rainfall data used as an input to the MUSIC model and the local IFD information from AR&R (1987) indicated that the period assessed using MUSIC (01/07/1998 to 31/01/2000) included a suitable event for comparison of peak flows.

During the January 24, 1999 storm, the maximum hourly rainfall intensity (40.9 mm/h) recorded was approximately the same as the 2 year ARI design rainfall intensity (41.9 mm/h) for the area. Full details of design rainfall relationships can be found in Lawson and Treloar (2003a).

The Mill Pond model was given first consideration during the validation process due to its complexity. The first stage of the model validation process for the Mill Pond model was to compare two of the model outflow (m^3/s) characteristics: -

- The 2 year ARI peak flows at the outlet of Engine Pond (at the concrete weir and SWSOOS), at the outlet of Pond No 3A (at the culvert under Wentworth Avenue and at the outlet of Pond No 6 (at the 2nd bridge downstream of Gardeners Road). The closest available reported event was the 10 year ARI (SMEC, 1992). The flows for this event at the above locations are listed in Table 6.5 for comparison. Accordingly the comparison between events of two different magnitudes means that a check can only be done to ensure the flows for the 2 year ARI flow event are less than those reported for the 10 year ARI event.

- The typical dry weather flows (baseflow) at the outlet of Engine Pond (at the concrete weir and SWSOOS). Based on the geometry of the weir structure at this location and field inspection, the typical baseflow was estimated as 0.2 m^3/s. Under exceptionally dry conditions, the outflow was considered close to zero.

Several 'water balance' parameters in MUSIC were adjusted to match the above characteristics. It was identified that apart from impervious/pervious ratios, the infiltration capacity coefficient 'a', the daily recharge rate and the daily drainage rate were the most sensitive model parameters to the model output, while other water balance parameters were less sensitive. During the trial-and-error validation process, the initial values for the infiltration capacity coefficient 'a', the daily recharge rate and the daily drainage rate were determined based on the soil properties. Given that the soil is highly permeable (Section 2.1), and previous studies show that very limited surface runoff is likely to be generated from pervious surfaces, the infiltration capacity and the recharge rate were assigned high values. The small baseflow observed during dry weather periods indicates there is some degree of groundwater contribution to the system. Initial values of respective parameters were thus assumed and then subsequently adjusted so that the above flow characteristics were satisfied. The impervious and pervious ratios for some residential source nodes were also adjusted within expected ranges to achieve a satisfactory comparison.

The comparison of the results of the MUSIC model and the reported 10 year ARI flows is shown in Table 6.5. This table indicates that 10 year ARI flows are close to but all higher than those reported for the 24 January 1999 event. Based on this comparison the MUSIC model results for flows can be considered reliable.

The base flows at the outlet of Mill Pond Creek estimated by MUSIC are in the range of 0.04 – 0.25 m^3/s, which is consistent with the dry weather flow values of 0.0 – 0.2 m^3/s calculated from observations during field inspections.

Table 6.5 Comparison of Mill Pond Flow Model Results

Location	**MUSIC** **Peak Discharge from 24 January 1999 Event (~2 year ARI Event) (m^3/s)**	**OTHER REPORTED** **SMEC (1992) (10 year ARI Design Event) (m^3/s)**
Outlet of Pond No 6	18.8	19.9
Outlet of Pond No 3A	21.9	24.1
Catchment Outlet (Engine Pond)	24.2	26.9

Given the similarities in the catchments, the resulting relevant model parameters from the Mill Pond model (governing base flow and soil water characteristics) were then transferred to the Springvale, Floodvale and Foreshore Beach catchments. Validation proceeded by adjusting the catchment impervious and pervious ratios and the runoff routing parameters.

The flow results of the Springvale Drain, Floodvale Drain and the Foreshore Beach catchments MUSIC model were then checked against peak flows from the same event in the RAFTS model developed for the flood assessments for the study (Lawson and Treloar, 2003a) and against the probabilistic rational method. The comparisons are shown in Table 6.6.

The minimum flows for Springvale, Floodvale and Foreshore Beach drains are all zero. This is also consistent with the zero dry weather flows observed during field inspections.

Table 6.6 Comparison of Springvale, Floodvale and Foreshore Beach Drains Model Results

Location	MUSIC Peak Discharge from 24 January 1999 Event (m^3/s)	RAFTS A Peak Discharge from 24 January 1999 Event* (m^3/s)	RAFTS B Peak Discharge from 24 January 1999 Event* (m^3/s)	Rational Method Peak Discharge from 2 year ARI Event (m^3/s)
Springvale	10.1	10.3	11.0	17.0
Floodvale	7.8	8.1	8.3	7.0
Drain 1	3.5	4.4	5.0	8.3
Drain 2	5.0	5.7	6.3	8.6
Drains 3 & 4	5.9	7.6	7.9	9.1
Drain 5	5.8	7.8	8.3	8.4

*See Volume 1 (Lawson and Treloar, 2003a) for full discussion of RAFTS modelling.

Note A RAFTS A used an initial loss of 100mm and a continuing loss of 15 mm/hr for pervious areas. (Note that as a guide, initial losses of 100 mm were assumed by SMEC (1992) for RAFTS modelling of the Mill Pond catchment).

Note B RAFTS B used an initial loss of 50mm and a continuing loss of 15 mm/hr for pervious areas (a more conservative approach used for flood modelling, reported in Volume 1, Lawson and Treloar (2003a)

Table 6.6 indicates that the MUSIC peak discharges compare well with both the RAFTS-A and RAFTS-B results for the event of 24 January 1999. The RAFTS-B results, using a more conservative initial loss value adopted for design flood modelling is slightly higher due to this conservatism. The rational method generally overestimates the peak flows as would be expected, as the method does not account for the significant initial and continuing losses within a high infiltration catchment such as is found in the Botany area.

Due to their smaller size, the Foreshore Beach catchments were established in MUSIC using a slightly different approach to those established for Springvale and Floodvale Drains. This involved a single routing estimate of flow through the overall catchment rather than a series of routing points through the catchment. In comparison, the RAFTS model for all catchments and the Floodvale and Springvale Drains MUSIC models use a series of routing points and similar lag times for the arrival of hydrographs. As such, the RAFTS model produces higher estimates of the peak flows from the Foreshore Beach drains catchments. An analysis of the sensitivity of the lag times in the RAFTS model was conducted and indicates that a reduction in the adopted lag times for RAFTS in the Foreshore Beach catchments produces lower peak discharges, closer to those reported from MUSIC. Given the size of these catchments and the purpose for which the results are to be used, the comparison is considered to be reasonable.

Based on these comparisons the MUSIC model results for flows for all of the catchments can be considered reliable.

6.4.2 Quality

The second stage of the model validation was to match the available water quality data for the Mill Pond at the City of Botany Bay Council (CBB) Water Quality Monitoring Site 9 (the outlet of Engine Pond at the concrete weir and SWSOOS) (Section 4.1.1).

In the validation process, the water quality parameters (i.e. the mean concentration and standard deviation values of designated pollutants for source nodes, and relevant parameters for designated pollutants for ponds and swales and other treatment nodes), were adjusted so that the estimated output values closely matched the measured values. In order to reflect the random nature of pollution generation, the pollutant time series for source nodes were statistically generated using mean and standard deviation values for pollutant concentrations.

The estimated flow and water quality time series from MUSIC for the Mill Pond model are shown with the actual values reported at CBB Site 9 in Figure 6.4. The figure shows that the estimated TSS, TP and TN concentrations are in the range of the measured data.

As a note of caution, all of the measured concentration values shown were taken under dry weather conditions. The examination of the rainfall data shows that there was no rainfall on the days the water quality data were measured. Council officers (City of Botany Bay) also report that all Council sampling is undertaken in dry weather conditions.

The model for the Springvale, Floodvale and Foreshore Beach catchments was validated in a similar fashion. The aim was to generally match the water quality characteristics at the City of Botany Bay Council water quality monitoring site number 26 (for Springvale drain) (Section 4.1.1).

The estimated flow and water quality time series from MUSIC for the Springvale model are shown with the actual values reported at CBB Site 26 in Figure 6.5. The figure shows that the estimated TSS, TP and TN concentrations are in the range of the measured data.

As with the Mill Pond data, all of the measured concentration values shown were taken under dry weather conditions. Figure 6.5 shows a single data point for Total Phosphorous that is considerably elevated above the other values. Given the other data for Total Nitrogen and Total Suspended Solids are not elevated, it is considered that this data point is either a data error or an outlier and therefore unreliable for the purposes of comparison for this study.

6.4.3 Adopted Parameters

The final (optimal) values of MUSIC parameters to achieve the above validation for the catchments are presented in Appendix D.

6.5 DISCUSSION OF RESULTS

The stormwater quality in the Mill Pond, Springvale, Floodvale and Foreshore Beach drains was simulated using the calibrated MUSIC models, the simulation period being from 01/07/1998 to 31/01/2000 with a 1-hour time step.

A summary of MUSIC model results for the 1999 calendar year is given in Table 6.7.

Table 6.7 shows that the water quality in the Mill Pond (upstream of the SWSOOS) is, on average, markedly better than all other drains (indicated by the average concentration). This is most likely due to the treatment processes occurring in the pond areas upstream of the outlet.

Table 6.7 also indicates that the modelled average concentrations for the catchments for Total Phosphorous ranges from 0.07 - 0.14 mg/L within minimum and maximum values of 0.06 and 0.53 mg/L respectively. Compared with an ANZECC (2000) guideline of 0.05 mg/L for freshwater lowland river systems, it is apparent that the catchment water quality at the catchment outlets can be elevated above the trigger values. Peak storm event concentrations are considerably elevated above the guidelines.

Similarly, Table 6.7 indicates that the modelled average concentrations for the catchments for Total Nitrogen ranges from 0.57 - 1.84 mg/L within minimum and maximum values of 0.51 and 3.89 mg/L respectively. Compared with an ANZECC (2000) guideline of 0.5 mg/L for freshwater lowland river systems, it is also apparent that the catchment water quality can be elevated above the trigger values. Peak storm event concentrations are considerably elevated above the guidelines.

Whilst not discussed elsewhere in this report, Table 6.7 provides a summary of the estimate of the MUSIC model of the Total Gross Pollutants (TGP) derived from the catchment. These values are from default parameters in the MUSIC model and have not been checked against any data for the area. The results also have not included any possible trapping of gross pollutants on their pathway down the catchment apart from at specified GPTs. However, these values may be useful as an indicator in sizing any future gross pollutant traps at the outlets of the catchments as part of any detailed design investigations.

Table 6.7: Summary of Statistics for Modelling Results for 1999 Calendar Year

	Mill Pond	Springvale	Floodvale	Drain 1	Drain 2	Drains 3 & 4	Drain 5
Total Runoff (mm)	660	849	1030	836	974	1015	1004
Volumetric Runoff Coefficient (C)	0.51	0.65	0.79	0.64	0.75	0.78	0.77
TSS Av Conc. (mg/L)	8.15	18.3	18.7	16.7	17.2	17.3	17.4
TSS Min Conc. (mg/L)	7.1	9.4	8.8	7.4	7.3	7.6	7.9
TSS Max Conc. (mg/L)	10.1	74.4	82.0	88.1	94.6	83.9	83.4
TSS 1999 Annual Load (Tonne)	98.3	82.1	48.7	27.5	36.8	42.1	43
TP Av Conc. (mg/L)	0.07	0.14	0.14	0.13	0.13	0.13	0.13
TP Min Conc. (mg/L)	0.06	0.09	0.09	0.07	0.07	0.08	0.08
TP Max Conc. (mg/L)	0.08	0.53	0.41	0.44	0.48	0.42	0.41
TP 1999 Annual Load (Tonne)	0.84	0.48	0.26	0.15	0.19	0.22	0.22
TN Av Conc. (mg/L)	0.57	1.84	1.84	1.82	1.82	1.82	1.82
TN Min Conc. (mg/L)	0.51	1.49	1.37	1.17	1.16	1.2	1.25
TN Max Conc. (mg/L)	0.61	2.99	3.27	3.53	3.89	3.4	3.34
TN 1999 Annual Load (Tonne)	17.1	4.13	2.5	1.38	1.68	1.88	1.92
Total Gross Pollutants 1999 Annual Load (Tonne)	57.4	29	15.6	5.38	8.95	13.5	13.5

where TSS Total Suspended Solids
TP Total Phosphorous
TN Total Nitrogen

7. ESTUARY MODELLING

Following on from catchment modelling, numerical modelling of key constituents for the area of interest was undertaken under existing conditions to establish a common and consistent baseline for the purposes of comparison.

To assess the impact of the proposed port expansion, numerical modelling of key constituents under the post port expansion conditions was then undertaken.

7.1 METHODOLOGY

The transport and dispersion of nutrients, contaminants and suspended solids in the northern section of Botany Bay between the Parallel Runway and Brotherson Dock is a complex process governed by the hydraulic characteristics of the area and the discharge of contaminants from stormwater drains into the area (Figure 7.1 and Lawson and Treloar, 2003a). The highest concentrations of contaminants will generally occur at the discharge locations diminishing with distance from those sites.

Construction of the new port area will partly enclose and modify the existing Penrhyn Estuary and will include associated works to enhance the habitat of the adjacent estuary. All of these works will reduce the present levels of flushing. To investigate the impacts of this enclosure and enhancement, numerical modelling has been undertaken.

For this investigation, individual contaminants and nutrients have been investigated separately and only the processes of dispersion and decay have been included. That is, the physico-chemical interaction dynamics have not been included. This will generally be a conservative position because it over-estimates concentrations.

The principal reason for this course is the lack of long-term, detailed site specific data that could be applied to such a very complex analysis as outlined in Section 4.2.4.

7.1.1 Model Setup

These processes can best be investigated using a numerical hydrodynamic model. For this study, the three dimensional (3D) modelling system Delft3d was applied (WL|Delft Hydraulics, 2002).

The model extent is shown in Figure 7.1. The southern open boundary was driven using predicted tides applying the tide prediction procedures of Foreman (1977) and tidal constants for Sydney presented in Australian National Tide Tables (2002).

The model was set up using an irregular rectangular grid so that grid resolution in the order of 5m could be achieved in the more narrow waterways of the study area. The model was applied with five vertical layers so that some three dimensional flow structure could be incorporated. Delft3d has a vertical sigma co-ordinate system so that in this case vertical grid sizes were all 20% of the local depth. Density was incorporated into the modelling by assuming that inflow from the stormwater drains was fresh (salinity of 0ppt) and that seawater had a salinity of 35ppt. Due to their fresh nature, all stormwater flows for water quality investigations enter the model in the top layer. In these analyses it has been assumed that sea water in Botany Bay near the southern end of the Parallel Runway and near Molineux Point included low background concentrations, except for faecal coliforms and suspended sediments; and that bio-chemical processes that affect contaminant concentrations are not important for the assessment of the relative impacts of the present Bay and the proposed expansion of the container port area.

No data was available for model verification (e.g. local current data). However, apart from the geophysical layout of the existing and proposed Port areas, few changes can be made in a calibration procedure. Seabed depths for Botany Bay were obtained from AUS Charts 198 and 199, as well as from detailed surveys of the Port Botany, Caltex and Runway areas provided by SPC in 2002 for this project in digital form (December 1999 of Foreshore Beach, November 2000 of Brotherson Dock Swinging Basin, June 2001 of Brotherson Dock and July 2001 of Botany Bay Main Channel).

From experience in model applications in many estuarine and bay regions, a bed friction factor of Manning's ‘n’ of 0.032 is generally appropriate. Recent transport dispersion modelling investigations of four marinas in the Perth region of Western Australia (Treloar - MP Rogers and Associates *pers comm*), demonstrated that a horizontal dispersion coefficient of $1m^2/s$ provided reliable agreement with estimated loads and observed concentrations of dissolved inorganic nitrogen at those sites when applying a 5 layer 3D model in a tidal flow dominated environment. These parameter values were adopted for this study. Vertical dispersion was described by selecting the 'k-$\in$' turbulence model within the Delft3d modelling system (Uittenbogaard et al, 1992).

Within this study this model is described as the ‘northern regional area model’ (Figure 7.1).

7.1.2 Existing Conditions

Modelling of existing conditions was undertaken to establish a baseline for the purposes of comparison with the conditions under the proposed port layout. The existing conditions model utilised the catchment inputs from the MUSIC model as described in Section 6. Output time series for each of the seven catchments formed inputs to the 3D model (Springvale Drain, Floodvale Drain, Mill Stream and Foreshore Beach drains).

Two cases were considered:

- a 'transient' (1 in 2 year ARI storm) case based on the January 1999 rainfall event and
- an 'ambient' dry weather flow case.

'Transient' impacts are defined as those observed during short-duration, wet-weather events when stormwater runoff can have significant impacts.

'Ambient' impacts are defined as those observed during the day to day delivery of low flows from the catchment in dry weather to the estuary.

The estuarine modelling is based on the reasonable assumption that the catchment will remain in its current state, that is, freshwater flows and contaminant loads were assumed to be the same for both the existing and developed (Section 7.1.3) cases.

The MUSIC modelling did not include the effects of SWSOOS overflows explicitly (Section 2.4), but contaminant data from the lower Penrhyn Estuary catchment and the lower Mill Pond catchments implicitly included that information and was used to prepare input contaminant concentrations for estuarine modelling.

7.1.3 Developed Conditions

Appendix A describes the proposed Port Botany Development. The container port expansion design is superimposed onto a recent aerial photograph of Botany Bay.

The developed conditions were simulated utilising the same catchment inputs as those used for modelling the baseline existing conditions.

The main features of the proposed port expansion are:-

- Expansion of the container port area
- Addition of a boat ramp to the Foreshore area north of the proposed container port area
- Addition of a railway bridge between Foreshore Road and the container port area
- Dredging of the berth area and a turning basin to provide spoil for berth construction. Additionally, some removal of high spots would be required in the entrance channel and port area, see Appendix A
- Habitat enhancement works within Penrhyn Estuary (involving changes to the bathymetry of this area).

It is understood that the public would not be permitted access to Penrhyn Estuary waters following the proposed port expansion.

7.2 RESULTS

Numerical modelling of the likely impacts of the proposed port expansion was undertaken for the following processes:-

- Impacts on aquatic ecosystems including:
  - nutrient dynamics (Section 7.2.1)
  - conservative contaminants (Section 7.2.2)
  - suspended sediment movement and siltation (Section 7.2.3)
  - temperature dynamics (Section 7.2.4)

  - oxygen processes (Section 7.2.5), and
- Impacts on recreational water quality and human health via an assessment of faecal coliform dynamics (Section 7.2.6).

Representative sites within the Penrhyn Estuary region were selected to report model results and provide an indication of the variations between the existing case and the proposed port expansion case. These representative sites are shown in Figure 7.2. Results from those locations are intended to describe the outcomes generally and not only at the specified locations.

As outlined for the existing case (Section 7.1.2), in general, for each case, both the 'Transient' and 'Ambient' impacts were considered.

Transient impacts are defined as those observed during short-duration, wet-weather events when stormwater runoff can have significant impacts. The derivation of input loads and concentrations of pollutants for this condition are described under each heading below.

Ambient impacts are defined as those observed during the day to day delivery of low flows from the catchment in dry weather to the estuary. The derivation of input loads and concentrations of pollutants for this condition are also described under each heading below.

The concept of Transient and Ambient conditions for the assessment of suspended sediment transport and siltation patterns does not apply in the same direct sense and are instead reported as 'plumes' (Transient) during a storm event and an 'annual siltation rate' (Ambient).

Similarly, the concept of Transient and Ambient conditions for the assessment of temperature impacts does not apply and instead the assessment is reported as a variation in an equilibrium state in typical summer conditions. This is more pertinent to an Ambient style assessment.

Dissolved oxygen has been addressed on the basis of Ambient conditions because the estuary does not respond immediately to changes in Biological Oxygen Demand (BOD).

An interpretation of the potential changes to other parameters through an assessment of the existing data (Section 4) and modelling results is provided in Section 7.2.2.

Where reliant on catchment inputs, the modelling for the proposed port layout assumes that the catchment will be unchanged in the future. This is a conservative assumption given that the current trend in development control for stormwater is moving towards a zero net impact of catchment development on stormwater pollutant loads. There are various stormwater quality improvement devices that are also likely to be implemented in the catchment as part of the Stormwater Management Plan (Willing and Partners, 1999).

7.2.1 Nutrient Dynamics

Process Overview for Nutrients

The majority of the nutrient loads are delivered to the receiving waters via stormwater runoff (Section 6). Catchment modelling (MUSIC) is limited to reporting loads and concentrations of Total Nitrogen and Total Phosphorous rather than considering the component species of these totals. Total Nitrogen consists of the sum of oxidised nitrogen (nitrates and nitrites), ammonium and organic nitrogen. Total Phosphorous is the sum of filterable and particulate forms.

For the purposes of this study, nutrient dynamics have been assessed using an advection-dispersion modelling approach. Whilst it is recognised that this approach does not incorporate all of the complexities of nutrient dynamics within a complex estuarine system, (such as nitrogen fixing from the atmosphere, the cycles of nitrification and de-nitrification within the processes of sediment uptake and release and the loss of particulate phosphorous through deposition), it is considered to be appropriate, given the available data (Section 4.2.4) and the nature of the proposed port expansion and the comparative nature of the studies undertaken.

In support of this approach, investigations within the available literature and discussions with other professionals (pers. comm. WL|Delft Hydraulics) showed that the overall decay through net loss via uptake and release of TN and TP is slow. An exponential decay rate of 0.05 $days^{-1}$ was adopted to include that process. However, it generally has minimal impact on model results.

The results of preliminary ambient case simulations had shown that dynamic equilibrium of contaminant concentration had not been reached after eight days of simulations. Therefore those cases were re-run over periods of eighteen days. Additionally, the preliminary simulations provided some basis for assessing an initial and boundary concentration that would assist the simulations to achieve dynamic equilibrium in reasonable time. These boundary concentrations were consistent with the available water quality data for Penrhyn Estuary. The time series plots of these model simulations show that this dynamic equilibrium condition is achieved with these longer simulations.

Transient Impacts

The one year (1999) of catchment modelling results (Section 6), in terms of discharges and contaminant concentrations, were examined. A period from 23 - 27 January, 1999, identified as being a relatively wet event that provided a significant contaminant load to the estuary, was selected for analysis. Discharges were assessed to have an average recurrence interval (ARI) in the order of 2 years and were therefore typical of those events that could cause significant short-term impacts on the estuarine water quality. It was considered that rainfall events having longer ARI's would not be as representative of important water quality impact issues. That is, choosing an event at the 100 years ARI, for example, would certainly discharge more stormwater and contaminants to the estuary, but occurs so rarely that impacts would not be noticed within generational periods (ie 25 - 30 year periods).

This period was simulated using the 3D northern area model, the astronomical tide for that period and the results of the catchment modelling in terms of the discharge and concentration time series. That is, natural phasing of tides and catchment runoff was adopted and no attempt was made to create the worst possible phasing of these processes.

Results are presented in Tables 7.1 and 7.2 for TN and TP, respectively, in terms of peak event concentrations for those locations shown in Figure 7.2. Figures 7.3 and 7.4 compare pre- and post-expansion cases.

Table 7.1: Peak Event Concentrations of Total Nitrogen - Transient Case Surface Layer

Location	Concentrations of TN (mg/L)					
	A	B	C	D	E	G
Existing Port Layout	0.08	0.62	2.25	0.35	1.00	0.81
Developed Port Layout	0.02	2.32	2.40	2.05	0.50	1.24

Table 7.2: Peak Event Concentrations of Total Phosphorous - Transient Case Surface Layer

Location	Concentrations of TP (mg/L)					
	A	B	C	D	E	G
Existing Port Layout	0.01	0.09	0.33	0.04	0.12	0.10
Developed Port Layout	<0.01	0.34	0.36	0.30	0.06	0.16

Concentrations increase at Locations B, C, D and G, but decrease at Locations A and E. There would be an increase in nutrient concentrations over the existing conditions within the estuary, generally in the region described by Locations C to B and then B to D. Only a marginal increase would occur at Location C. In reality, that increase at Location C would not be identifiable.

The results also indicate that nutrient concentrations would remain at higher levels for longer periods of time. For example, Figure 7.3 shows that the present peak level of TN concentration at Locations B and D would now be maintained for about 24 hours, instead of the present duration of 2 hours.

Location A may be taken as describing changes within the Bay beyond the development area. Generally, because a greater mass of nutrients would be retained within the estuary following development (see discussion on Ambient Impacts), concentrations in the Bay beyond Penrhyn Estuary would reduce marginally.

Concentrations would reduce at Location E partially because the water depth is increased, thereby leading to greater dilution. Additionally, tidal currents at Location E in the existing conditions do not have much influence on the transport of contaminants. However, in the developed case the tidal currents become much more important as a process in the transport of contaminants.

Concentrations would increase at Location G in the developed case. This is due to the same loads from the Mill Stream and the total load from Penrhyn Estuary being directed toward this location via the proposed channel. No increases in tidal currents will occur at this location to result in additional transport of contaminants to accommodate the load increase.

It is understood that public access to Penrhyn Estuary will not be permitted following port expansion.

Ambient Impacts

Two approaches to determine the ambient impacts on nutrient concentrations were considered:

- use of a period of typical annual discharges and average nutrient concentrations (considering the total annual load producing a more conservative result)
- use of a period of typical annual discharges and average nutrient concentrations (considering the annual dry weather load only, this scenario being more characteristic of all ambient periods).

In the first instance, output time series for each of the seven catchments to northern Botany Bay (Springvale, Floodvale, Mill Stream and Foreshore Beach Drains), were analysed to develop total annual discharge, total nitrogen (TN) and total phosphorus (TP) loads for the 1999 calendar year. Total loads of TN and TP for that year are presented in Table 7.3(a). Those parameters were used to develop typical annual discharges and average concentrations of TN and TP for model input.

Table 7.3(a): Total Annual Nutrient Loads to Penrhyn Estuary

Discharge	Total Annual Loads (kg) - 1999	
	TN	TP
Springvale	4130	480
Floodvale	2500	260
Mill Stream	17100	780
Drain 1	1380	150
Drain 2	1680	190
Drains 3 & 4	1880	220
Drain 5	1920	220

The total annual load approach would have caused concentrations that were unrealistically high for non-wet weather events because it included loads from the transient events, which have already been discussed above. Therefore, the discharge time series for all catchments were examined and a consistent procedure developed for excluding these wet weather events from the ambient case. In the first instance, discharges greater than a threshold discharge of 1.5m^3/s in the Mill Stream were excluded and then the total so-called annual dry weather flow and nutrient loads for that catchment determined for 1999. The ratio of each other annual catchment flow to the annual Mill Stream flow was then used to factor the 1.5m^3/s Mill Stream flow to provide equivalent threshold discharges for the other catchments. The resulting annual dry weather loads are presented in Table 7.3(b).

Table 7.3(b): Total Annual Dry Weather Nutrient Loads to Penrhyn Estuary

Discharge	Total Annual Loads (kg) - 1999	
	TN	TP
Springvale	1500	140
Floodvale	630	60
Mill Stream	4400	550
Drain 1	510	40
Drain 2	420	40
Drains 3 & 4	420	40
Drain 5	430	40

Ambient levels of TN and TP at selected locations were then determined by modelling a period of eighteen days for both cases using the constant discharges and concentrations determined from the procedures described above. Boundary concentrations to the south in Botany Bay, selected on the basis of preliminary simulations and review of indicative recorded data, together with astronomical tides, were applied to model simulations. Boundary concentrations for TN and TP were 0.08mg/L and 0.01mg/L, respectively. Eighteen days of simulation were considered to be adequate to achieve quasi-equilibrium conditions for the present and proposed developed Port Botany configurations because dynamic equilibrium was achieved over that time.

Tables 7.4 and 7.5 show the variations in the tidally averaged annual and dry weather annual concentrations whilst Figures 7.5 and 7.6 compare pre - and post-development cases at Locations B, C, D and E for the dry weather annual load case only. Figures 7.5 and 7.6 show that the representative sites of interest have significant tidal character. Note that changes in tidal variation in concentration do not indicate changes in tidal range, but are the results of changes in tidal current character and water particle movements.

Table 7.4: Median Concentrations of Total Nitrogen - Ambient Case Surface Layer

Location	Concentrations of TN (mg/L)					
	A	B	C	D	E	G
Existing Port Layout Total Annual Load	0.06	0.07	0.13	0.05	0.08	0.10
Existing Port Layout Dry Weather Load*	0.06	0.057	0.10	0.04	0.07	0.10
Developed Port Layout Total Annual Load	0.06	0.31	0.39	0.20	0.07	0.09
Developed Port Layout Dry Weather Load*	0.06	0.15	0.17	0.12	0.06	0.09

**These cases only are shown in Figure 7.5*

Table 7.5: Median Concentrations of Total Phosphorous - Ambient Case Surface Layer

Location	Concentrations of TP (mg/L)					
	A	B	C	D	E	G
Existing Port Layout Total Annual Load	0.008	0.007	0.015	0.008	0.009	0.011
Existing Port Layout Dry Weather Load*	0.008	0.006	0.013	0.005	0.008	0.011
Developed Port Layout Total Annual Load	0.008	0.034	0.045	0.022	0.008	0.010
Developed Port Layout Dry Weather Load*	0.008	0.015	0.021	0.014	0.007	0.010

**These cases only are shown in Figure 7.6*

The results presented in Tables 7.4 and 7.5 indicate that there would be no increase in nutrient concentrations beyond the proposed port development area. Within the Penrhyn Estuary area there would be increases in concentrations, except at Location E where there is a marginal reduction because the depth in that area would become deeper. The increase in concentrations within the estuary indicate that estuarine flushing would be reduced and therefore that concentrations within the remainder of the Bay can not be increased by the proposed development because total nutrient mass is conserved.

At Location E the concentration alters in the developed case since the ebb tide structure associated with the proposed channel influences the Mill Stream ebb tide structure such that contaminants from the Mill Stream are directed away from E, more so than under the existing case.

The most representative results, which are those for the dry weather loads, do not exceed ANZECC (2000) water quality guidelines of 0.3 mg/L and 0.03 mg/L for TN and TP, respectively.

7.2.2 Conservative Contaminants

The overall "flushing" of contaminants from the Penrhyn Estuary area has been assessed on the basis of conservative catchment loads in ambient conditions. These contaminants may also enter the estuary area with the same catchment flows as the nutrients (Section 7.2.1). The flushing of conservative contaminants was assessed by determining the concentrations of a marker contaminant discharged through all drains with a concentration of 1mg/L at the average annual discharge rates. Additionally, a background concentration in the receiving waters of 0.01mg/L was adopted.

Simulation results for the conservative contaminants are presented in Table 7.6.

Table 7.6: Median Concentrations of Conservative Contaminant - Ambient Case Surface Layer

Location	Concentrations (mg/L)					
	A	B	C	D	E	G
Existing Port Layout Dry Weather Load	0.013	0.025	0.07	0.025	0.04	0.06
Developed Port Layout Dry Weather Load	0.010	0.18	0.23	0.12	0.03	0.05

These results apply generally to all conservative contaminants. When applied to a selected contaminant the result will be "conservative" if it were discharged from fewer than eight drains, for example, Floodvale Drain only. For example, some catchments may be a source of zinc, but others may have no zinc source. This approach assumes all catchments are a source of any contaminants that may be considered.

The results are applied by proportionately adjusting the Table 7.6 results in terms of the selected contaminant concentration of 1mg/L and the selected background concentration of 0.01mg/L.

For example, selecting a conservative contaminant with a concentration of $C_i$mg/L in incoming flows, together with a background concentration of $C_b$mg/L in the Bay, the concentration of that contaminant at Location B in the post port-expansion scenario would be estimated from:-

$$\text{Contaminant Concentration at Location B} = (0.18 - 0.01) \times C_i/1.00 + C_b$$

Where 0.18 is from Table 7.6
0.01 is the C_b applied in the modelling
1.00 is the C_i applied in the modelling.

7.2.3 Suspended Sediments and Siltation

Physical Processes

The dominant flows within Botany Bay are driven by the astronomical tides, with winds causing some circulation, principally in the more shallow areas and where tidal currents are low. Tides in Botany Bay are described in the Australian National Tide Tables (2002) as predominantly semi-diurnal. Typical spring tide ranges are in the order of 1.4m with neap tides in the range of 0.6m being common. However, spring tide ranges of 1.8m may occur. As a result there is a significant range in tidal current speeds.

Catchment runoff and the associated fine silt load from the Springvale, Floodvale and Mill Stream stormwater drains and the local hinterland was investigated for this study (see Section 6). In an average year (taken to be 1999) the estimated sediment loads delivered to the Port Botany area from these sources are presented in Table 7.7.

Table 7.7: Annual Silt Loads for Northern Botany Bay

Catchment	Sediment Load (kg)
Springvale	82100
Floodvale	48700
Mill Stream	91400
Drain 1	27500
Drain 2	36800
Drains 3 & 4	42100
Drain 5	43000
TOTAL	371600

Thus, on average, the total annual fine sediment load delivered to the Bay from these sources is in the order of 370,000kg. As outlined in Section 6, this is likely to be a conservative estimate as the MUSIC modelling assumes an unlimited supply of material available to be washed from the catchment. However, the estimate provides a basis for comparing the present and post-development port layouts on a rational basis. Considering the loads delivered directly to Penrhyn Estuary from Springvale and Floodvale Drains (a total of 130,800 kg) and adopting a settled density of 320kg/m^3 of solids with a 30% voids ratio leads to an average total deposited volume of 585m^3 per year. Even if all of this sediment were to settle within the inner Penrhyn Estuary area (between the present boat ramp and Foreshore Road, an area of approximately 44,000 m^2), it represents a deposition depth of about 1.3cm/year. Since the present estuary has been there since about 1980, and there is clearly much less deposition than this rate would suggest (ie less than 30 cm of deposition), then either the estimated annual load is very conservative, or fine sediments are dispersed over a much greater area. This low silt deposition environment is typical of large bay estuaries in NSW. A similar environment and sandy catchment exists in the more pristine area of north-east Jervis Bay at Carama Inlet where little or no silt deposition occurs.

The catchment can be described as a sandy area, but the sediments delivered to the Bay in suspension from these sources will be fine sediments. The movement and resuspension of sediment particles commences when the fluid force on a particle is just larger than the resisting force related to the submerged particle weight and friction coefficient. In the case of this site and the fine silts that settle in Penrhyn Estuary, cohesive forces are also important. Thus, settled silt particles remain in a stable state on the seabed until they are disturbed by forces which exceed those needed to initiate sediment motion. These forces are mainly caused by tidal and wind driven currents in Botany Bay, as well as by wave action. There is little wave action in Penrhyn Estuary and so sediment movement is dominated by tidal currents. However, discharge from the creeks and drains increases current speeds locally thereby causing settlement some distance from the drain outlets. At low tide local wind waves would be able to cause re-suspension near the still water line.

A site inspection of the estuary conducted at low tide showed that there is a general thin 'dusting' of blackish silt on the lower seabed in this region, see Figure 3.4. Silt thickness up to 5cm in small indentations on the sandy seabed was observed, being thicker and more extensive at locations closer to the Springvale and Floodvale Drain outlets. Some minor siltation could be observed seaward of the neck or shallow area immediately north of the recently constructed Penrhyn Road boat ramp. However, wave-related re-suspension of deposited fine particles would be greatest there and there would be little likelihood of silt remaining on the shoreline.

Once suspended, the particles may be transported within the estuary, ultimately settling in a more tranquil environment, in typically deeper areas. Therefore, apart from protected areas near drain outlets, long-term retention of silts in shallow, exposed shoreline areas is unlikely.

The main parameters in the settlement and re-suspension processes are: -

w_s	setting velocity (m/s)
τ_{cd}	critical shear stress for deposition (N/m^2)
τ_{ce}	critical shear stress for erosion (N/m^2)
E	an erosion coefficient ($g/m^2/s$)

Shear stresses are related to the water particle velocities. Muddy sediments that settle on the seabed gain strength quickly due to consolidation and bio-chemical reactions in the bed. Therefore the shear stress (or velocity) needed to keep the cohesive sediments in suspension τ_{cd} is always smaller than the shear stress needed to erode the sediments from the bed, τ_{ce}. The parameter E is part of site specific calibration, when re-suspension is to be considered, and data is available. Thus the following regimes may occur:-

$\tau_{cd} < \tau < \tau_{ce}$	no deposition and no erosion, only pure horizontal transport
$\tau \leq \tau_{cd}$	only deposition and horizontal transport
$\tau > \tau_{ce}$	only erosion and horizontal transport

In reality, cohesive sediment transport is controlled by chemical and biological laws in addition to these physical processes. The transport is also dependent on the type of sediment and therefore analytical expressions that describe these processes are semi-empirical. Therefore much of this information has been obtained from laboratory and field experiments. Another important issue in controlling processes is salinity. Fine clay particles have electrostatic properties and flocculate in saline water. The extent of flocculation depends upon the salinity and concentration of suspended particles. Where this is greater than about 0.3g/L, flocculation becomes important.

In a natural environment these processes develop a state of quasi-equilibrium. Full equilibrium can not be achieved because the met-ocean environment is changing constantly. However, where the form of the waterway is altered substantially by human activity, this quasi-equilibrium is disturbed. In areas where the degree of tranquillity is changed, as would be the case with the proposed port development, the pattern of siltation may change.

The trend is then for the geomorphological processes to try and restore the seabed to a form consistent with the physiography of the new form of the estuary and the physical environment (oceanographic and meteorological processes). Thus the siltation pattern in the Penrhyn Estuary area may change upon construction of the new container port area and it is the purpose of this study to quantify that change. The rate of siltation will depend on the transport/suspension capacities of the stormwater drains into the port area. Transport capacity with Penrhyn Estuary depends on depth and current speeds. Progressive consolidation also occurs following settlement, the rate of consolidation being rapid immediately following settlement, and becoming progressively slower.

Storm Event Plumes (Transient Impacts)

During storm events sediment plumes will develop within the northern Botany Bay region. This section describes the typical characteristics of plumes of suspended sediments that develop presently and that would develop following proposed port expansion.

The numerical modelling system of the northern bay area (Section 7.1.1), was applied to the investigation of suspended sediment plume processes in the Penrhyn Estuary area. The model was operated in 3D mode and assumed flows from the drains were 'freshwater', that is, buoyant at the entry points to the estuary. The storm period from 23 to 27 January, 1999 was adopted, with output from the MUSIC catchment modelling applied. This is also the storm that was adopted for the investigation of nutrient dynamics.

The Delft3d 'Online Sediment Module' used in this analysis applies a full 3D description of sediment transport and suspended sediment plume processes at each time step. Fall velocity variations between freshwater and saltwater are included, as well as shear stresses for initiation of erosion and siltation and the effects of density on fall velocity. The model has been applied with success recently at Cairns where some model verification data was available. A zero concentration of suspended sediments was adopted at the southern model boundary.

Figures 7.7 and 7.8 compare suspended sediment surface-plumes in the study area for this storm event for pre- and post-development of the proposed container port expansion works. These results show peak concentrations in the order of 50mg/L within Penrhyn Estuary, rapidly reducing to the zero boundary concentration adopted for modelling. Following construction, the plume would be confined to the north-west Penrhyn Estuary waterway, where higher concentrations would occur. However, those higher concentrations would not persist for longer than about 4 hours, typically.

Annual Siltation Rate (Ambient Impacts)

In this case the same model system was applied, but the average annual discharge and discharge-weighted average suspended sediment concentration for each catchment was applied. This procedure conservatively included both wet and dry period annual loads. A spring-neap period of tides was applied (seven days, with one day to establish dynamic equilibrium). The model utilises a morphological 'bed factor' which can be set to different values to simulate different periods of analyses. For this assessment the bed factor was set to 52 to simulate the equivalent of one year of siltation. The modelling also included a southerly wind of 5m/s and waves of H_S = 0.1m (local sea). These are typical ambient wind and local sea conditions in ern Botany Bay.

The outcomes of this modelling are presented in Figures 7.9 and 7.10. In this case, one can see that the maximum siltation depths (initial, and re-suspension included) are in the order of 2.6cm/annum within a very localised portion of the inner Penrhyn Estuary for both cases. As expected, no siltation occurs at the shorelines, the fine silt discharged from the Foreshore Beach shoreline drains being dispersed to more tranquil areas so that siltation depths at the drains that discharge to the shoreline are too small to evaluate.

Nevertheless, it is true to say that the proposed port development is likely to increase sediment deposition in the Penrhyn Estuary area as a result of reduced flushing. However, the rate of deposition will be low. It depends upon sources within the catchment and would be reduced by the installation of a sediment trap upstream of the estuary.

Current Speeds in Penrhyn Estuary and Potential Resuspension of Silts

In the post port expansion layout, increased current speeds in Penrhyn Estuary may cause an increase in the frequency of the suspension of fine silts deposited on the seabed. Model results have been examined for spring tides combined with 1 year and 5 years ARI flows for the stormwater inflow points to provide the following information in Table 7.8. The current speeds in Table 7.8 represent current conditions in the vicinity of each of these locations.

Table 7.8: Peak Current Speeds (m/s) in Penrhyn Estuary

1 Year ARI	**Location***			
	B	**C**	**D**	**E**
Existing	0.06	0.13	0.05	0.08
Developed Layout	0.04	0.11	0.10	0.09
5 Years ARI				
Existing	0.08	0.30	0.06	0.11
Developed Layout	0.07	0.26	0.12	0.14

**Note:- Locations are described in Figure 7.2*

Fine sediments may typically be resuspended when the shear stress caused by the currents and waves exceeds about 0.5N/m^2. Note that fine sediment resuspension depends on consolidation and the presence of fine sediment. At present, Penrhyn Estuary may be affected by local sea which is typically in the order of 0.05m (median H_S), see Volume 3 of the L&T report series (Lawson and Treloar, 2003b). The estuary will become protected from local sea following the proposed port development.

In a typical water depth of 1m within the shallow regions of the estuary, a bed shear stress of 0.5N/m^2 requires a current speed of 0.25m/s to exceed this threshold. Thus, only for freshwater flow events of lower frequency than the 5 year ARI event would sediments be resuspended from near Location C in the existing condition and transported further afield. The current speed near Location C will change little following the proposed port development (a reduction has occurred because the seabed would be re-shaped).

The investigations and site inspections have shown that most of the fine sediments from the catchment settle upstream of Location C (where current speeds are lower than at Location C). Hence only fine sediments that deposit near Location C would be resuspended from time to time and transported further seaward.

In the present condition the local sea environment keeps these sediments in suspension and they are dispersed. No deposits can be seen along the northern foreshore.

Following proposed port expansion, the lower energy local sea wave climate will not cause this re-suspension process and fine silts will have a longterm tendency to accumulate within the estuary.

However, the investigations and site inspections have shown that the accumulated volume has been small over the past 20 years because the catchments are sandy and well developed and there will be limited silt transported to the estuary.

Thus although there will be increased propensity for silt build-up in the so-called outer Penrhyn Estuary (seaward of the neck constriction near the existing boat ramp), the total volumes are small. Monitoring of any fine sediment deposition should be undertaken following the proposed port expansion. This could be undertaken at low water every five years (either by inspection or by detailed hydrographic survey).

Flow Channel in Proposed Enhanced Penrhyn Estuary

Appendix A shows the proposed initial channel structure to be formed through the inter-tidal flats and seagrass areas as part of the proposed Penrhyn Estuary Habitat Enhancement. During fresh-water floods it is likely that the flows paths will vary from established tidal flow paths. Should significant flow occur outside of this channel, it is possible that the inter-tidal flat and seagrass areas would be disturbed. However, without constructing the sides of this channel above the seabed, it would not be possible to constrain the flow to this channel at times of high tide. Therefore there would be flow-path wandering from time to time. Nevertheless, there would be lengthy periods of lower flows allowing recovery of those areas.

7.2.4 Temperature Dynamics

The partial enclosure of Penrhyn Estuary as a result of the proposed port expansion will reduce water circulation and mixing of Penrhyn Estuary water with the larger body of water in Botany Bay. However, solar radiation will deliver the same heat load to the surface water of Penrhyn Estuary. This process may lead to some increase in average water temperatures within the Penrhyn Estuary water area.

As a guide, seawater temperatures in the Sydney region may reach temperatures in the order of 22-24°C during the summer months (Australian Oceanographic Data Centre, 2003).

In order to investigate possible changes in this equilibrium, the northern bay area model was applied with tidal boundaries and a constant solar heat load. In this analysis typical summer conditions were considered with a summer water temperature of 24°C. Some solar radiation information was obtained from the Bureau of Meteorology. However, that data is prepared from satellite information rather than site specific observations and only provides an indication of the solar heat input. The approach adopted was to vary the heat load within a physically realistic range until a new equilibrium temperature state developed in the existing case model. The range adopted was estimated from 300Watts/m^2 to 125Watts/m^2. This outcome is similar to that determined by University of NSW observations at Berowra Creek (Taylor, 2002). In that condition, the temperature is not constant throughout the modelled area because some areas are much shallower and somewhat warmer than others.

The same tides and solar radiation inputs were applied to the case of the proposed port expansion layout. The relative changes between the two cases were then assessed. The results are presented in Table 7.9 in terms of estimated temperature changes at selected locations.

Table 7.9: Post-Port Expansion Temperature Changes

Location*	Temperature Change (°C)
A	-0.02
B	0.29
C	0.29
D	0.13
E	-0.09
G	-0.12

**Note:- Locations are described in Figure 7.2*

These results show that only small changes would occur within the Penrhyn Estuary area as a result of the proposed port layout. Temperatures would reduce at three locations, mainly because water depths there would be slightly deeper at these locations in the proposed port expansion or there would be less mixing with Penrhyn Estuary water. There would be likely increases in depth averaged temperatures in the order of 0.3°C within the inner Penrhyn Estuary, mainly because the average water depths at this location would reduce due to the proposed creation of intertidal flats as part of the habitat enhancement for the estuary.

7.2.5 Oxygen Processes

The concentration of dissolved oxygen in the waters of Penrhyn Estuary provides an important measure of the health of the aquatic ecosystem, and to some extent beyond into Botany Bay.

A number of processes affect oxygen concentration. They include:-

Reaction depends upon the dissolved oxygen concentration, wind speed, the speed of the flow, salinity and water temperature.

Nitrification is the process by which ammonia (NH_3) is converted to nitrate (NO_3^-).

Photosynthesis is the process by which oxygen is created by aquatic plants when exposed to sunlight.

Respiration in this instance, is the process by which aquatic plants consume oxygen at night.

Degradation of organic matter, biological oxygen demand (BOD), may be a principal process by which oxygen is consumed in a waterway area when catchment loads include significant carbonaceous material.

Ammonia is sourced generally from human waste entering the waterway. Although faecal coliform concentrations may be high at times in the catchments that flow to Penrhyn Estuary, they will be caused by other contamination processes - assuming that the SWSOOS is functioning correctly (Section 2.4).

The main process that influences the oxygen concentration negatively is the decomposition (mineralisation) of organic carbon in waste, carbon detritus and carbon in bed sediments. This process consumes oxygen at a molar ratio of 1:1. With the production of algae (phytoplankton), oxygen concentration is influenced positively, since CO_2, nutrients and light are used to form organic carbon. The net growth of algae produces oxygen at a molar rate of 1:1.

Since oxygen is present as a gas, transport across the air-water interface will occur. The flux is proportional to the difference between the actual dissolved oxygen concentration and the saturated concentration in water. The saturated oxygen concentration is based on water temperature and salinity. The re-aeration flux is temperature dependent. The re-aeration rate can be a function of several other factors, including depth, velocity and wind conditions.

This study addressed the basic BOD-DO processes and the interaction with the reduced flushing potential associated with the proposed container port expansion.

The northern bay model was used to investigate the DO concentrations in the Penrhyn Estuary area for existing conditions and for those that would arise following proposed port expansion.

For this study it was considered that the BOD-DO oxygen processes were important to the estuarine ecology and the WAQ module of the Delft3d northern Botany Bay regional model was applied to an investigation of those processes.

This module solves the advection-dispersion-reaction equations for a predefined computational area and for a wide range of model substances. Data on the underlying flow field was provided by a previous run of the Delft3d hydrodynamic module; using the tidal boundary and stormwater inflows. These processes can include the whole range of oxygen processes, conservative substances for example, decay, suspended sediment, temperature, nutrients, algal growth and mortality, heavy metals and volatilisation of organic micro-pollutants.

BOD loads and DO concentrations on an hourly basis were estimated through a review of the dissolved oxygen data collected (Section 5), BOD data for the catchment collected by the Council of the City of Botany Bay (Section 4) and calculated stormwater discharges from the MUSIC model (Section 6).

DO levels in Springvale Drain were based on observed data from the McPherson Street Monitoring Site and are very low (Section 5). One other site was available further downstream, but that second site was located in a tidal region where DO will have been affected by waters from Botany Bay. Hence the McPherson Street site was adopted.

The flow outputs under ambient conditions from the MUSIC model were analysed to provide discharge-weighted average BOD and DO concentrations for each catchment to form inputs to the 3D model. These results are shown in Table 7.10.

Table 7.10: Estimated Weighted Average BOD and DO Input Loads

Catchment	Concentration (mg/L)	
	BOD	DO
Springvale	6.2	0.5
Floodvale	5.4	3.9
Mill Pond	8.9	5.1
Drain 1	3.1	8.5
Drain 2	4.0	8.4
Drains 3 & 4	4.5	8.4
Drain 5	4.4	8.4

DO concentrations will be lower in the cooler weather and an ambient temperature of 18°C was adopted so that a period of lower DO levels could be assessed with regard to identifying worst case scenarios for the purposes of environmental impact assessment. A low wind speed of 3m/s (median at Sydney Airport is 5m/s) was adopted for re-aeration. A period of seven days from 23/01/1999 was adopted to provide quasi-equilibrium over a spring-neap period. Any rainfall recorded over this period was ignored to consider ambient conditions only. An equilibrium Botany Bay

DO concentration of 7mg/L was adopted as the boundary concentration following trial simulations.

Time series plots of DO for the existing case and for the proposed port layout at Locations B, C, D and E (see Figure 7.2) are presented in Figure 7.11. The results show the following characteristics: -

- There are only small reductions in the average DO concentration (0.5 mg/L) following the proposed port expansion. In no circumstances does the DO level approach 4mg/L (Camp Dresser McKee, 1988), the level below which marine organisms are likely to become seriously affected (though not fatally).

- There is a smaller range of DO concentrations within Penrhyn Estuary following the proposed port expansion. That outcome is caused by the tidal current structure change, with the lower concentration Botany Bay DO being transported into Penrhyn Estuary on the flood tide, and where inflows from the drains have slightly lower DO concentrations than bay water.

Thus, the proposed port expansion will have no negative impact on DO concentrations within Penrhyn Estuary or Botany Bay.

7.2.6 Faecal Contamination

Faecal coliform bacteria (Fc) are commonly used as an indicator organism for the assessment of water quality in terms of quantifying appropriate microbiological water quality conditions (for both recreational primary and secondary contact values).

Fc from the catchments of the drains that discharge to Penrhyn Estuary will generally be derived from waste materials found on the land within the catchments and from occasional dry and wet weather sewage overflows. For this investigation it has been assumed that the SWSOOS is functioning in a similar manner to it's current performance (Section 2.4).

The Council of the City of Botany Bay has monitored faecal coliforms at a number of sites within the catchments of the Floodvale and Springvale Drains and for the Northern Foreshore Drains (see Section 4). Those data have been analysed to describe typical faecal coliform concentrations in these stormwater drains for Ambient and Transient discharge cases. The outcomes are presented in Table 7.11.

Table 7.11: Faecal Coliform Concentrations (cfu/100mL)
(Based on Analyses of City of Botany Bay Data)

Drain	Ambient	Transient
Springvale	400	4×10^6
Floodvale	400	4×10^6
Mill Stream	200	2×10^6
Drain 1	20	2×10^5
Drain 2	20	2×10^5
Drains 3 & 4	20	2×10^5
Drain 5	20	2×10^5

Transient Case

During periods of high runoff, especially after extended dry periods, faecal coliform concentrations in the stormwater runoff will be significantly higher, for short periods of time. Following the proposed port expansion, the reduced flushing capacity of the estuary, coupled with the change in the structure of tidal current circulations, may affect peak Fc concentrations and distributions. This situation was investigated using the high rainfall period from 23 January, 1999; the same period that was adopted for other Transient case investigations. Coliform die-off was included in the simulation using a T_{90} of 9 hours and the initial concentration in the Bay was considered to be zero. The storm event was only of about 3 hours duration, with a total simulation period occurring over 18 hours.

Time series plots of Fc concentration for both existing and developed conditions in the surface layer at Locations B, C, D and E (see Figure 7.2) are presented in Figure 7.12. The time of peak discharge and peak concentration was at time 0200 on 23 January, 1999, rising rapidly from the continuous, low flow concentrations to peak concentration (Table 7.13). This was a time near high water ebb, which causes an initial rise in Fc concentration. The event peak did not occur until about a day later for the existing layout, but generally occurred sooner for the proposed layout.

Peak concentrations for the selected sites are presented for selected sites (Figure 7.2) in Table 7.12. At Location C there is a slightly lower peak at the time of peak stormwater inflow.

Table 7.12: Peak Faecal Coliform Concentrations - Transient Case (cfu/100mL)

	Location*					
	A	**B**	**C**	**D**	**E**	**G**
Existing	160	1250	5700	360	520	1100
Developed Port Layout	20	8000	10700	4600	1000	900

**Note:- Locations are described in Figure 7.2*

These results show that within Penrhyn Estuary itself, Locations B, C and D, there is an increase in peak concentration. The highest concentrations occur at Location C closest to Springvale and Floodvale drains. This outcome arises because the peak concentration at Location C is a function of initial dilution rather than of transport and dispersion. There is some change in volume for initial dilution of flows from the Springvale and Floodvale drains in the proposed port layout case as a result of the development of new inter-tidal flats.

Although there is a significant increase in faecal coliforms at Location D, it is understood that public access for primary recreational contact will be prohibited.

It is notable that peak concentrations would be reduced at Location G. This outcome arises because the freshwater flows from the Springvale and Floodvale Drains would now leave the estuary area past Location E and slightly displace the Millstream flow westward. Concentrations of Fc from the Springvale and Floodvale Drains would be reduced by die-off. This outcome is important because this area may be the possible site for future boat-ramp and beach facilities. Based on this analysis, Fc concentrations at this site will only exceed 600 cfu/100mL in a storm event. This is the 80 percentile limit specified in ANZECC (2000).

Note that where this concentration will be exceeded, these events will be of short duration. Note that under the current conditions the EPA Harbourwatch data indicates that the ANZECC (2000) guidelines for faecal bacteria are at present, exceeded for approximately 20% of the time (Section 4.1.1). At some locations within the proposed port expansion area this period of exceedence will reduce and in other areas this will increase.

Note also that the relative increases in Fc concentrations following proposed port development would be smaller than those expected for TN and TP because of Fc die-off.

Ambient Case

For this investigation the average catchment flows determined from analyses of catchment discharges were used as input to the northern bay model. Simulations were undertaken over a period of 18 days to allow for the development of quasi-equilibrium concentrations in the Penrhyn Estuary region and to include neap-spring tide effects. These simulations also included faecal coliform die-off in terms of T_{90} = 1 day. This is a conservatively long die-off rate, greater than that used for the transient case to simulate a worst-case scenario. Model output at the selected locations (A to G, see Figure 7.2) is presented in Table 7.13.

Table 7.13: Median Faecal Coliforms - Ambient Case (cfu/100mL)

	Location*					
	A	B	C	D	E	G
Existing	1	5	20	4	12	20
Developed	0	65	90	37	8	15

**Note:- Locations are described in Figure 7.2*

Figure 7.13 describes the order of day-to-day changes in faecal coliform concentrations that are likely to occur within the estuary.

In all cases the median Fc concentrations are less than 150 cfu/100mL as specified as the primary contact trigger level in Section 5.2.3.1 of ANZECC (2000) Water Quality Guidelines. Furthermore maxima do not exceed 100 cfu/100mL, which is less than the 80 percentile limit of 600 cfu/100mL specified in ANZECC (2000).

Although Figure 7.13 shows that a quasi-equilibrium state had not fully been reached, in reality discharge conditions are likely to change over periods of 6 to 7 days and no equilibrium is ever actually reached. It is also likely that a wet weather event would occur in this time frame and thus transient conditions would be dominant.

8. IMPACTS AND MANAGEMENT OF PROPOSED PORT DEVELOPMENT

8.1 EXISTING CONDITIONS OVERVIEW

Both data (Sections 4 and 5) and modelling (Sections 6 and 7) show that under the existing conditions, freshwater inputs to the study area have high nutrient levels, elevated BOD and low Dissolved Oxygen levels. In addition Total Petroleum Hydrocarbons (TPH) levels can be very high and metals levels may also greatly exceed guideline levels (particularly Mercury).

In Penrhyn Estuary, and to a greater extent Botany Bay, contaminant inputs from the Floodvale and Springvale Drains catchments and the Mill Stream quickly become mixed with estuarine waters and nutrient levels reduce towards more acceptable levels. Dissolved Oxygen levels also tend to be acceptable and within ANZECC (2000) guidelines for estuarine systems.

Whilst Total Petroleum Hydrocarbon (TPH) levels are reduced once delivered to the bay and estuary, they can still exceed guidelines trigger levels under existing conditions. However, it is likely that volatile aromatic hydrocarbons may not be as great an issue as would be expected for receiving waters, such as Penrhyn Estuary. This is since the high volatility and relatively low water solubility of these chemicals are such that they would be rapidly lost to the atmosphere from a water body (ANZECC, 2000). Additionally, these chemicals are not likely to adsorb to sediments. However, chemicals such as Tetrachloroethene and Trichloroethene (which have been recorded in Penrhyn Estuary) sink in water because of their poor water solubility and high density. Thus, these chemicals may accumulate in groundwater and surface water.

In contrast to hydrocarbons, metal levels in Penrhyn Estuary and the Bay remain at high levels suggesting they are accumulating in the receiving waters under existing conditions. Whilst the available data are limited, measured levels can greatly exceed guideline trigger levels for a variety of metals including Aluminium, Arsenic, Cadmium, Copper, Chromium, Lead, Manganese, Mercury and Zinc.

It is important to note that the proposed port development will not alter or impact upon the source or load of pollutants derived from the catchments.

8.2 POST DEVELOPMENT IMPACTS

Based on an understanding of the manner in which the hydrodynamics and water quality will alter as a result of the proposed port configuration, gained through numerical modelling (Section 7), the following key impacts have been identified:

- Nutrients
  - Transient conditions would see an increase in the level of the peak concentration observed. The increased concentrations within the estuary would generally be in the region described by Locations C to B and then B to D. Only a marginal increase would occur at Location C. The duration for which an elevated level occurs would be extended for example, the present

peak level of TN concentration at Locations B and D would now be maintained for about 24 hours, instead of the present duration of 2 hours
  - Ambient conditions would see an increase in the level of the average concentration, but not above ANZECC (2000) guidelines
- Conservative contaminants
  - Ambient conditions - based on the observed concentrations in the catchment (under its existing conditions) ANZECC (2000) guidelines are already exceeded in the estuary for concentrations of metals in the dissolved phase. Under the proposed port scenario there will continue to be exceedence of some ANZECC (2000) guidelines.
  - Suspended sediment and deposition
  - Ambient conditions - siltation depths under the proposed port scenario will be similar to the existing case, in the order of a maximum localised rate of 2.6 cm/annum within the inner Penrhyn Estuary. Under the proposed port scenario, no siltation will occur at the shorelines, the fine silt discharged from the Foreshore Beach shoreline drains being dispersed to more tranquil areas so that siltation depths at the shoreline are too small to evaluate. However, as a result of reduced flushing of the estuary there will some increase in siltation.
  - Transient conditions - Under the existing conditions suspended sediment plumes are dispersed from Penrhyn Estuary. Under the proposed port scenario, suspended sediment plumes would be confined to the 130 m wide channel, where higher concentrations than those observed in the existing case would occur. However, those higher concentrations would typically not persist for longer than about 4 hours.
  - Ambient Temperature changes - only small changes would occur within the proposed port layout. Ambient temperatures (based on depth averaging) would reduce at three locations in the outer estuary mainly because water depths there would be slightly deeper. However, there would be likely increases in depth averaged temperatures in the order of 0.3^{o}C within the inner Penrhyn Estuary under summer conditions due to habitat enhancement works. This increase is considered to be negligible.
- Ambient Dissolved Oxygen changes - small reductions in the average DO concentration will occur following the proposed port expansion but in no circumstances does the DO level approach 6.5mg/L (noting that 4 mg/L is an indicative trigger level for some organisms).
- Faecal coliform concentrations
  - Transient conditions within Penrhyn Estuary are such that there is an increase in peak concentration (and an extension of the duration of the increased Fc levels) with the highest concentrations occurring at closest to Springvale and Floodvale drains. Peak concentrations would be reduced at the possible site for a future boat-ramp and beach facilities (as shown in Appendix A)
  - Ambient conditions - median Faecal coliform concentrations will be less than 150 cfu/100mL (ANZECC, 2000 primary recreational contact trigger level). Maxima do not exceed 100 cfu/100mL, which is less than the 80th percentile limit of 600 cfu/100mL specified in ANZECC (2000) (also for primary recreational contact).

8.3 MANAGEMENT OPTIONS

In general the impact of the proposed port expansion has been demonstrated by both ambient and transient conditions modelling. The ambient conditions modelling indicates that the ANZECC (2000) guidelines for contaminants examined will not be exceeded. However, the transient conditions modelling indicates that some changes in the levels of contaminants over the existing case may be observed for short periods of time. These conditions are not comparable with ANZECC (2000) guidelines (Section 4.3).

A means of reducing contaminant loads delivered from both ambient and transient inflows from the catchments of Floodvale and Springvale Drains to Penrhyn Estuary would be through the installation of a single or series of stormwater quality improvement devices (SQIDs).

Two separate devices could be installed immediately downstream of the inflow points of Floodvale and Springvale Drains. The primary mechanism of reducing the load from the catchment delivered to the estuary would be through the capture of coarse and suspended sediments. Other natural and anthropogenic materials (gross pollutants, litter and the like) could also be captured within such a structure. These types of structures are generally designed for the 1 in 3 month flow event and would need to be maintained on a regular basis to ensure their effectiveness. Appropriate sizing and design could be undertaken based on the results of the MUSIC modelling (Section 6).

As a guide, these types of devices have the potential to reduce pollutant loads delivered to the estuary by up to 40%. It should be noted that the management of the catchment is the responsibility of groups other than Sydney Ports Corporation (SPC) and thus SPC are not able to control those loads being delivered to the receiving waters from the catchment.

With regard to the approach adopted for the assessments, it is important to recognise the comparative nature of the study. Thus, the effect of considering a wet weather event of the order of a 2 year average recurrence interval (ARI) rainfall event may not represent the worst case scenario in terms of water quality impacts associated with pollutant loads. The 2 year ARI event is likely to be representative of a range of events with regard to concentrations of pollutants due to the nature of 'build up' and 'wash off' processes that occur on the surface of the catchment. As outlined in Section 4.2.4, there have been no measurements of water quality during such events or events greater than these recurrence intervals and as such the approach is a reasonable assessment of less frequent events that will have an impact within the proposed port area.

As a result, it may be prudent for consideration of wet weather event monitoring to resolve this data gap in the future. Wet weather monitoring has a number of logistical issues and there is no guarantee that the design of the sampling methodology will be sufficient to cover all possible occurrences, particularly due to the inherent difficulties in forecasting such an event in advance. As a consequence, it may be appropriate to consider the installation of in-situ water quality samplers and probes before, during and after the construction to monitor water quality.

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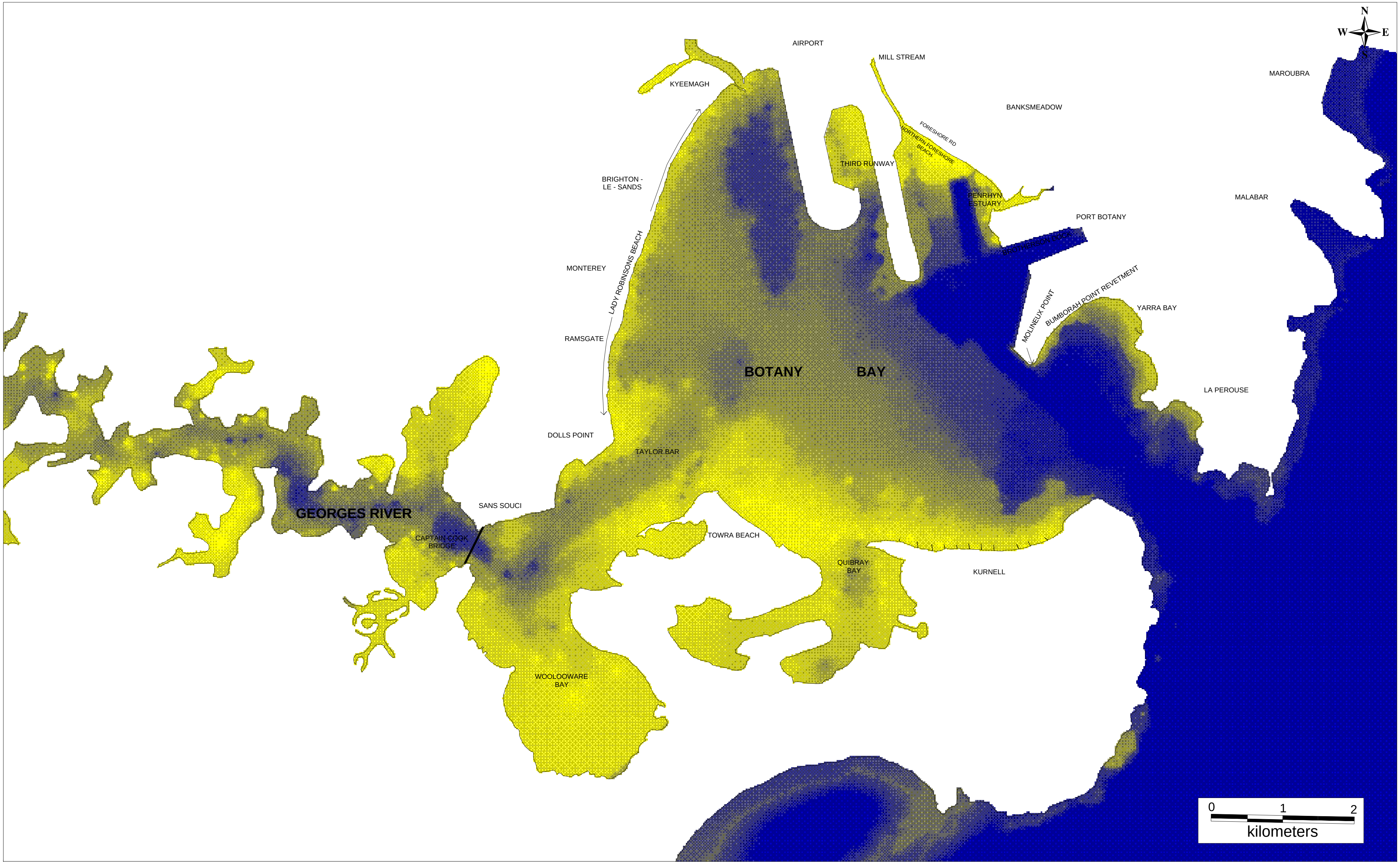
10. QUALIFICATIONS

This report has been prepared by Lawson and Treloar to provide a water quality study of Mill Pond Creek Catchment and Penrhyn Estuary for Sydney Ports Corporation (SPC). As such, this report is specific to this purpose and may not be used by third parties without reference to Lawson and Treloar.

The investigation and modeling procedures adopted for this study follow current best practice and considerable care has been applied to the preparation of the results. However, model setup and calibration depends on the quality of data available and there will always be some uncertainties. The hydrological regime and the water quality in the study area are complex and can only be represented by schematized model layouts. Hence there will be an unknown level of uncertainty in the results and this should be borne in mind in interpreting the results.

The study area has undergone many changes to accommodate development for residential, urban infrastructure, industrial and recreational uses. These changes altered the landscape, the hydrological regime and the ecological system of the area. As such, information for a certain time period could not represent the whole history. Apart from the above constraints, there is also lack of measured data for model calibration and identification of the origin, quantity, timing and transportation of pollutants. These all add up the complexity and uncertainty involved in this study.

FIGURES



Lawson and Treloar

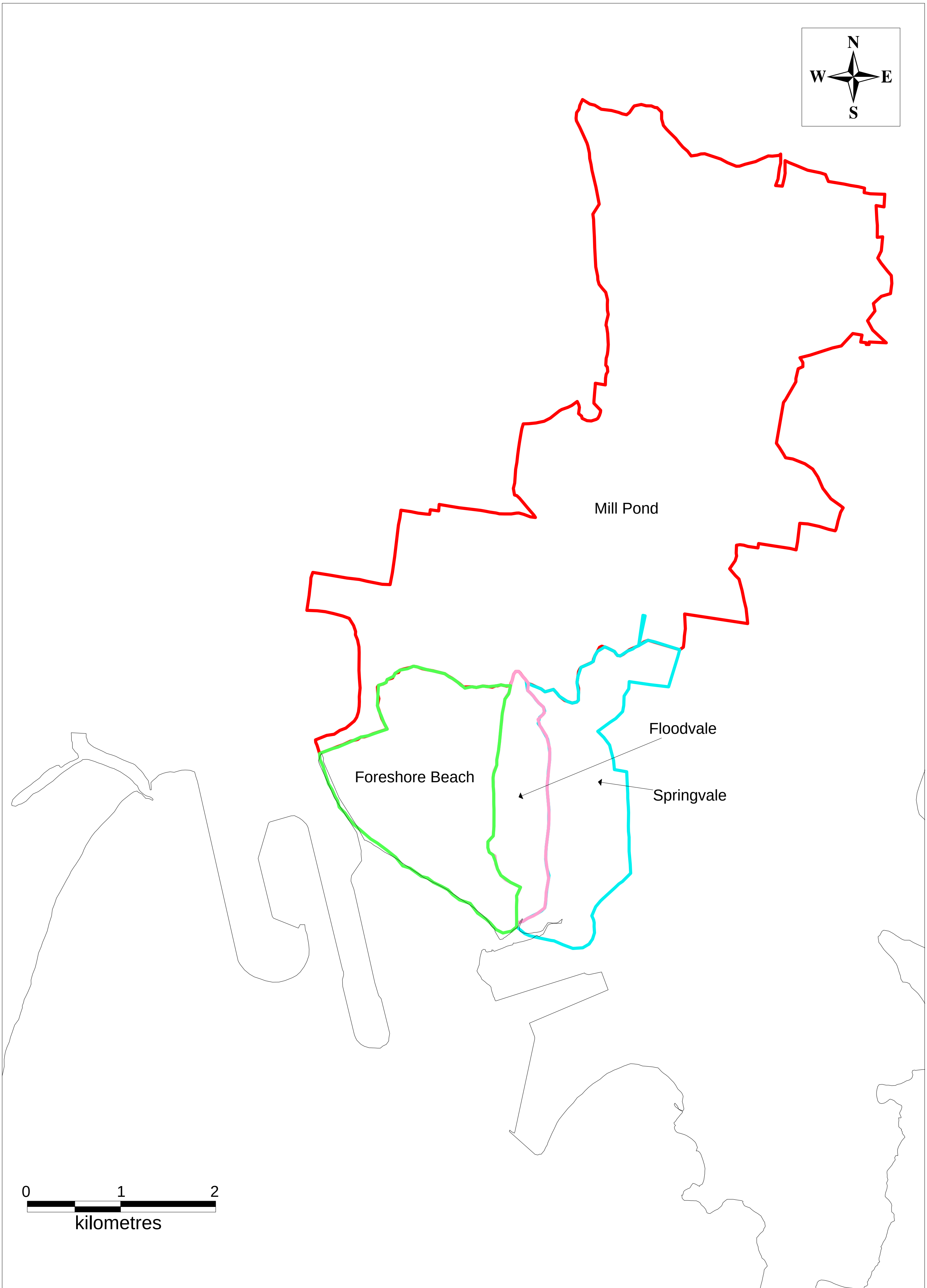
J2076/R1999 Vol2/V5 23/05/2003

File: J2076\Vol2 WQ Figs V5\Fig1.1 Locality Plan.Wor

Proposed Expansion of Container Port Facilities, Botany Bay

LOCALITY PLAN

Figure 1.1



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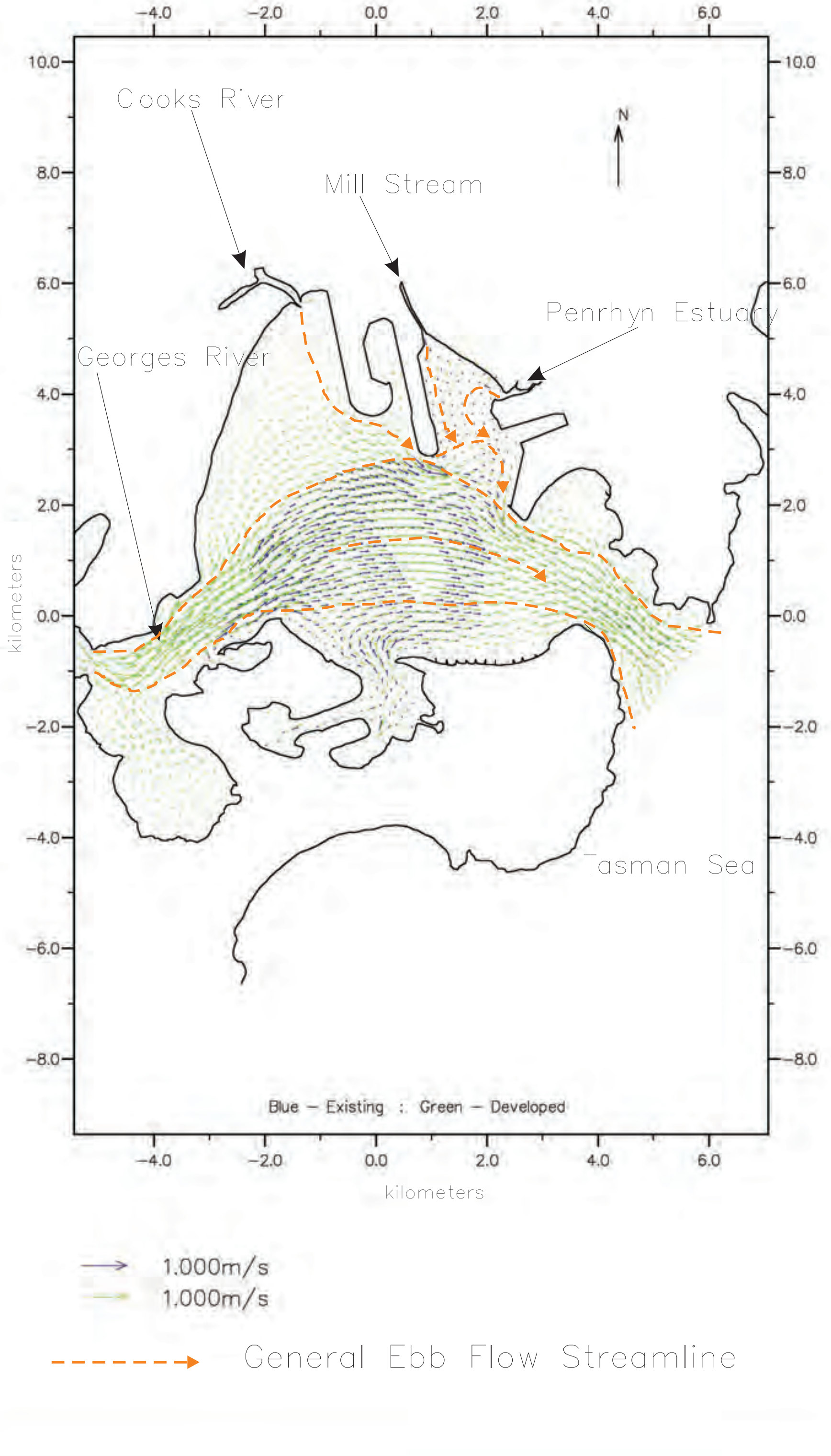
J2076/R1999/Vol 2/V5 23/05/2003
J2076\Vol2 WQ Figs V5\Fig 2.1 Catchments.Wor

Proposed Expansion of Container Port Facilities, Botany Bay

CATCHMENT AREAS

Figure 2.1



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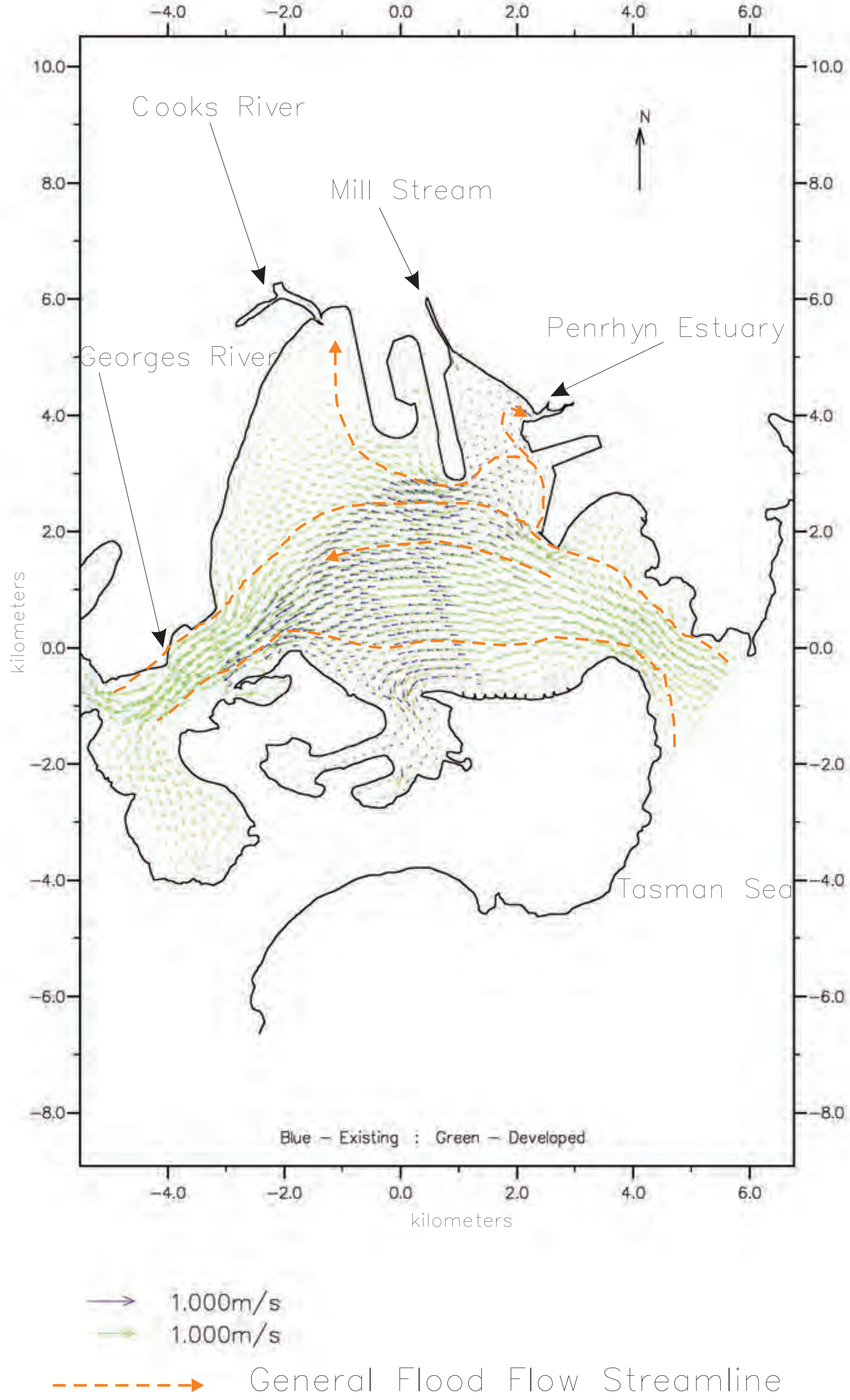
J2076/R1999 Vol2\V5 23/05/2003
File: J2076\Vol2 WQ Figs V5\Fig3.1 vol2 Concept Ebb.cdr

Proposed Expansion of Container Port Facilities, Botany Bay

CONCEPT PLAN OF TIDAL EBB FLOWS
Figure 3.1



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File: J2076\Vol2 WQ Figs V5\Fig3.2 vol2 Concept Flood.cdr

Proposed Expansion of Container Port Facilities, Botany Bay

CONCEPT PLAN OF TIDAL FLOOD FLOWS

Figure 3.2

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J2076/R1999 Vol 2\V5 23/05/2003
File: J2076\Vol2 WQ Figs V5\Figure 3.3 vol2 Penrhyn High Tide.cdr

Proposed Expansion of Container Facilities, Botany Bay

PENRHYRN ESTUARY AT HIGH TIDE

Figure 3.3

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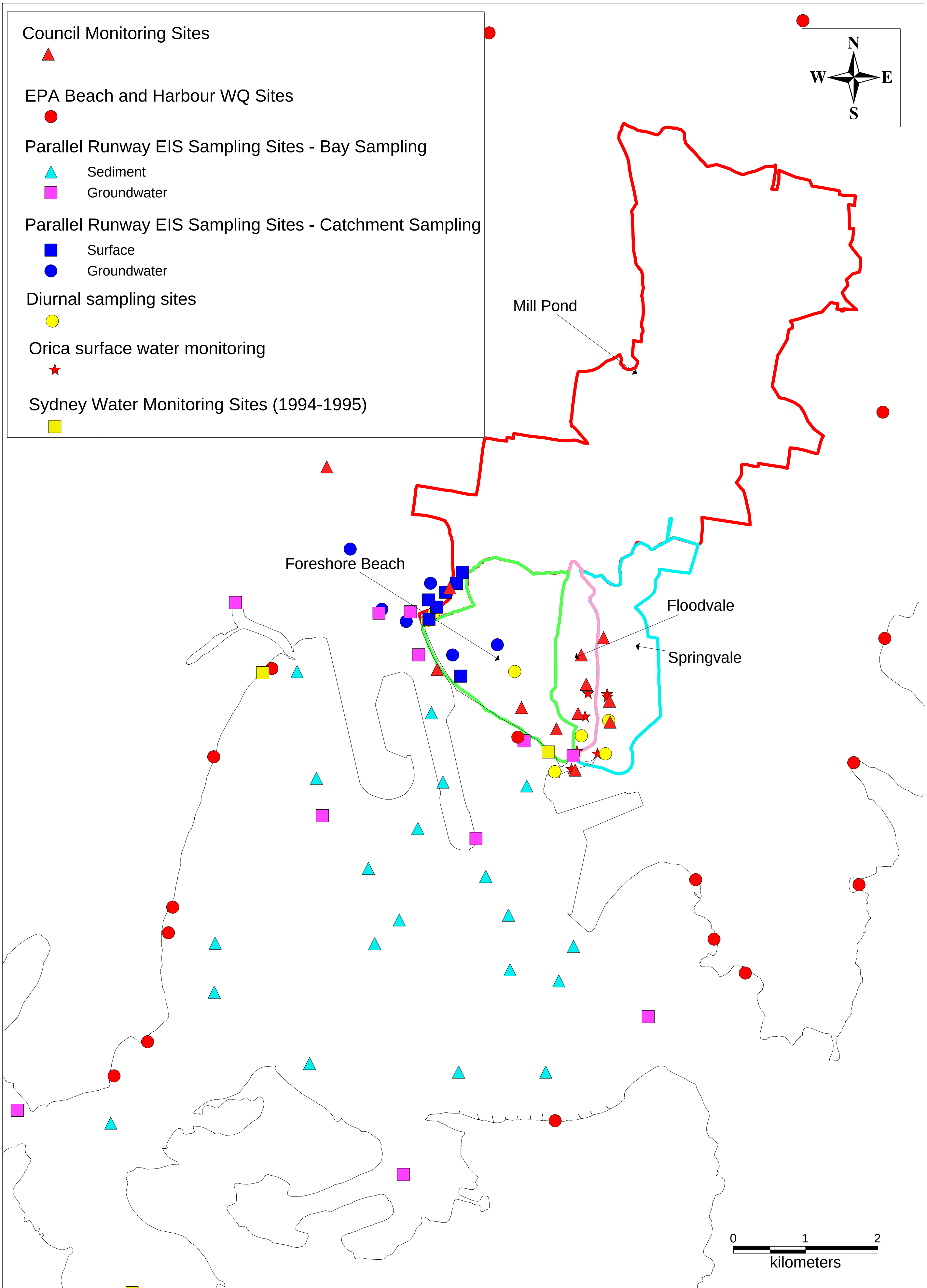
File: J2076\Vol2 WQ Figs V5\Figure 3.4Penrhyn Low Tide.cdr

Proposed Expansion of Container Facilities, Botany Bay

PENRHYRN ESTUARY AT LOW TIDE

Figure 3.4



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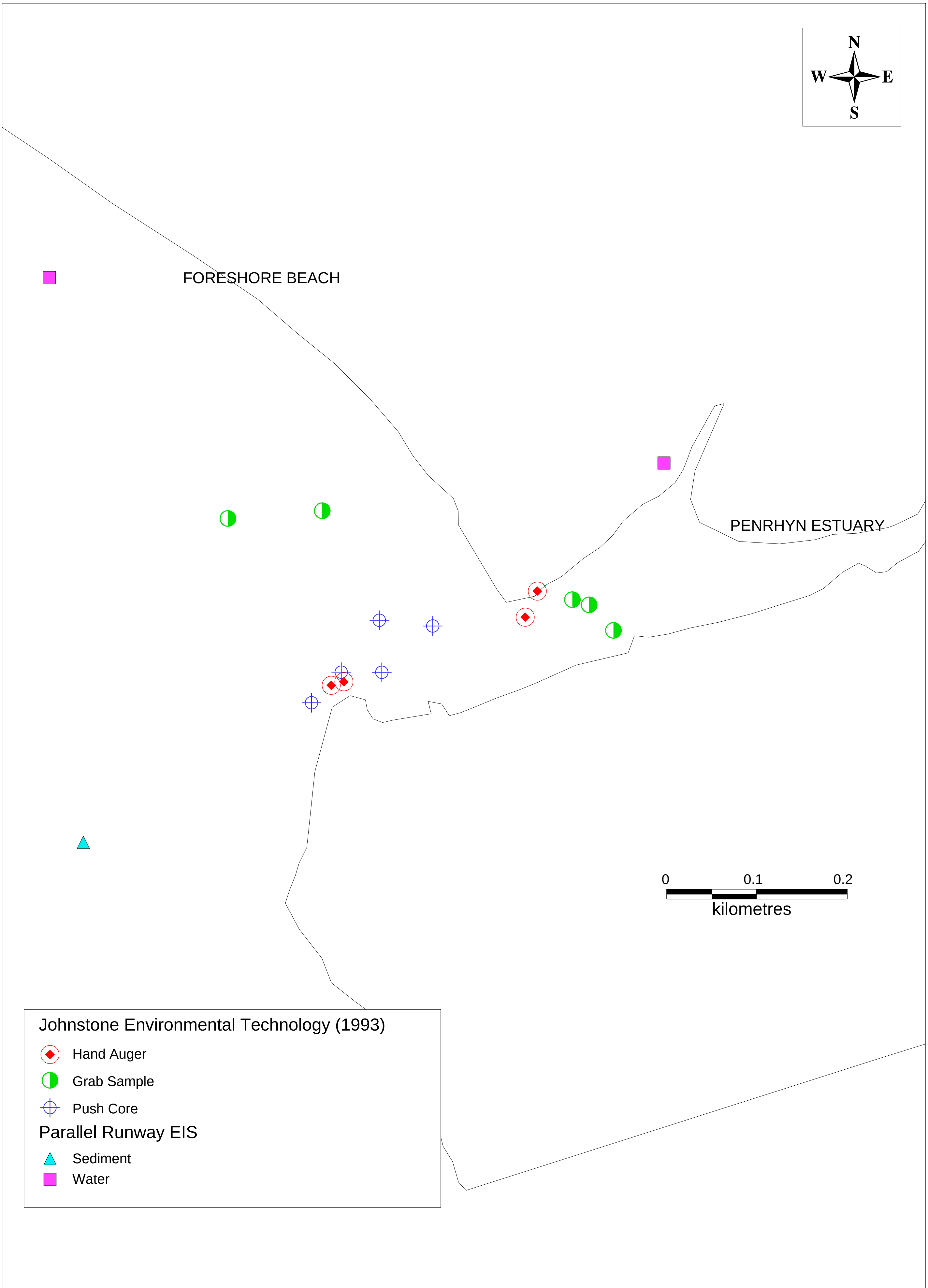
J2076/R1999 Vol2\V5 23/05/2003
FILE: J2076\Vol2 WQ Figs V5\Figures\Fig 4.1 vol2 WQSites.Wor

Proposed Expansion of Container Port Facilities, Botany Bay

EXISTING WATER QUALITY SAMPLING SITES

Figure 4.1



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FILE: J2076\Vol2 WQ Figs V5\Fig 4.2 vol2 SQSites.WOR

Proposed Expansion of Container Port Facilities, Botany Bay

EXISTING SEDIMENT QUALITY SAMPLING SITES

Figure 4.2

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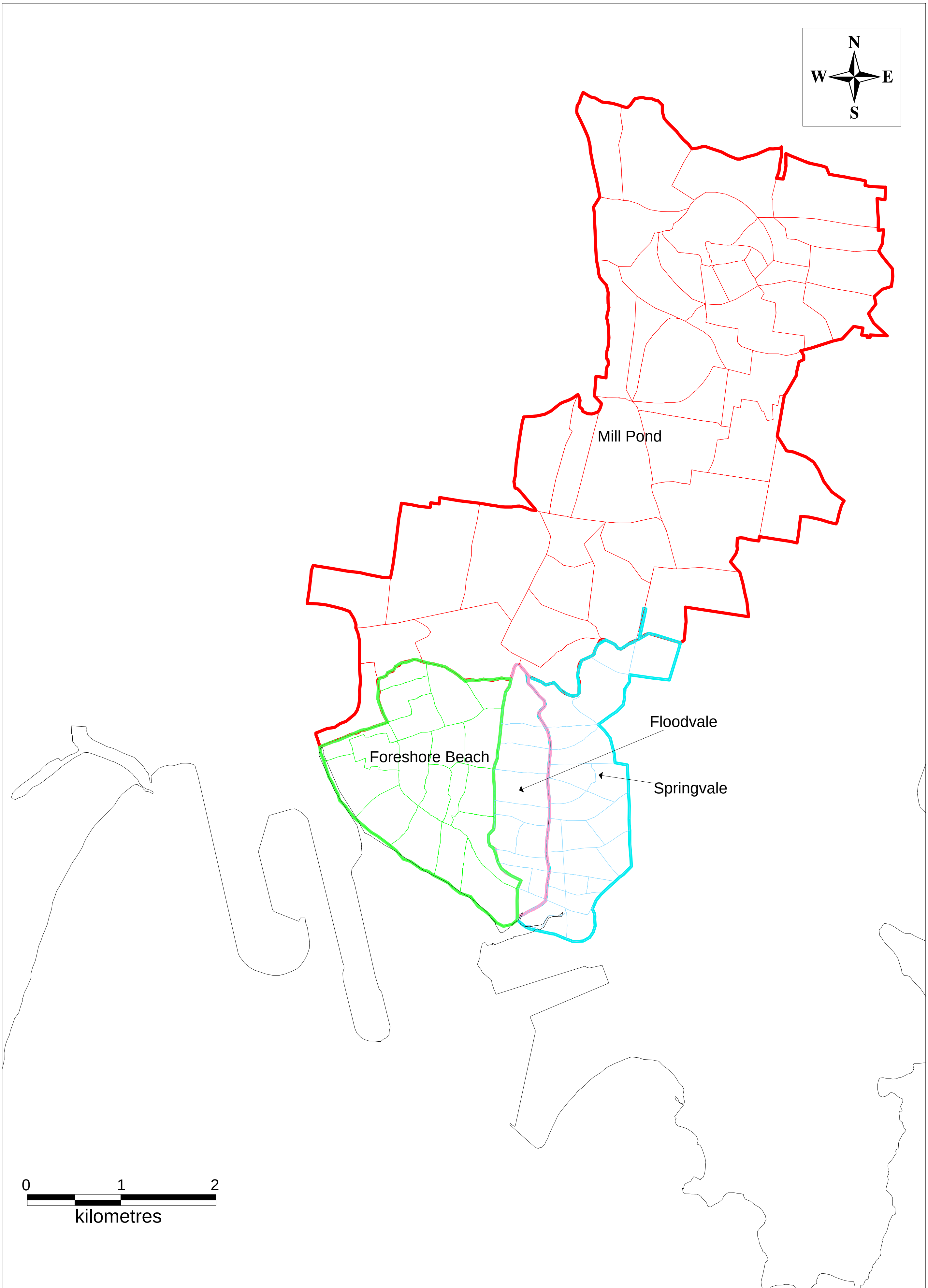
FILE: J2076\Vol2 WQ Figs V5\Fig 5.1 vol2 SQSites.WOR

Proposed Expansion of Container Port Facilities, Botany Bay

FIELD DATA COLLECTION SAMPLING SITES

Figure 5.1



LAWSON & TRELOAR

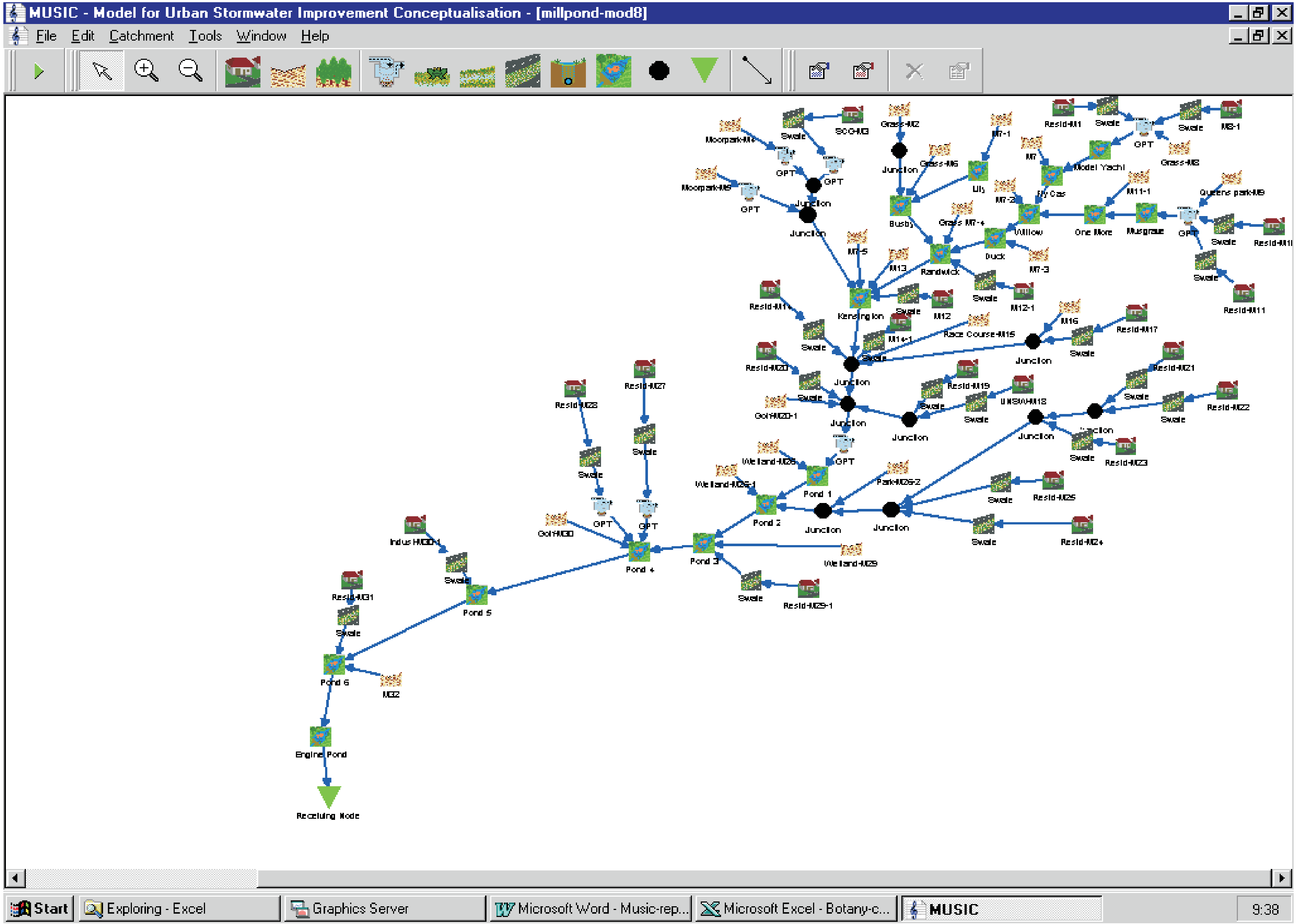
J2076/R1999 Vol 2\V5 23/05/2003

FILE: J2076\Vol2 03 Figs V5\Figure 6.1 SubCatchments.Wor

Proposed Expansion of Container Port Facilities, Botany Bay

SUBCATCHMENT AREAS

Figure 6.1



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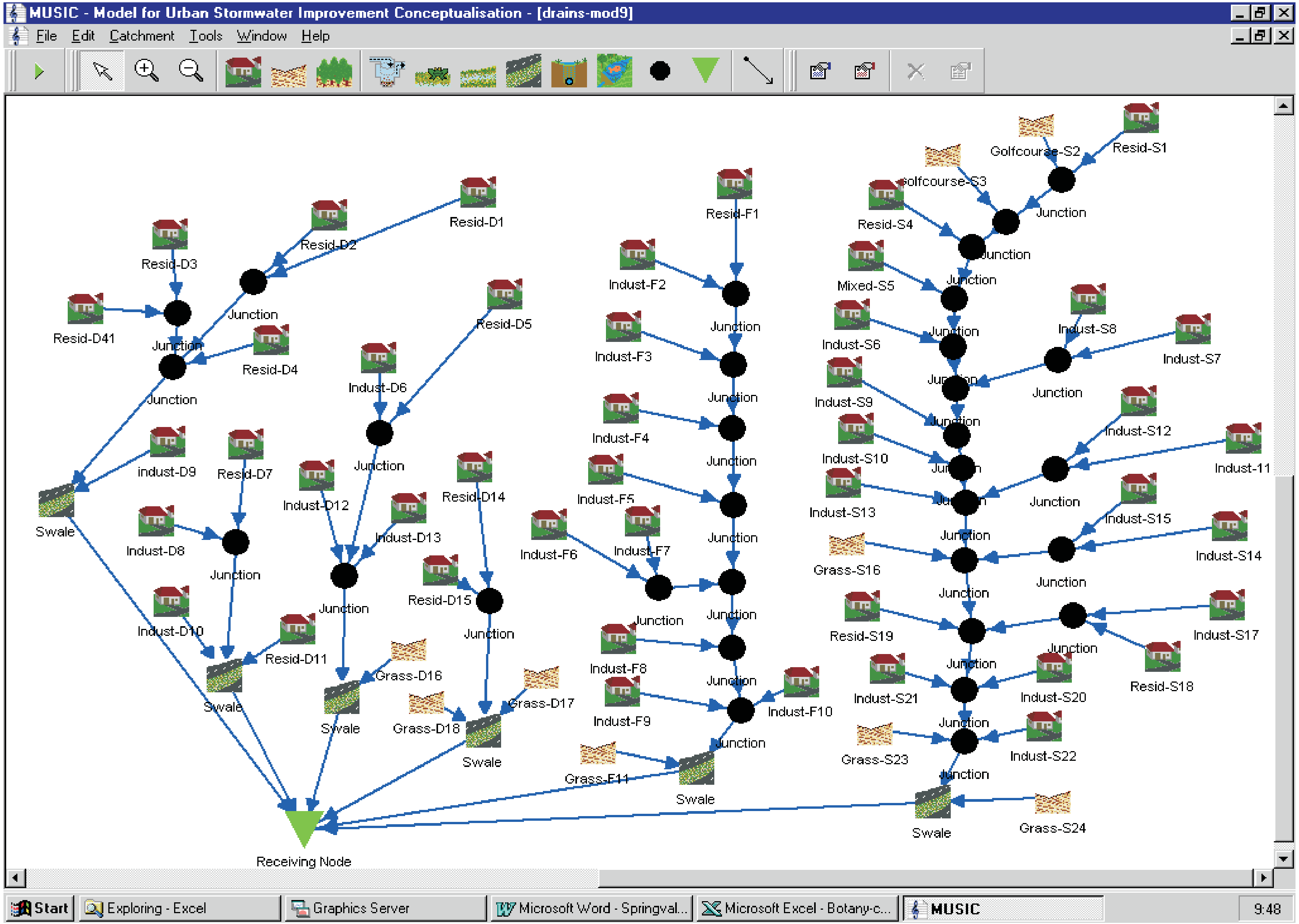
J2076/R1999 Vol 2\V5 23/05/2003
File: J2076\Vol2 WQ Figs V5\Fig6.2 vol2 Music Millpond.cdr

Proposed Expansion of Container Port Facilities, Botany Bay

MUSIC MODEL LAYOUT - MILLPOND CATCHMENT

Figure 6.2



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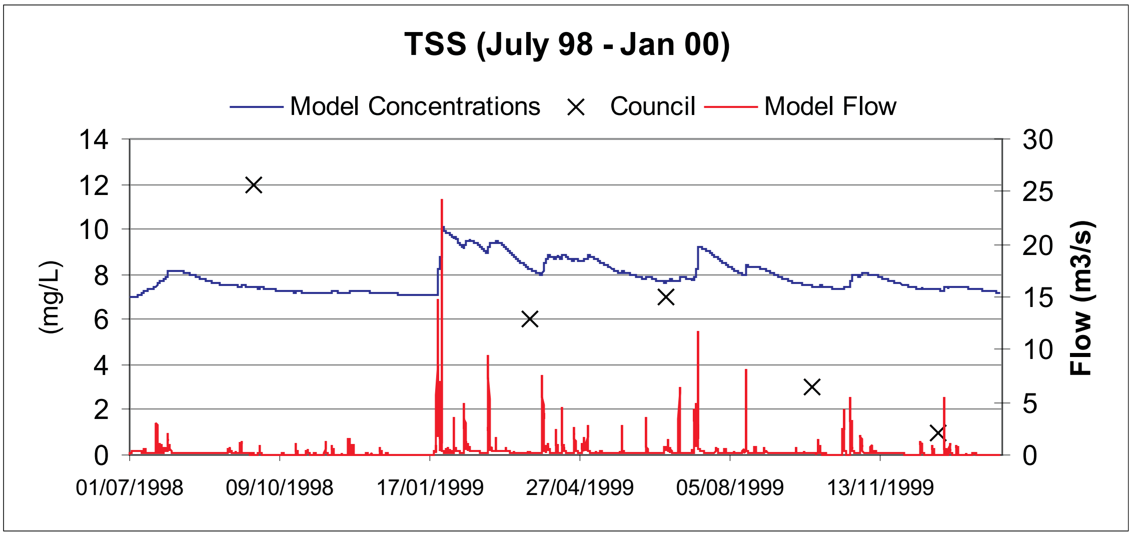
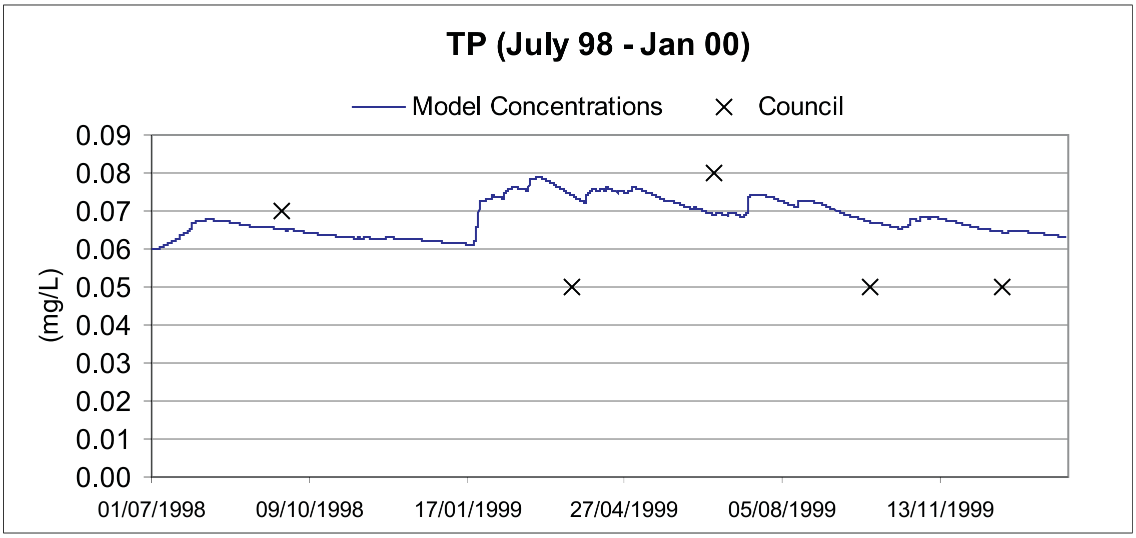
File: J2076\Vol2 WQ Figs V5\Fig6.3 vol2 Music Springvale.cdr

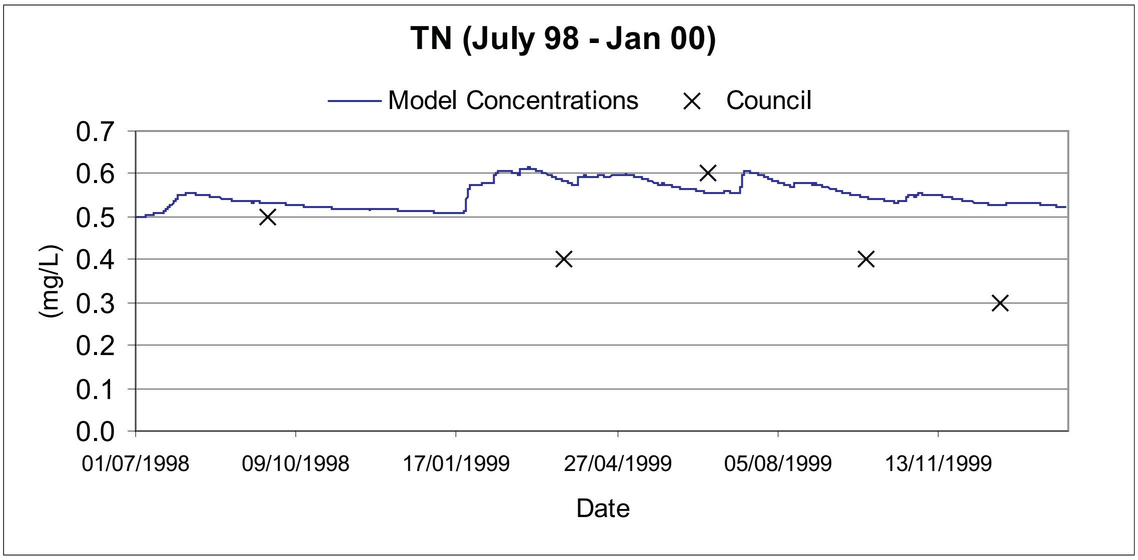
Proposed Expansion of Container Port Facilities, Botany Bay

MUSIC MODEL LAYOUT - SPRINGVALE, FLOODVALE AND FORESHORE BEACH CATCHMENTS

Figure 6.3







LOCATION: CBBC Site 9

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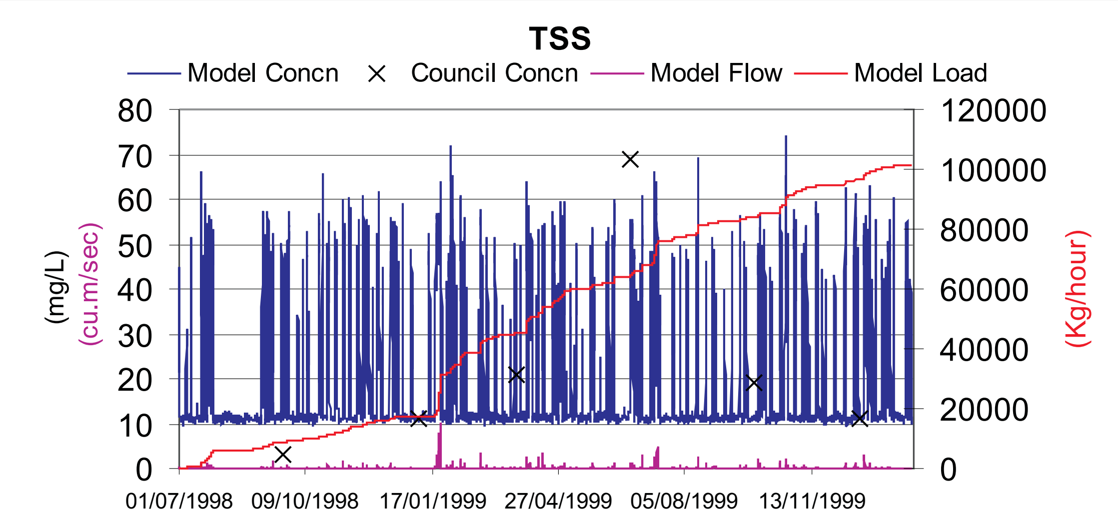
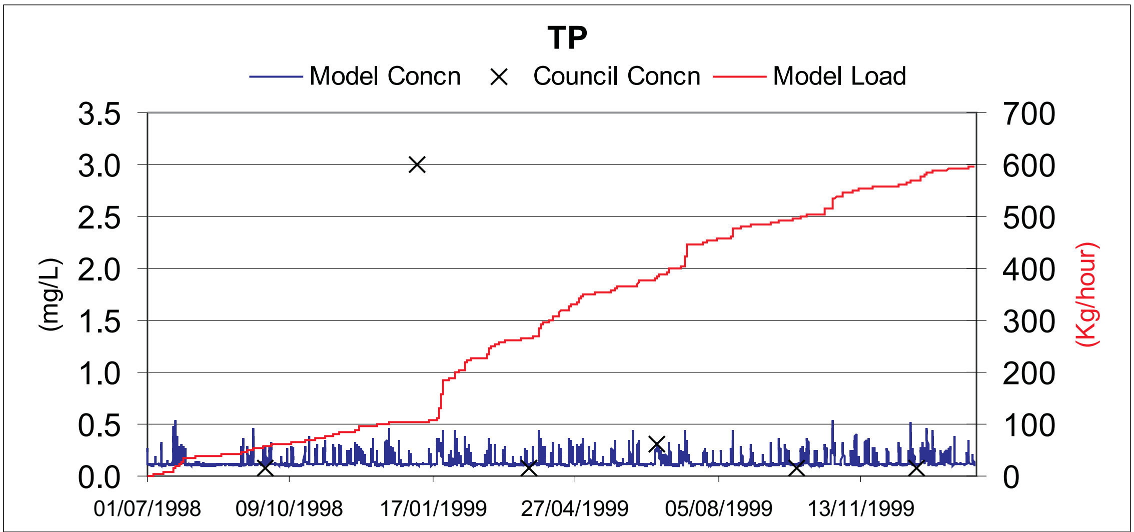
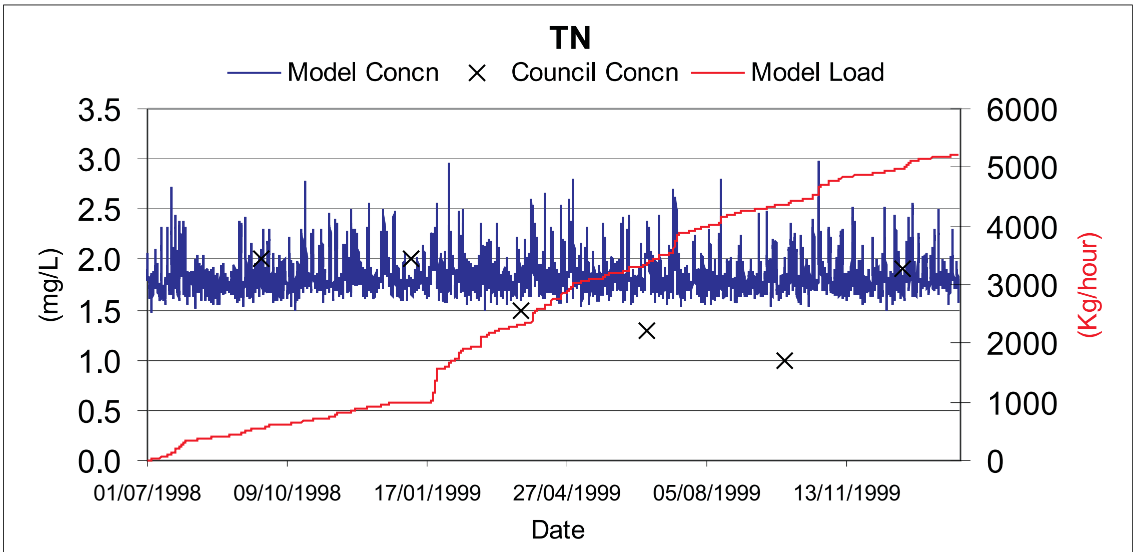
File: J2076\Vol2 WQ Figs V5\Fig6.4 vol2 (Music).cdr

Proposed Expansion of Container Port Facilities, Botany Bay

MILL POND MUSIC MODEL RESULTS
Figure 6.4







LOCATION: CBBC Site D6

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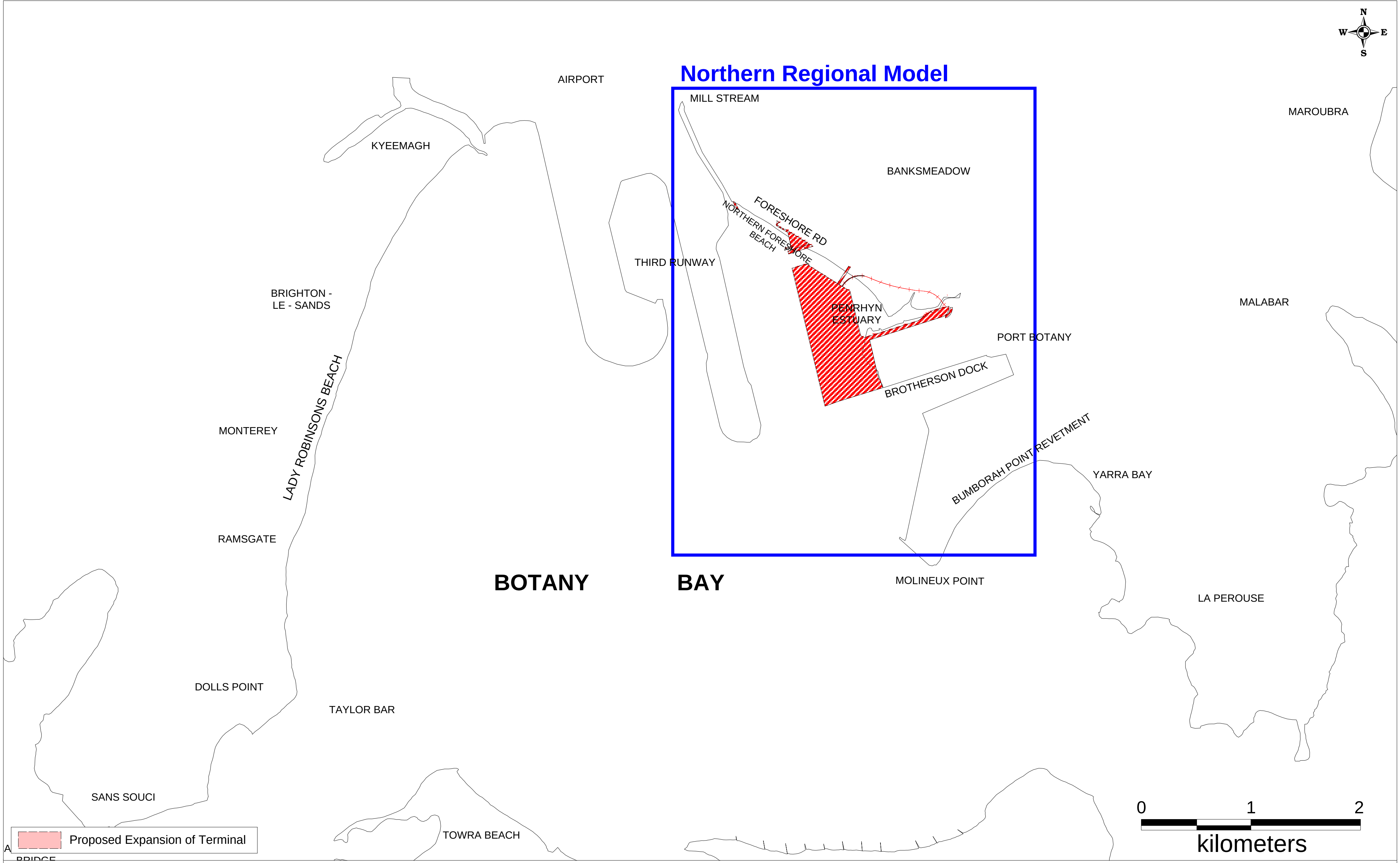
File: J2076\Vol2 03 Figs V5\Fig6.5 vol2 (Music).cdr

Proposed Expansion of Container Port Facilities, Botany Bay

SPRINGVALE DRAIN MUSIC MODEL RESULTS

Figure 6.5



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FILE: J2076\Vol2 WQ Figs V5\Fig7.1 Vol2.Wor

Proposed Expansion of Container Port Facilities, Botany Bay

EXTENT OF NORTHERN REGIONAL FLOW MODEL

Figure 7.1

KEY ✚ 3D model output locations
(99,81) = model grid cordinates

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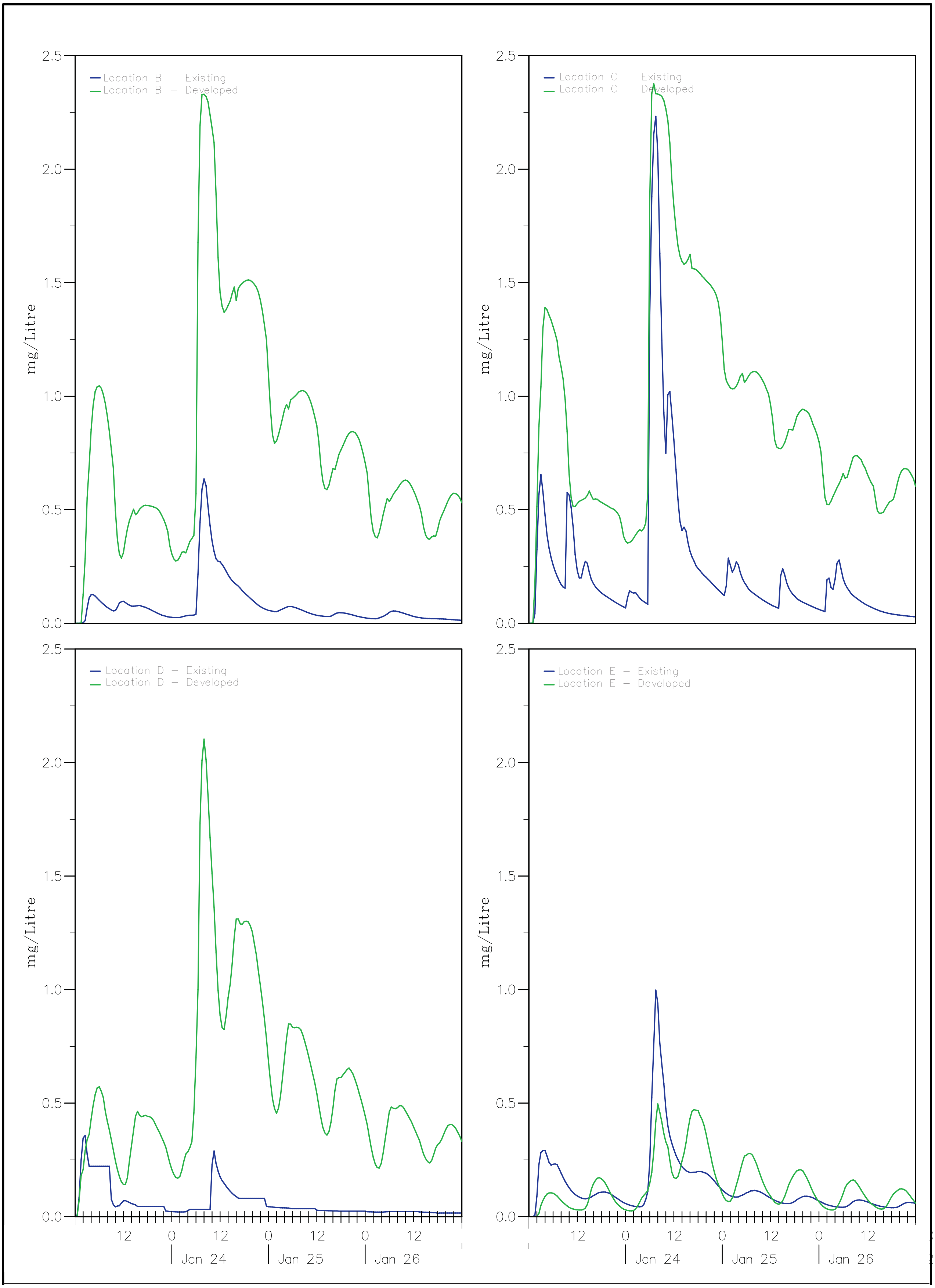
File: J2076\Vol2 WQ Figs V5\Fig 7.2 Vol2.Wor

Proposed Expansion of Container Port Facilities, Botany Bay

3D MODEL OUTPUT LOCATIONS

Figure 7.2



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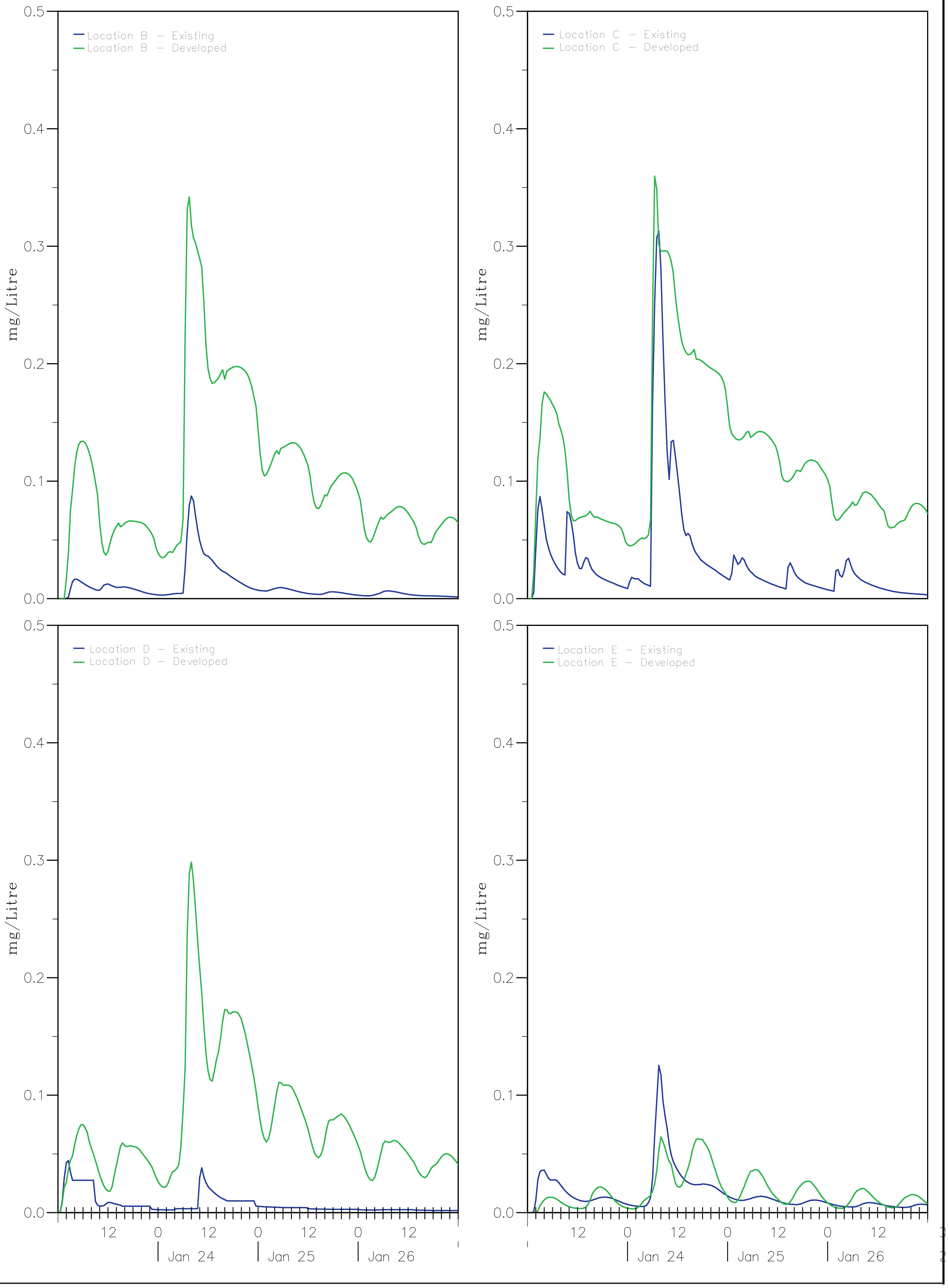
FILE: J2076\Vol2 WQ Figs V5/Fig7.3.cdr

Proposed Expansion of Container Port Facilities, Botany Bay

TN IN PENRHYN ESTUARY - TRANSIENT

Figure 7.3



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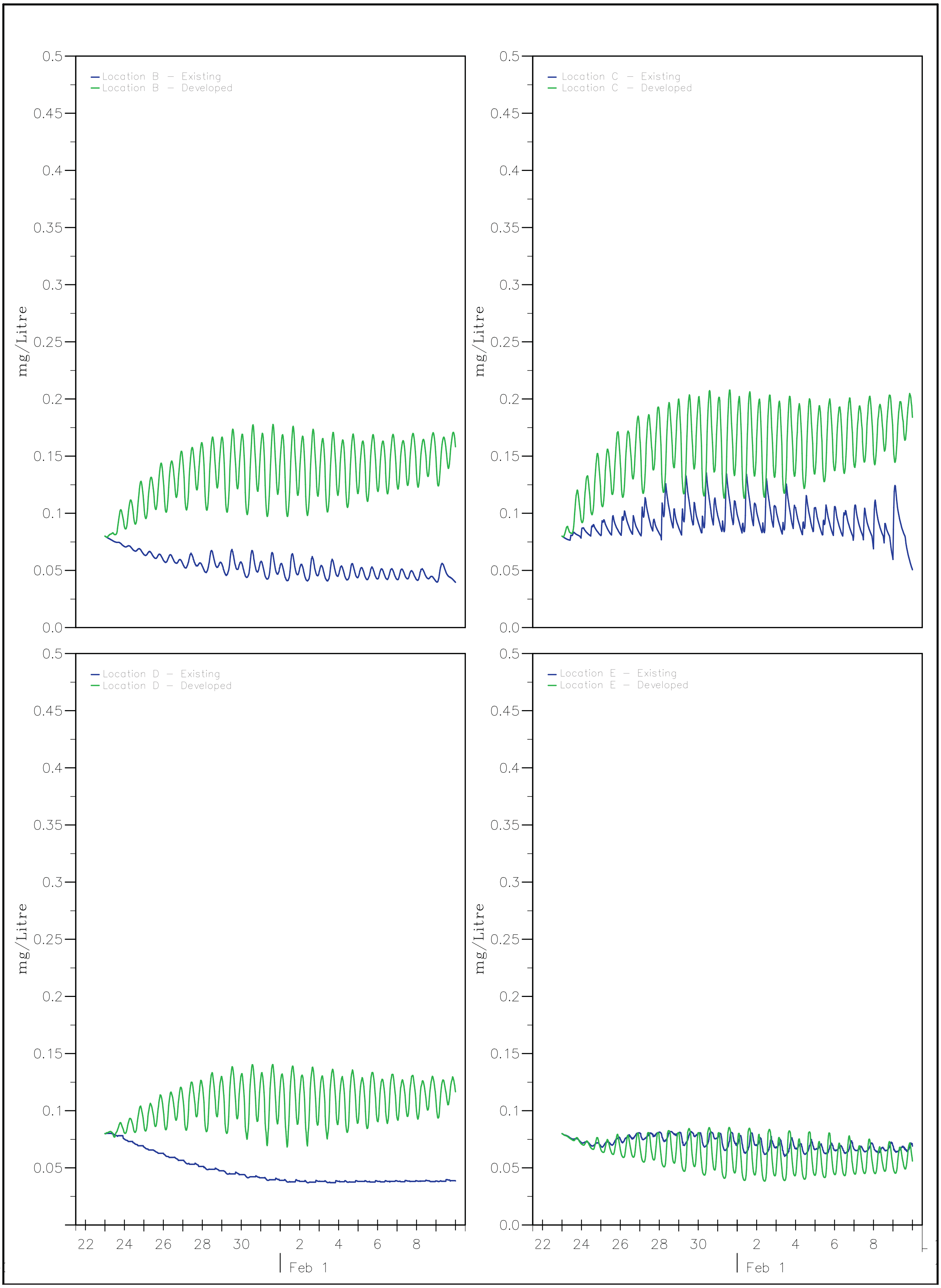
FILE: J2076\Vol2 WQ Figs V5/Fig7.4.cdr

Proposed Expansion of Container Port Facilities, Botany Bay

TP IN PENRHYN ESTUARY - TRANSIENT

Figure 7.4



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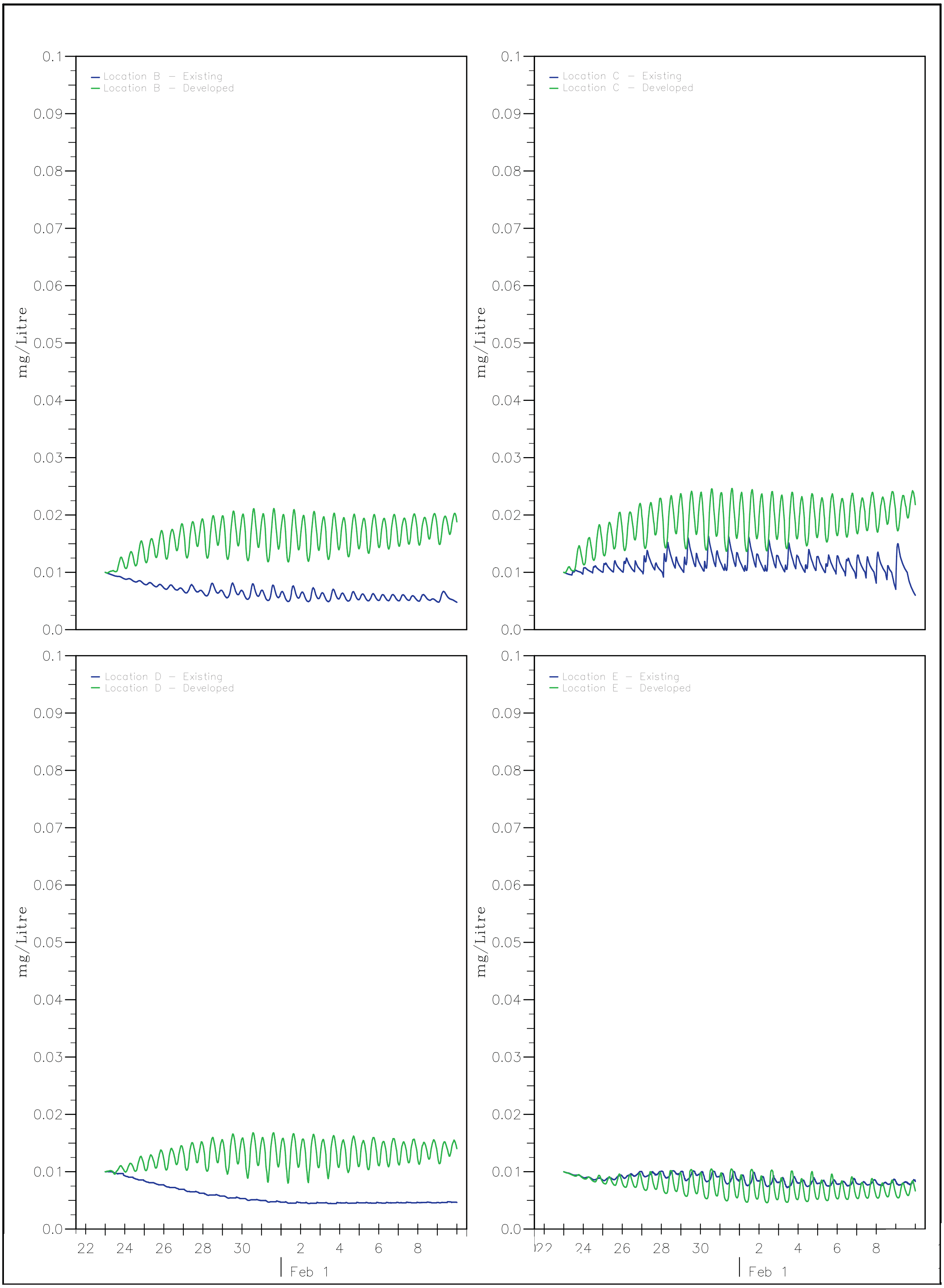
FILE: J2076\Vol2 V5 Figs/Fig7.5.cdr

Proposed Expansion of Container Port Facilities, Botany Bay

TN IN PENRHYN ESTUARY - AMBIENT

Figure 7.5



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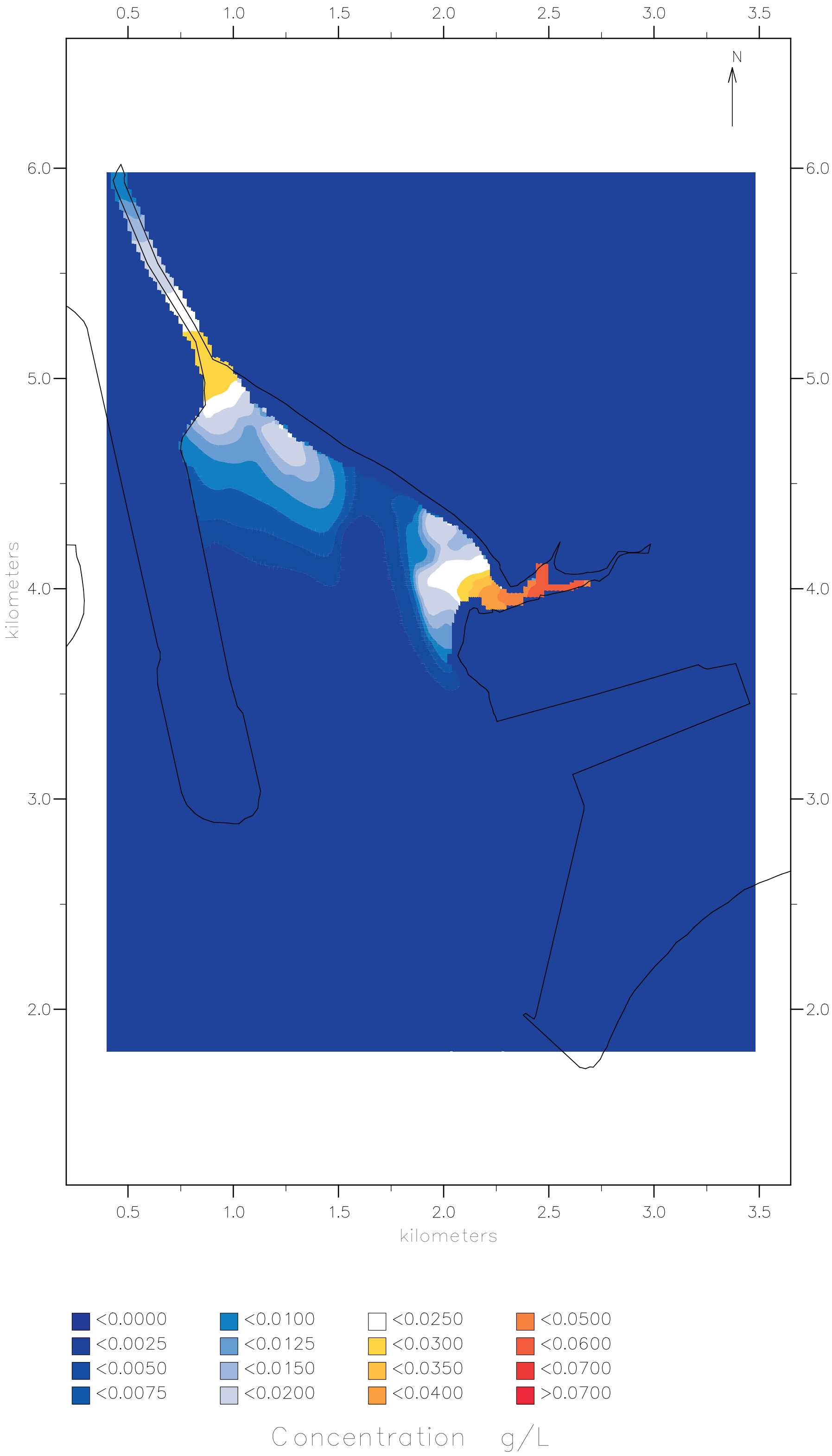
FILE: J2076\Vol2 Figs V5/Fig7.6.cdr

Proposed Expansion of Container Port Facilities, Botany Bay

TP IN PENRHYN ESTUARY - AMBIENT

Figure 7.6



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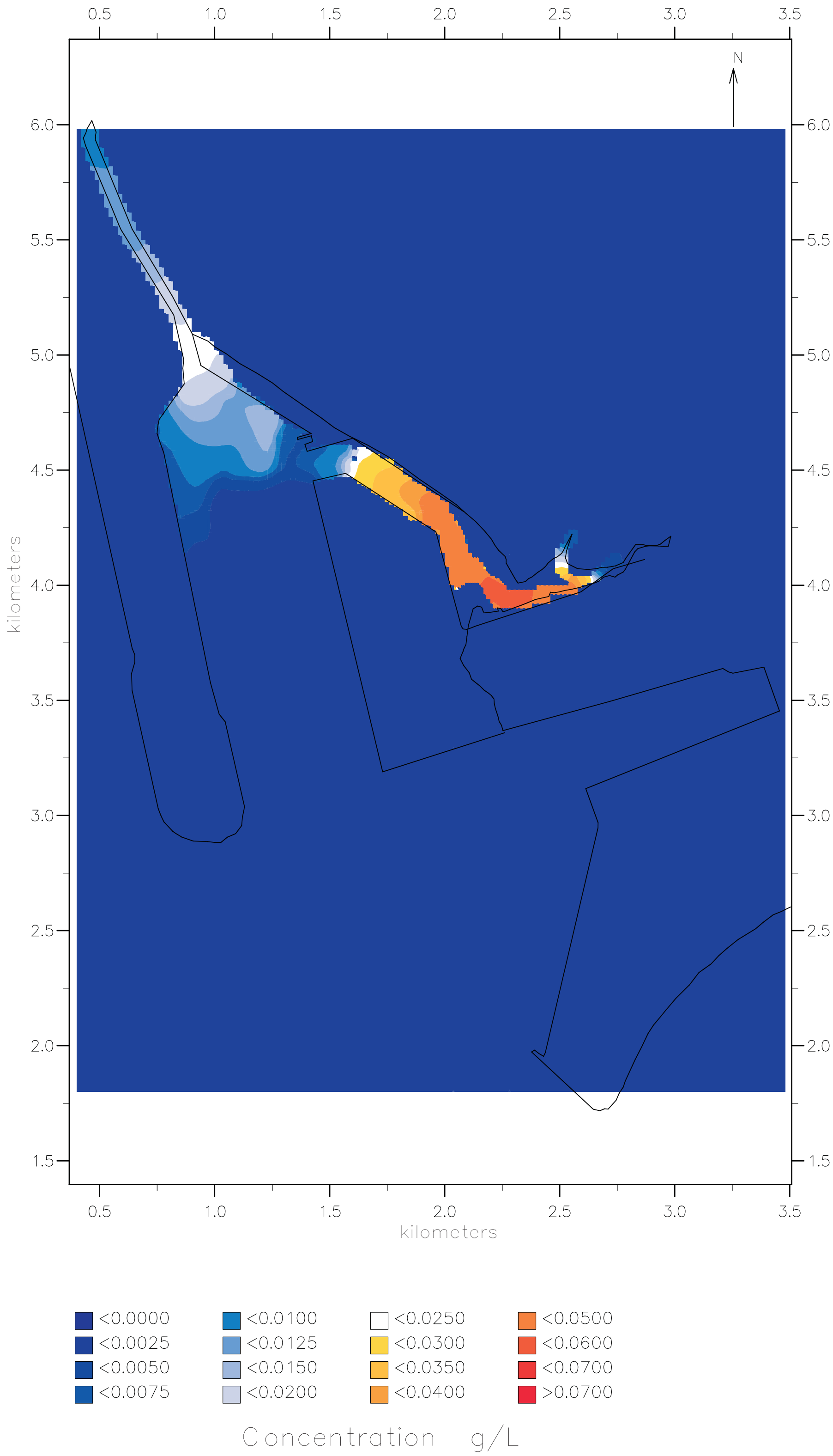
FILE: J2076\Vol2WQ V5 Figs/Fig7.7.cdr

Proposed Expansion of Container Port Facilities, Botany Bay

PEAK SUSPENDED SEDIMENT CONCENTRATION
PEAK STORM DISCHARGE - EXISTING

Figure 7.7



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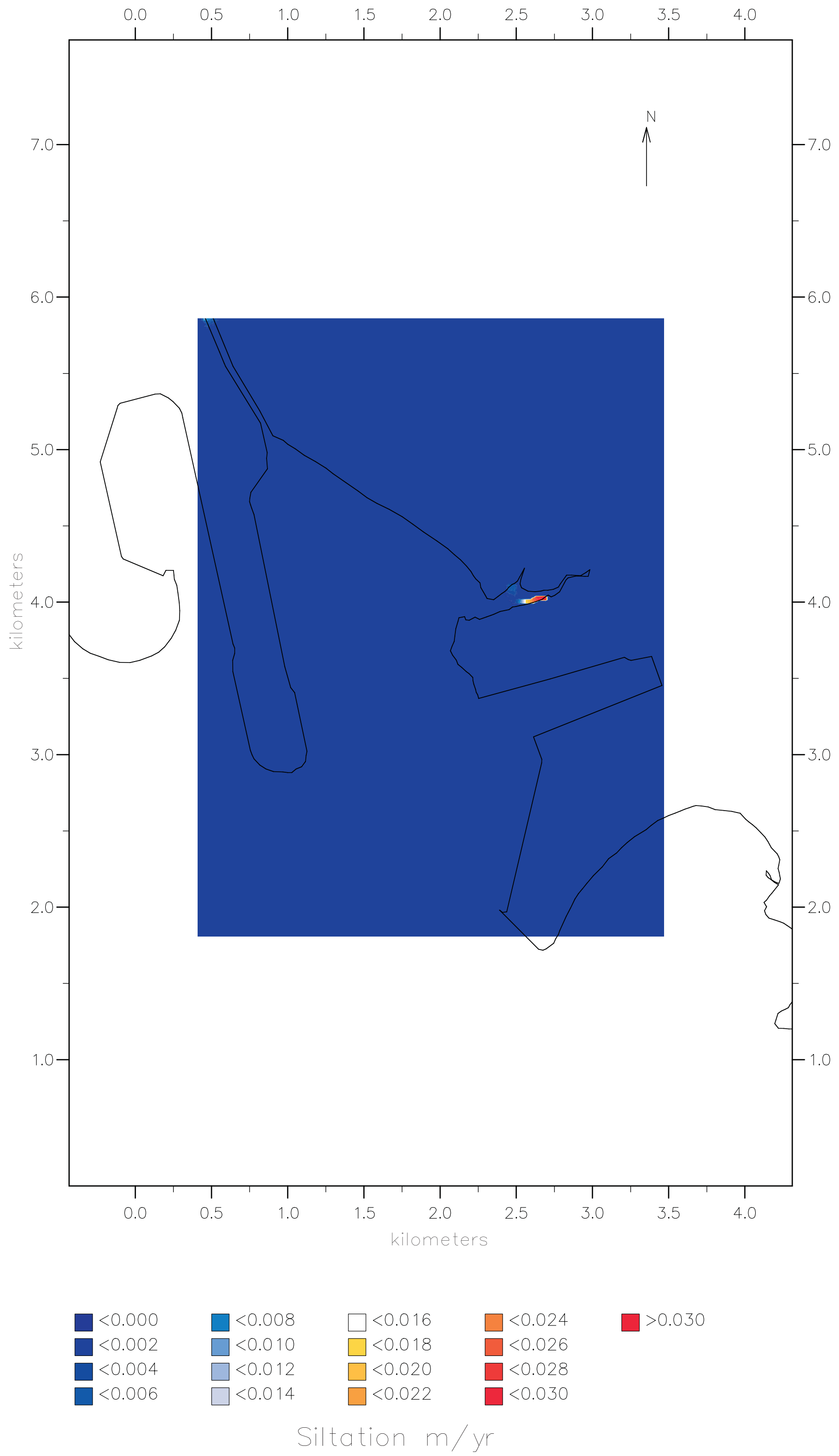
FILE: J2076\Vol2 WQ V5 Figs/Fig7.8.cdr

Proposed Expansion of Container Port Facilities, Botany Bay

PEAK SUSPENDED SEDIMENT CONCENTRATION

PEAK STORM DISCHARGE - DEVELOPED

Figure 7.8



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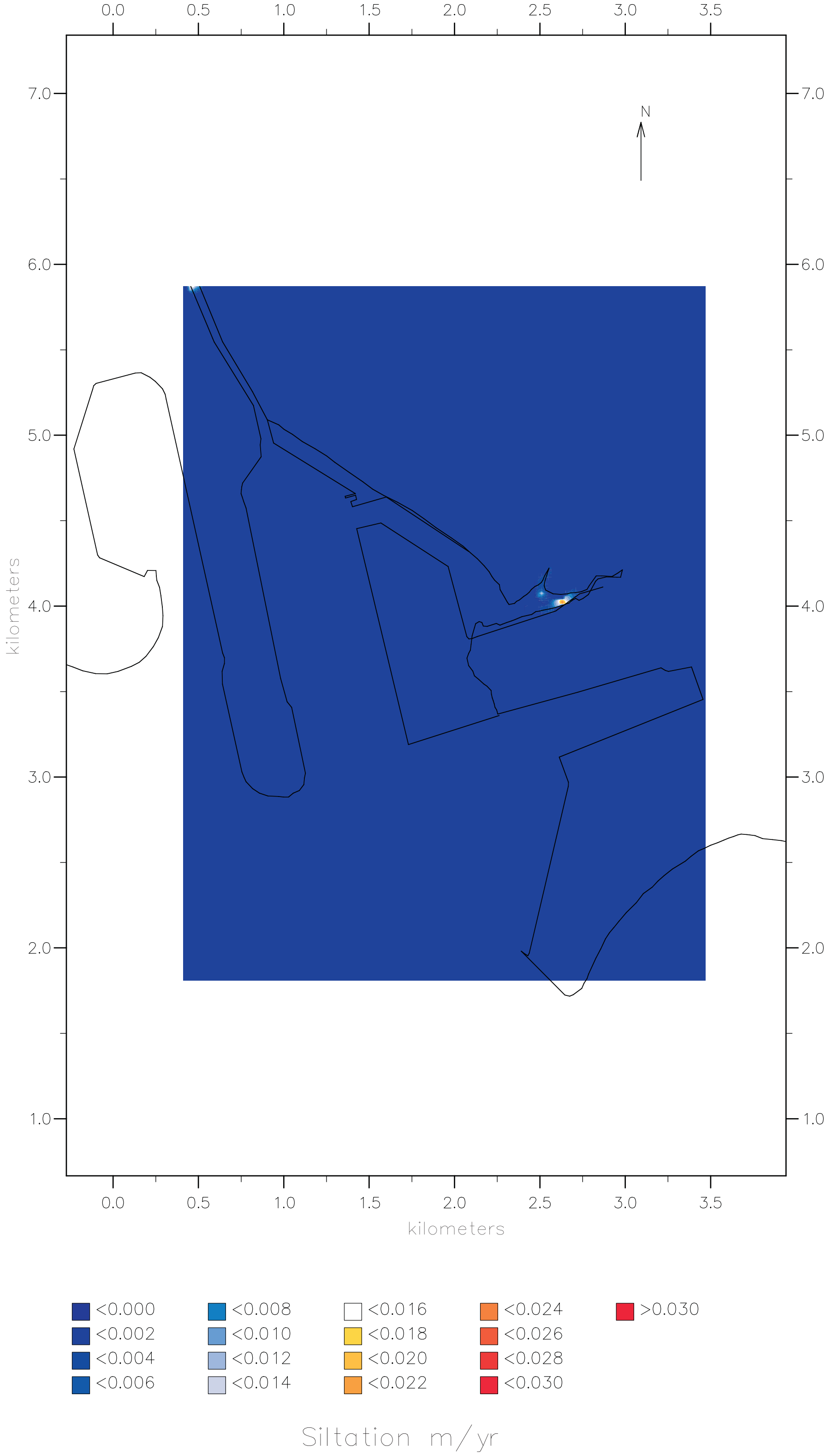
FILE: J2076\Vol2 WQ Figs V5\Fig7.9.cdr

Proposed Expansion of Container Port Facilities, Botany Bay

ANNUAL SILTATION IN PENRHYN ESTUARY - EXISTING

Figure 7.9



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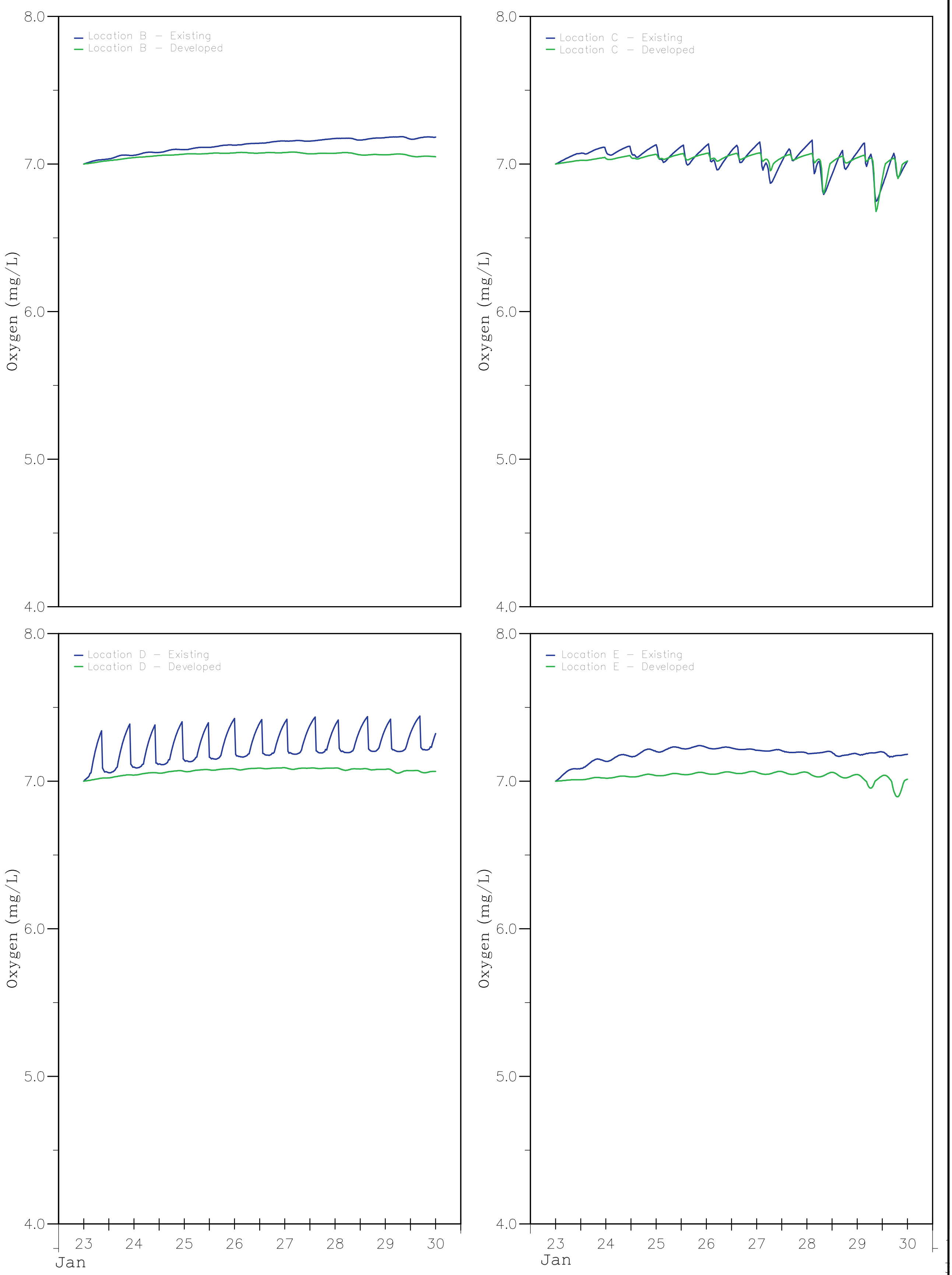
J2076/R1999 Vol2/V5 23/05/2003
FILE: J2076\Vol2 WQ Figs V5/Fig7.10.cdr

Proposed Expansion of Container Port Facilities, Botany Bay

ANNUAL SILTATION IN PENRHYN ESTUARY - DEVELOPED

Figure 7.10



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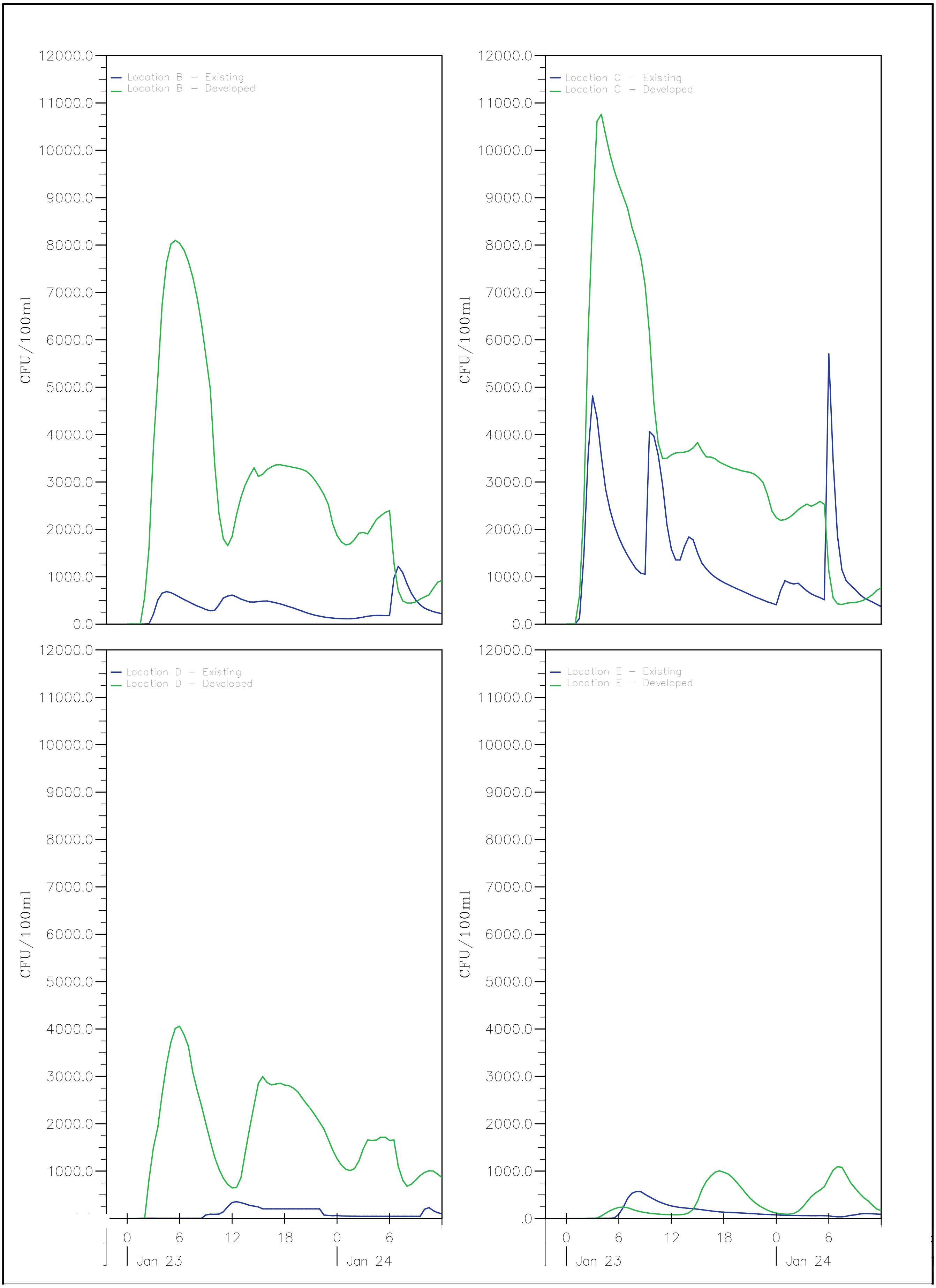
File: J2076\Vol 2 WQ V5/Fig7.11.cdr

Proposed Expansion of Container Port Facilities, Botany Bay

DO IN PENRHYN ESTUARY - AMBIENT

Figure 7.11



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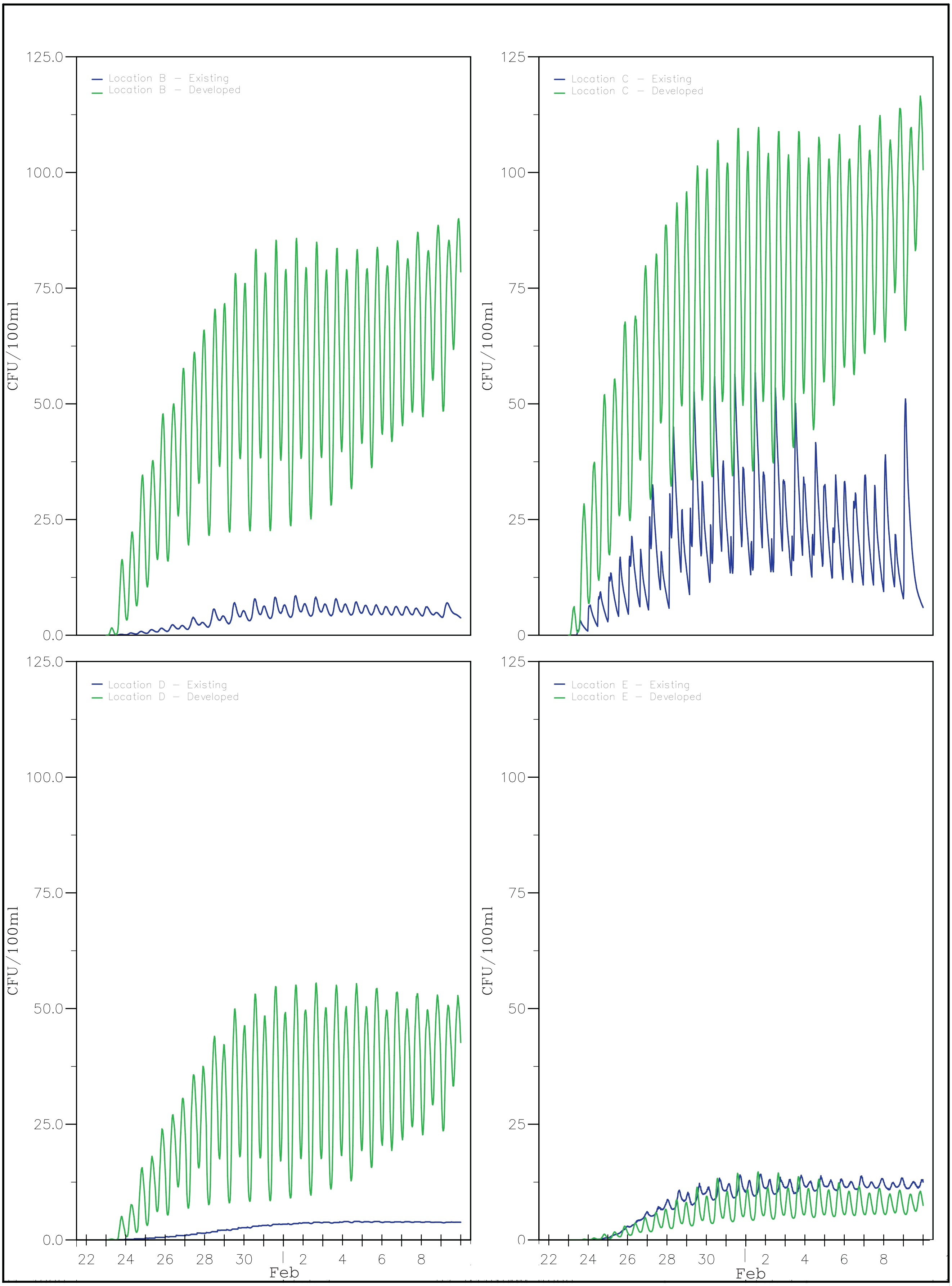
FILE: J2076\Vol2 WQ Figs V5/Fig7.12.cdr

Proposed Expansion of Container Port Facilities, Botany Bay

FAECAL COLIFORMS IN PENRYHN ESTUARY - TRANSIENT

Figure No 7.12



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FILE: J2076\Vol2 WQ Figs V5/Fig7.13.cdr

Proposed Expansion of Container Port Facilities, Botany Bay

FAECAL COLIFORMS IN PENRYHN ESTUARY - AMBIENT

Figure 7.13

APPENDICES

APPENDIX A

PROPOSED CONTAINER PORT EXPANSION DETAILS

-16	DENOTES MINIMUM DREDGED DEPTH
(hatched)	BERTHING BOX (50m WIDE) TO BE DREDGED TO -16
(dark red)	AREA TO BE DREDGED TO MAXIMUM DEPTH OF -17.5
(green)	HIGH SPOTS TO BE DREDGED TO -16.5

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J2076/R1999 Vol 3 18/02/2003
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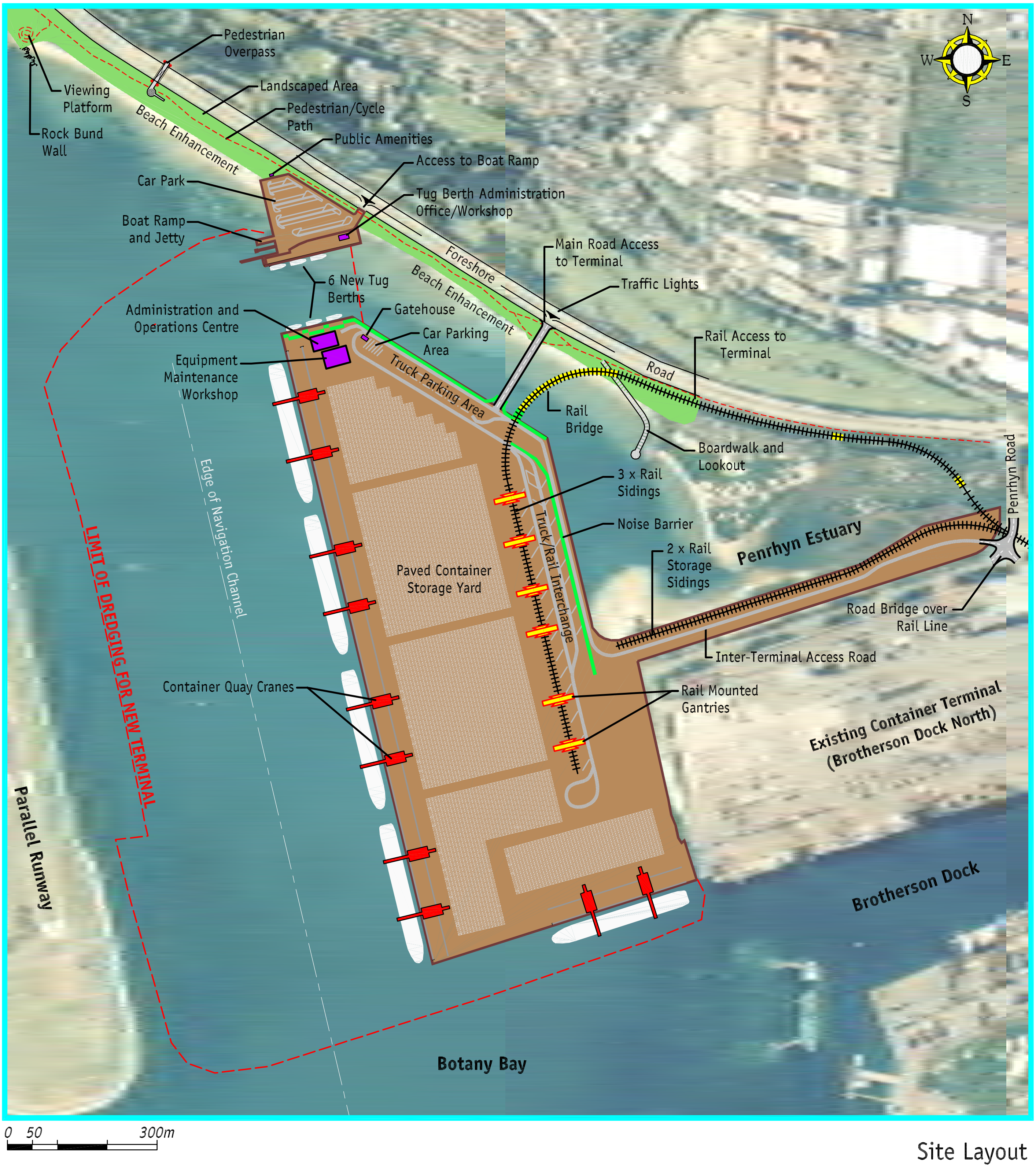
Proposed Expansion of Container Port Facilities, Botany Bay

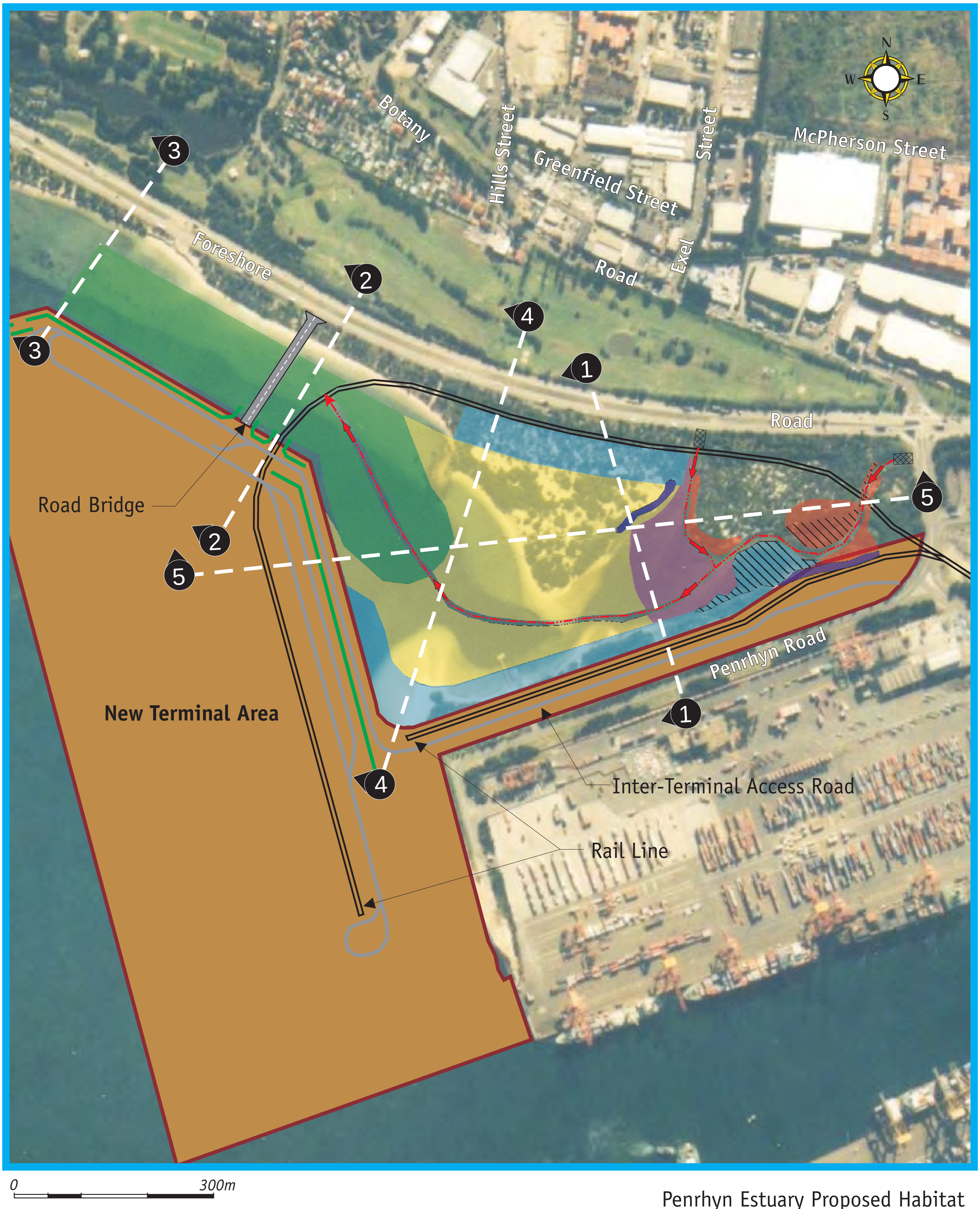
PROPOSED BATHYMETRY OF PORT AREA

Appendix A



Pedestrian Overpass
Viewing Platform
Rock Bund Wall
Landscaped Area
Pedestrian/Cycle Path
Beach Enhancement
Public Amenities
Access to Boat Ramp
Car Park
Tug Berth Administration Office/Workshop
Boat Ramp and Jetty
Foreshore
Main Road Access to Terminal
6 New Tug Berths
Beach Enhancement
Traffic Lights
Administration and Operations Centre
Gatehouse
Car Parking Area
Rail Access to Terminal
Equipment Maintenance Workshop
Truck Parking Area
Road
Rail Bridge
Boardwalk and Lookout
Edge of Navigation Channel
3 x Rail Sidings
Noise Barrier
Penrhyn Road
Paved Container Storage Yard
Truck/Rail Interchange
2 x Rail Storage Sidings
Penrhyn Estuary
Road Bridge over Rail Line
Inter-Terminal Access Road
LIMIT OF DREDGING FOR NEW TERMINAL
Container Quay Cranes
Rail Mounted Gantries
Existing Container Terminal (Brotherson Dock North)
Parallel Runway
Brotherson Dock
Botany Bay
N
W
E
S
0 50 300m

Site Layout



Proposed Intertidal Sand/Mud Flats (area 11.0ha)

Existing Mudflats To Be Retained (area 1.5ha)

Proposed Saltmarsh Habitat (area 5.2ha including 0.6ha of existing mangroves to be removed)

Existing Saltmarsh To Be Transplanted into Proposed Saltmarsh Habitat (area 0.35ha)

Existing Saltmarsh To Be Retained (area 1.0ha)

Existing Mangroves To Be Removed & Replaced With Saltmarsh Habitat

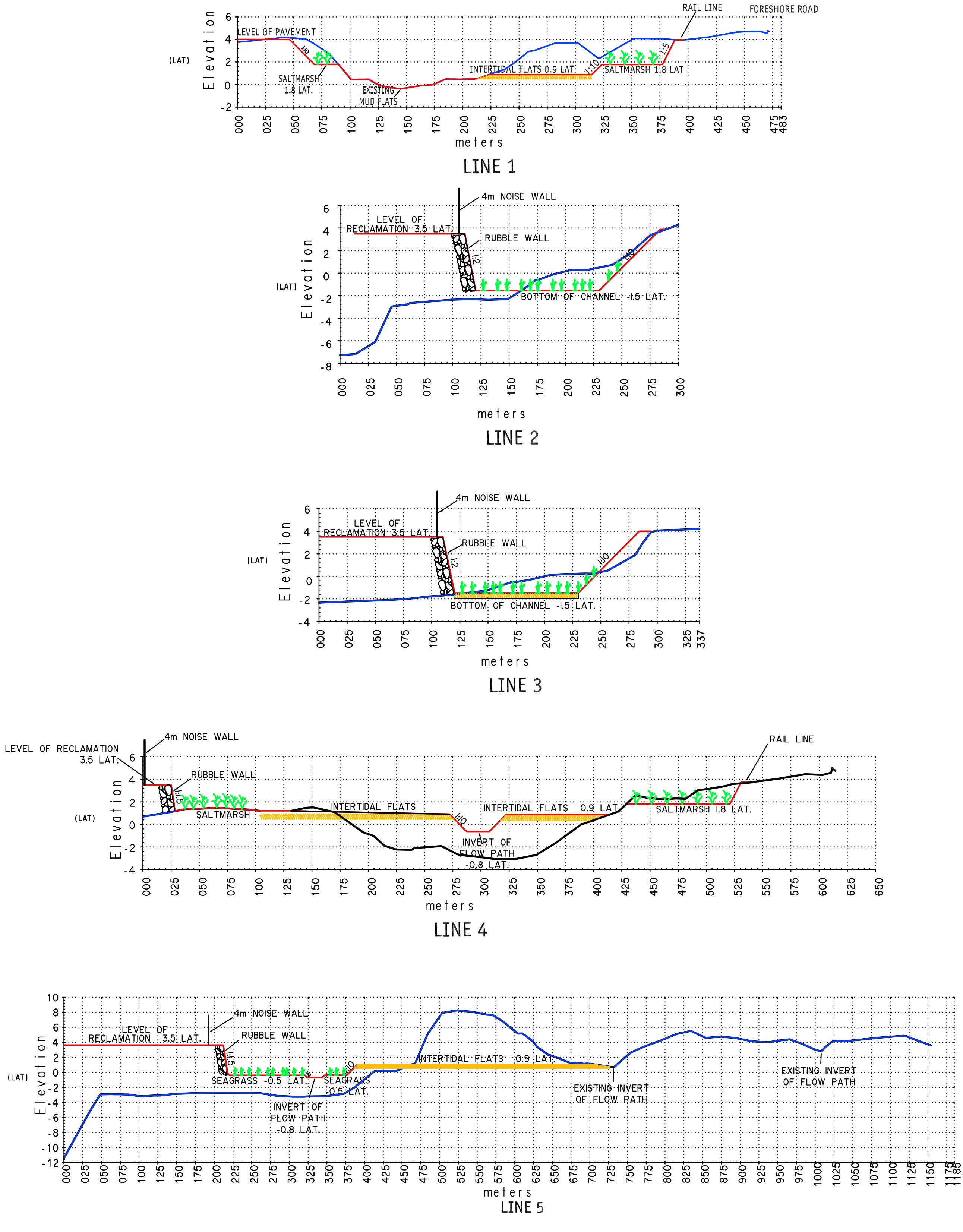
Proposed Seagrass Habitat (area 8.1ha)

Potential Opportunity For Sediment/litter Traps (subject to detailed assessment on drain hydraulics)

Proposed Preferential Flow Channel

Proposed Preferred Noise Wall Location (approx. 4m High)

Penrhyn Estuary Proposed Habitat Enhancement Plan



Vertical Exaggeration = 10x

All areas and measurements are approximations

Natural Surface

Proposed Development

Penrhyn Estuary Proposed Habitat Enhancement Cross Sections

APPENDIX B

GLOSSARY

GLOSSARY*

Abatement The reduction in degree or intensity of pollution.

Absorption Assimilation of molecules or other substances into the physical structure of a liquid or solid without chemical reaction. An example is the absorption of water into soil.

Accretion **Natural accretion** - the build-up of land, solely by the action of the forces of nature, on a beach by deposition of water or airborne material.
Artificial accretion - similar build-up of land by reason of an act of man, such as the accretion formed by a groin, breakwater, or beach fill deposited by mechanical/hydraulic means.

Acute Toxicity Level of mortality by a group of organisms that have been affected by the properties of a substance, such as contaminated sediment. The acute toxicity of sediment is determined by quantifying the mortality of appropriately sensitive organisms that are exposed to the sediment, under either field or laboratory conditions, for a specified period.

Adsorption Adhesion of an extremely thin layer of molecules (as of gas, solids or liquids) to the surface of solid or liquids with which they are in contact.

Aeration Any process which includes the introduction of air (oxygen) but generally refers to a step in the sewage treatment process. It is a method of water treatment, in which water and air are brought into immediate contact, with air blown into water, or water diffused into air. Aeration promotes oxidation and digestion by aerobic microorganisms, purifying water by removing organic compounds, hydrogen sulphide, methane gas and so on.

Aerobic Bacteria Aerobic bacteria refers to the bacteria that oxidize substrate (feed) by oxygen respiration and live on the energy generated in the process. Aerobic bacteria are the opposite of anaerobic bacteria, which need no oxygen gas. Aerobic bacteria play an important role in the natural purification process of water bodies, the activated sludge process, the sprinkling filter method and other water quality preservation processes.

Aerobic Treatment Process by which microbes decompose complex organic compounds in the presence of oxygen and use the liberated energy for reproduction and growth. Types of aerobic processes include extended aeration, trickling filtration and rotating biological contactors.

Algal Bloom A sudden growth of algae in an aquatic ecosystem, a characteristic symptom of eutrophication. It can occur naturally in spring or early summer when primary production exceeds consumption by aquatic herbivores. Algal blooms may also be induced by nutrient enrichment of waters due to pollution. (also see: eutrophication)

Alkyl Mercury Alkyl mercury is an organic mercury which is the alleged cause of Minamata Disease. Symptoms of alkyl mercury poisoning include central nervous disorders, such as perceptive, hearing and speech disorders, paralysed limbs, and even death. Alkyl mercury could be released into the environment from chemical plants and dry cell manufacturers' premises.

Alluvial Made of soil and sands deposited by rivers or floods.

Ambient	Usual or surrounding conditions of temperatures, humidity, etc.
Ambient Impacts	Defined in this study as those observed during the day to day delivery of low flows from the catchment in dry weather to the estuary.
Amenity	The word "amenity" is used to express "environmental comfort," "environmental attractiveness" and "quality of life". In general, "amenity" refers to a notion of quality and matter of comfort found in a place, climate, milieu and scenery, whose value is difficult to quantify in monetary or other units; it represents a value indispensable for residents and beyond quantification.
Ammonia Nitrogen (NH4-N)	Nitrogen is an essential element contained in protein that constitutes plants and animals. Ammonia nitrogen, the first nitrogen of inorganic form generated from the decomposition of plants and animals (organic matter), serves as an effective index of water contamination by kitchen garbage, human and animal waste, foods, leather, human hair, etc. A high excessive concentration of ammonia nitrogen in agricultural water causes damage to crops.
Anaerobic	Oxidation occurring in the absence of free or dissolved oxygen often facilitated by specific bacterial strains, e.g. methane producing bacteria present during the anaerobic digestion of sewage sludge.
Anaerobic Bacteria	Anaerobic bacteria refers to the bacteria that grow without dissolved oxygen. The decomposition of organic substances by anaerobic bacteria produces hydrogen sulphide, ammonia, methane and low molecular fatty acid. The process of digestion by anaerobic bacteria is applied to the treatment of human waste and sewage sludge.
Anoxic	Deficient in or lacking oxygen.
Anthropogenic	Effects from the influence of human beings on natural systems.
Aquatic Habitat	Typical submerged water communities in the sea, river, or lake, such as tidal flats, oyster beds, clam flats, seagrass beds, or fishing reefs.
Aquifer	A porous, subsurface geological structure carrying or holding water, such as a well. A subsurface rock unit from which water can be produced.
Aquifers	Permeable geological formation of water-bearing rock, sand, soil or gravel which can supply water in usable quantities, for example to wells or springs.
ARI	Average Recurrence Interval
Assimilation	The ability of a body of water to purify itself of pollutants.
Atmospheric Deposition	The process whereby solids or chemical inorganic or organic substances are deposited via atmospheric conditions e.g. rain at ground level.
Background Level	The level of pollutants present in ambient air, water, soil or any other medium from natural sources.
Ballast Water	Water taken on board a vessel to ensure stability whilst navigating in an unladen or partially laden state.
Baseline Study	An inventory of a natural community or environment to provide a measure of its condition at a point of time -- often done to describe the status of diversity and environmental condition against which future change can be

	gauged (usually development drive); baseline data may be used in models for planning or for establishing goals for allowable environmental impacts (also, "reference study" sites).
Beach Nourishment	Beach restoration or augmentation using clean dredged or fill sand. Dredged sand is usually hydraulically pumped and placed directly onto an eroded beach or placed in the littoral transport system. When the sand is dredged in combination with constructing, improving, or maintaining a navigation project, beach nourishment is a form of beneficial use of dredged material.
Bedload	The quantity of sediment transported by a current. It includes the suspended load of small and large particles that move along the bottom.
Benthic	Of, pertaining to, or living on or in the bottom of the water body; upon or attached to the bottom.
Benthos	Benthos is a biotic community that lives on the bottom of a body of water. According to size, benthos is classified into megalobenthos, macrobenthos, mediobenthos and microbenthos. Unlike plankton, benthos is almost sedentary and therefore closely reflects the characteristics of environmental conditions of a limited water body area. For this trait, benthos serves as an effective biotic index of the environment on the bottom of a body of water.
Best Available Techniques (BAT)	The latest stage in the development of activities, processes and their methods of operation which indicate the practical suitability of particular techniques as the basis of preventing or minimising emissions to the environment.
Best Environmental Practice	Practices which prevent or minimise the negative impacts of substances on the environment (e.g. prevention of run off of agrochemicals).
Bioaccumulation	The accumulation of contaminants in the tissues of organisms through any route, including respiration, ingestion, or direct contact with contaminated water, sediment, or dredged material.
Bioassay	A bioassay is an assay using a biological system. It involves exposing an organism to a test material and determining a response. There are two major types of bioassays differentiated by response: toxicity tests which measure an effect (e.g. acute toxicity, sublethal/Chronic toxicity) and bioaccumulation tests which measure a phenomenon (e.g. the take of contaminants into tissues).
Bioavailable	Generally refers to pollutants or contaminants which can be taken up by organisms, i.e., from water, sediment, suspended particles, food.
Biochemical Oxygen Demand (BOD)	The amount of oxygen required during the aerobic decomposition of organic matter in a body of water. Or, a measure of the quantity of oxygen used in the biochemical oxidation of carbonaceous and nitrogenous compounds in a specified time, at a specified temperature and under specified conditions. The standard measurement is made for five days at 20^0C and is termed BOD_5. BOD is an indicator of the presence of organic matter in the water.
Bioconcentration	Bioaccumulation of a substance in tissues to levels higher than in the source. Note that, in some cases, bioconcentration is used interchangeably with bioaccumulation, referring to the amount of a substance accumulated from water.

Biodegradable	An organic material's capacity for decomposition as a result of attack by microorganisms. Sewage-treatment routines are based on this property. Biodegradable materials do not persist in nature.
Biodiversity	The range of different species of flora and fauna found in a given region, area, habitat or within an ecosystem.
Biological Indicator	The use of living organisms or plants to characterise an environment or detect environmental change. The species should have a narrow ecological amplitude with respect to one or more environmental factors and therefore indicative of a particular environmental condition.
Biological Monitoring	Systematic determination of the effects on aquatic life including accumulation of pollutants in tissue, in receiving waters as a result of the discharge of pollutants (a) by techniques and procedures, including sampling of organisms representative of appropriate levels of the food chain appropriate to the volume and the physical chemical, and biological characteristics of the effluent, and (b) at appropriate frequencies and locations.
Biological Treatment	Biological treatment refers to the method of treating waste water, sewage, human waste, etc., by utilising the metabolism of organisms (bacteria, moulds, protozoa); it is mainly classified into aerobic treatment using aerobic organisms and anaerobic treatment using anaerobic organisms. **Aerobic treatment** involves decomposing organic substances in waste water into carbon dioxide, ammonia or water using aerobic organisms that are active when dissolved oxygen in water is sufficient. Aerobic treatment methods include activated sludge process and sprinkling filtration. **Anaerobic treatment** involves decomposing organic substances in wastewater into methane, carbon dioxide, hydrogen sulphide, ammonia or water, using anaerobic organisms that are active when dissolved oxygen in water is insufficient. Anaerobic treatment methods include methane fermentation, which is suitable for the treatment of high BOD industrial wastewater.
Biomagnification	Bioconcentration of the food chain, e.g., the route of accumulation is solely through food.
Biomass	The total mass of living matter, usually within a given area or volume of environment.
Biota	Living organisms, including animals, plants and bacteria in a given ecosystem.
Brackish	Brackish refers to an area of low salinity where fresh water and sea water are mixed near the estuary of a river flowing into the sea. In addition, tidal flats and lagoons of low salinity are also considered brackish areas.
Carcinogen	A material that either causes cancer in humans, or, because it causes cancer in animals, is considered capable of causing cancer in humans. Findings are based on the feeding of large quantities of a material to test animals or by the application of concentrated solutions to the animals' skin.
Catchment	The area of the drainage basin of a river.
Chemical Oxygen Demand (COD); also Chemical Oxygen Consumption	The amount of oxygen required to oxidize organic chemical compounds and oxidizable inorganic compounds in a body of water. COD, an indicator of water contamination, is the amount of oxygen consumed

(COC)	(mg/l) by potassium permanganate or other oxidation agents for oxidizing organic substances or pollutants in water. The higher the COD value, the more pollutants are in the water. (also see: Biochemical Oxygen Demand (BOD))
Chloride Ion	Chloride ion refers to ionized chloride (Cl^-), which forms ionized compounds with various metals. Chloride ion is also found in natural water, measuring several ppm in river water and 1.9% in sea water.
Coliform Bacteria	Coliform bacteria are present in the intestines, particularly large intestines, of humans and animals in large numbers and also widely found in the outside environment contaminated by excreta. Bacteria tests are considered to examine the presence of bacteria in foodstuffs and drinking water, and coliform bacteria culture tests to gauge the extent of contamination in rivers and lakes. Although coliform bacteria are avirulent and may not directly cause diseases, their presence signals contamination by human or animal excreta, which may contain pathogenic bacteria, as well as aggravated water contamination.
Coliform Count	Coliform count is used as a measure of water contamination, especially by human and animal excreta. There are several bacteria that have similar characteristics to those of coliforms. Since daily routine tests cannot distinguish between these bacteria and coliforms, the two are regarded as the coliform group in a coliform count. The coliform group is constantly present in the intestines of humans and animals. Although the coliform group does not entirely originate from excreta, its absence refutes contamination by excreta. A high coliform count indicates a high possibility of contamination by pathogenic bacteria related to digestive organs. A coliform count is indicated by the number of coliform bacteria in, for example, 100 mL of river water as the most probable number (MPN).
Colour	Pure water is colourless, transparent and clear, but water acquires colour when it contains various dissolved substances. Colour is expressed as compared to a standard solution.
Community (Biotic)	An assemblage of plant, animal and microbial species populations living in a given location at a given time; involves interrelationships between the species and is considered to constitute a functional system.
Contaminant	Any foreign component present in another substance; e.g., in the case of water, a chemical or biological substance in a form that can be incorporated into, onto, or be ingested by and that harms aquatic organisms, consumers of aquatic organisms, or users of the aquatic environment.
Contaminated Sediment or Contaminated Dredged Material	Sediments or materials that have unacceptable level of contaminant(s); that have been demonstrated to cause an unacceptable adverse effect on human health or the environment.
Contamination	Introduction of any undesirable foreign substance -- physical, chemical or biological -- into an *ecosystem*. Does not imply an effect (see *pollution*). Usually refers to the introduction of human-made substances.
Criteria	The standards established by regulatory bodies for certain pollutants, which not only limit the concentration, but also set a limit to the number of violations per year.

Cumulative Impact The evaluation of multiple projects and the interactions between them, to determine the combined impact of the projects on the system as a whole.

Cyanide Cyanides are compounds of metals with hydrocyanic acid. Highly toxic, cyanide ingested in a human body causes dyspnea and death within several seconds; the lethal dose is estimated at 0.06 g. Cyanide is contained in waste water discharged from plating factories, mining and other industries using hydrocyanic acid compounds.

Degradable That which can be reduced, broken down or chemically separated.

Detergent Detergent is mainly classified into soap, which has been in use since ancient times; and synthetic detergent, a product of modern chemical industry. Soap is made of higher fatty acid as its main ingredient, to which a builder is added to enhance cleansing capability. An aqueous solution of soap is weak alkaline, damages aquatic life and human skin.

Dioxin Common name for any of a family of compounds chemically known as tetrachloro-dibenzo-p-dioxins. Concern about them arises from their potential toxicity and contaminants in commercial products. Tests on laboratory animals indicate that it is one of the most toxic man-made chemicals known.

Discharge (Rate) The flow rate of a fluid at a given instant expressed as volume per unit of time.

Dissolved Oxygen (DO) Dissolved oxygen (DO) refers to the amount of oxygen dissolved in water. DO is essential for the self-purification process of water and aquatic organisms. Factors such as water temperature, air pressure and salt content affect DO. Highly contaminated water consumes a large amount of oxygen, leaving only a small amount of DO. On the other hand, clear water contains a large amount of oxygen.
In general, a DO of 5 mg/l or more is necessary for the life of fish and shellfish. The DO drops when large quantities of organic decayed substances enter and contaminate water.

Dredging Dredging refers to loosening and lifting earth and sand from the bottom of water bodies. Dredging is often carried out to widen the stream of a river, deepen a harbour or navigational channel, or collect earth and sand for landfill; it is also carried out to remove contaminated bottom deposit or sludge to improve water quality.

Ecological Impact The total effect of an environmental change, natural or man-made, on the community of living things.

Ecology The study of the relationships of organisms to their environment. The term 'ecology' refers to a branch of biology, but it also applies to a broader meaning. In the Concise Oxford Dictionary, the term is defined as "the scientific study of the inter-relationships among organisms and between organisms, and between them and all aspects ... of their environment."
Ecology has come into focus following the recognition that pollution has been brought about by human activities neglecting the natural environment and that human beings, as part of the natural system, must live in harmony with the natural environment for its preservation.

Ecosystem Ecosystem refers to the system of life formation by, organisms (animals, plants, etc) and close interactions between them and their physical environment. Or, a natural unit consisting of living and non-living parts interacting with each other, formed by the organisms of a natural

	community and their environment.
EDC	Ethylene dichloride, 1,2-Dichloroethane
Effluent	The outflow of a sewer, industry pipe, or other waste discharge.
Entero-Viruses	Viruses indicative of domestic sewage and a high risk of disease if not controlled or eradicated.
Environmental Assimilating Capacity	Human beings maintain life by harnessing resources in the environment into necessary objects or directly consuming natural resources. Wastes produced in these processes are returned to the environment, where they are assimilated into ecosystems, purified and reduced to resources. Environmental assimilating capacity refers to limits to the capability of ecosystems that purifies wastes and reduces them into resources, i.e. the natural purification capacity of the environment. If wastes are returned to the environment beyond the capacity, ecosystems are disturbed or even destroyed.
Environmental Indicator	Environmental indicator refers to a measure for evaluating a given environmental state as quantitatively as possible. Environmental indicators are used for various purposes, including (1) assistance to devising plans and measures, (2) assistance to the evaluation of plans and measures, (3) assistance to environmental monitoring, and (4) assistance to environmental education and community involvement. Environmental indicators should be determined comprehensively, based on conventional pollution-related data, natural environmental conditions, information concerning ecosystems and environmental comfort, and residents' environmental awareness. In preparing environmental indicators, voluminous chronological and a wide range of data must be collected and processed, and results must be rendered by visual modes, such as maps. Therefore, computer data processing systems are indispensable.
Erosion	A natural physical process where either wind, wave, rain or surface water run-off loosen and remove soil particles from land surfaces often deposited in rivers and lakes.
Eutrophication	The process of over-fertilisation of a body of water by nutrients producing more organic matter than the self-purification processes can overcome. In a body of water, where little exchange of water occurs, the inflow of industrial, domestic and agricultural waste water increases aquatic nutrients such as nitrogen and phosphorus, which, together with sunlight, trigger excessive growth of algae and plankton. In the decay process of algae and plankton, more phosphorus and nitrogen are released into the water, increasing a nutrient salt content therein. This phenomenon is called eutrophication.
Evaporation	The physical change of water into humidity or moisture suspended in the air.
Faecal Coliforms	Bacteria common to the digestive tract of human beings present in and indicative of domestic sewage and a high risk of disease if not controlled or eradicated.
Faecal Streptococci	An organism indicative of human and animal excreta and a high risk of disease if not controlled or eradicated.
Fertiliser	Any substance containing a nitrogen compound or nitrogen compounds

utilised on land to enhance growth of vegetation; it may include livestock manure, the residues from fish farms and sewage sludge.

Flocculation Particles suspended in a body of water generally have a negative electric charge, repelling each other and avoiding contact and bonding. When an electrolyte is added to a body of water, the electric charge of particles is neutralised, allowing particles to cohere, form flocs (groups) and settle. This phenomenon is applied to the coagulation-sedimentation method.

Groundwater All subsurface water that fills voids between highly permeable ground strata comprised of sand, gravel, broken rocks, porous rocks, etc. and move under the influence of gravitation. On the Earth, besides the sea water and the Antarctic water, far more groundwater exists than water in rivers, lakes and marshes.

Hardness The hardness of water is indicated by the content of dissolved calcium and magnesium salts. Calcium and magnesium salts that are transformed to insoluble salts by boiling denote temporary hardness, while calcium and magnesium salts that do not settle when boiled denote permanent hardness. The sum of temporary and permanent hardness is called total hardness.

Hazardous Substances Substances which have adverse impacts on living organisms, e.g. toxic, carcinogenic, mutagenic, teratogenic, harmful for the environment.

HCB Hexachlorobenzene

Heavy Metals Metallic elements of large atomic weight (eg. mercury, lead, nickel, zinc, copper and cadmium) that are of environmental concern because they do not degrade over time -- many are essential to life but can be toxic at certain concentrations.

Heterotrophic Growth In a water pollution context, this will mean growth of organisms - bacteria and fungus - based on the consumption of organic material and oxygen. Contrary to autotrophic (plant) growth which produces oxygen and organic matter.

Hydrocarbons Compounds found in fossil fuels, that contain carbon and hydrogen and may be carcinogenic.

Indicator Species Biological species and their distributions or formations vary, depending on environmental factors. Such biological variations can be used as indicators of environmental change.
Indicator species is a means (method) of describing environmental conditions of narrow ecological amplitude with respect to one or more environmental factors.
A good indicator species is, therefore, the species distributed over the smallest possible environment.

Industrial Wastes Wastes are classified into two types: industrial and ordinary. Industrial wastes are generated in or as a result of industrial activities and includes ashes, sludge, waste oil, waste acid, waste alkali, waste plastic, waste construction materials and so on.
Industrial wastes impart significant effect on the environment both in quantity and quality, and must be treated and disposed of in accordance with strict standards drawn up for different characteristics. Ordinary wastes refer to wastes other than industrial wastes.

LC50 (Median Lethal LC50 stands for median lethal concentration, i.e. the concentration of a

Concentration)	test substance estimated to kill 50% of test organisms. It is indicated with the testing time (e.g. 96 hLC_{50}).
LD50 (Median Lethal Dose)	LD50 stands for median lethal dose, the amount of a test substance estimated to kill 50% of test organisms.
Leachate	Liquid which has percolated through a substrate (e.g. soil, ore, waste dump, etc.).
Load	The quantity off a substance or material carried or transported by a river (and its associated hydrological processes).
Methyl Mercury	Methyl (organic) mercury compounds found in industrial effluent are generated in acetaldehyde manufacturing plants which use mercury sulphate as a catalyst. Incidents of mercury poisoning are associated with methyl mercury compounds.
Micro-Pollutants	Substances - like PCB, Dioxin, Cadmium, Mercury, etc. - that will create negative health impacts or adverse ecological changes even when available in low concentrations.
Microbiological Contamination	Pollution with microorganisms - like viruses, bacteria, protozoa, etc. - that might cause diseases in humans or animals.
mL	milli-Litres, one thousandth of a Litre
Mineral Oil	Residues of natural fossil fuels.
MPN	MPN stands for "most probable number", e.g. MPN/100 mL indicates the most probable number of bacteria in 100 mL reagent.
Nephalometric Turbidity Unit (NTU)	The measure of light penetration in seawater or another liquid used in electronic turbidity meters which corresponds closely to the Jackson Candle, or Jackson Turbidity Unit, because all instruments are calibrated to the equivalent of: 1 mg/l of SiO_2 = 1 NTU.
Nitrification	Nitrification refers to the process in which ammonia, produced by biological catabolism or the effect of putrefactive bacteria, is oxidized to nitrite and then to nitrate. Second-phase oxygen demand (on and after the 10th day) on BOD curves is mainly attributable to nitrification.
Nutrient	A substance, element or compound necessary for the growth and development of plants and animals.
Organic Materials	Compounds composed of carbon, hydrogen and other elements with chain or ring structures. Almost all chemical constituents of living matter are of this type, but very many compounds of this type are manufactured and do not occur naturally.
Organic Matter	Carbonaceous waste contained in plant or animal matter and originated from domestic or industrial sources.
Organic Pollutant	All substances are classified into organic and inorganic. Carbon compounds (excluding carbon monoxide and carbon dioxide) are collectively called organic substances. Substances other than organic substances are called inorganic substances (e.g. mercury, cadmium). The majority of pollutants contained in industrial and domestic waste water are organic. Pollutants other than organic pollutants are inorganic pollutants.

Organism	Any living thing.
Outfall	The place where an effluent is discharged into receiving waters.
Oxidation	In sewage treatment, the consuming or breaking down of organic wastes or chemicals in sewage by bacteria and chemical oxidants.
PAHs (Polynuclear or Polycyclic Aromatic Hydrocarbons)	A class of complex organic compounds, having more than one benzene ring, some of which are persistent and cancer-causing -- PAHs are often produced by coal gasification plants and oil refineries and may be formed by the combustion of petroleum.
Particulates	Fine liquid or solid particles such as dust, smoke, mist, fumes, or smog, found in the air or emissions.
Parts Per Million	This is a weight per volume or weight per weight measurement used in contaminant analysis. It is interchangeable with "milligrams per litre" or "milligrams per kilogram" in the case of liquids. Chemical dosages are often referred to as parts per million, e.g., 100 ppm of polymer. 100 ppm = 0.01%.
Pathogens	Disease causing organisms.
PCBs	Polychlorinated Biphenyls (see below)
PCP	PCP stands for pentachlorophenol, a chemical used in disinfectants, herbicides, defoliants, termite exterminating agents, preservatives for timber, etc. It has a peculiar smell and causes skin rash occasionally, although low in toxicity.
Persistent Chemicals	Substances that resist biodegradation and/or chemical oxidation when released into the environment and tend to accumulate on land, in air, in water, or in organic matter.
Pesticide	Any substance used to control pests ranging from rats, weeds, and insects to algae and fungi. Pesticides can accumulate in the food chain and can contaminate the environment if misused.
pH	A measure of the acidity or basicity of a solution i.e. the negative of the logarithm of the hydrogen ion concentration; "Hydrogen ion exponent", a unit for measuring hydrogen ion concentrations. A scale (0 to 14) represents an aqueous solution's acidity or alkalinity. Low pH values indicate acidity and high values, alkalinity. The scale's mid-point, 7, is neutral. Substances in an aqueous solution ionize to various extents, giving different concentrations of H and OH ions. Strong acids have excess H ions and a pH of 1 to 3 (HCl, pH = 1). Strong bases have excess OH ions and a pH of 11 to 13 (NaOH, pH = 12).
Phenols	Organic compounds that are by-products of petroleum refining, tanning, textile, dye, and resin manufacture. Low concentrations can cause taste and odour problems in water, higher concentrations can kill aquatic life.
Phytoplankton	Collectively, all the microscopic plants, such as certain algae, living unattached in aquatic habitats.
Phytoplankton Bloom (Algal Bloom)	An excessive growth of phytoplankton.
Plankton	Minute plants (phytoplankton) and animals (zooplankton) which either have relatively small powers of locomotion or drift in the water subject to

the action of waves and currents. The chief constituents of phytoplankton are unicellular algae. The zooplankton consists of protozoa, small crustaceans and various invertebrate larvae. Fish feed on plankton, and quantitative and qualitative changes in plankton serve as data for water quality control.

Point Source; Non-Point Source
A local discharge of pollutants (e.g. from an industrial plant); diffuse pollution in a catchment area (e.g. agricultural run-off).

Pollutant
A contaminant at a concentration high enough to endanger the environment or the public health.

Pollution (Water)
The discharge, directly or indirectly, of compounds from sources into the aquatic environment in such quantity as to pose risks to human health, living resources or to aquatic ecosystems, damage to amenities or interference with other legitimate uses of water.

Pollution Load
Pollution Load, usually indicated in kg or kg/day, refers to a total amount of water-contaminating substances generated by human activities or a total amount of pollutants contained in a unit amount of contaminated water. In a factory, the total pollution load refers to the total amount of pollutants generated in factory operation; in a river or sea area, it refers to the total amount of pollutants collected in the catchment area concerned.

Polychlorinated Biphenyls (PCBs)
One of a range of synthetic compounds, mainly used as liquid insulators in heavy-duty electrical transformers. They are resistant in the environment and are associated with reduced reproduction in marine birds and mammals and are believed to compromise the immune systems. Restrictions on their use were imposed in North America and Europe in the early 1970s.

ppb
Parts per billion, commonly considered equivalent to micrograms per litre or kilogram (g/L or   g/kg).

ppm
Parts per million, commonly considered equivalent to milligrams per litre or kilogram (mg/L or mg/kg).

ppt
Parts per trillion, commonly considered equivalent to nanograms per litre or kilogram (ng/L or ng/kg).

Precipitation
Rainfall, snowfall or any condensate.

Redox
A measure of the oxidation-reduction state, usually measured in milli Volts (mV)

Risk Assessment
In dealing with environmental problems, a certain degree of uncertainty is unavoidable, despite advances made thus far in the scientific elucidation of negative impact (or risk) on human beings and the natural environment. However, irreversible damage could be made if necessary measures were delayed until complete scientific elucidation is achieved.
In such a situation, an integrated policy-making approach of two processes, scientifically estimating and evaluating the negative impact of human activities on humans and the environment (risk assessment) and deciding and executing rational policies for risk mitigation based on risk assessment (risk management), is becoming established. International agreement made on the protection of the ozone layer is a precedent of this approach.

Scum
Scum refers to suspended matter found on the surface of a sedimentation

or fire extinguishing tank. Scum usually has a large content of fat.

Secchi Disk A disk about 20 cm (8 in) in diameter with a four-part propeller design of alternating black and white triangles painted on its surface; it is lowered with a rope fastened at its centre to measure vertical transparency of the water (via the depth of its "disappearance").

Sediment Solid fragmental material originating from weathering or rocks or by other processes and transported or deposited by air water or ice, or that accumulated by other processes such as chemical precipitation from solution or secretion by organisms. The term is usually applied to material held in suspension in water or recently deposited from suspension and to all kinds of deposits, essentially of unconsolidated materials.

Sediment Load The amount of sediment passing a cross section of a river or stream, in a specified period of time.

Sediment Monitoring Sediments represent one of the most important environmental factors that determine the distribution of living things. In the aquatic environment, in particular, sediments are closely related to water contamination. For this reason, sediment monitoring is conducted to obtain reliable data for judging the state of water contamination.

Sewage Sewage refers to waste water or rainwater originating from, or accompanying, domestic, industrial or commercial activities (excluding farming).

Sewerage Sewerage refers to a whole system of pipes, drains and other facilities installed to drain sewage (excluding irrigation facilities), treatment facilities connected to conduits pumping stations and so on.

Silt Fine particulate organic and inorganic material; strictly confined to material with an average particle size intermediate between those of sands and clays, but often taken to include all material finer than sands.

Silt Curtain (Silt Screen) A curtain suspended in the water to prevent silt from escaping from an aquatic construction site.

Species Group of related individuals with a common hereditary morphology, chromosomic number and structure, physiological characteristics and way of life, separated from neighbouring groups by a barrier, which is generally sexual in nature, and occupying a definable geographic area.

SQID Stormwater quality improvement device

Stakeholder A person, organisation or subgroup of an organisation that have a common interest in a project or activity. Also, a person who holds a sum of money deposed by the buyer in a transfer of ownership of land or a building; the deposit will be paid to the seller only if the buyer agrees, and vice versa.

Suspended Material The part of the sediment load that is in suspension.

Suspended Solids Inorganic and organic particles that are suspended in water. The term includes fine sand-, silt-, and clay-size particles as well as other solids such as biological materials suspended in the water column.

Thermal Effluent In nuclear and thermal power plants, large quantities of sea water is used as cooling water and sent back to the sea. The water discharged following the cooling process is slightly warm from the heat of vapour. For this reason, it is called thermal effluent.

Thermal Effluent Pollution Thermal effluent pollution refers to damage caused by thermal effluent discharged from nuclear or thermal power plants where large quantities of cooling water is used. A sudden water temperature rise in the body of water into which thermal effluent is discharged causes serious damage to the physiological functions of fish and shellfish, which do not have homothermal blood. High temperatures during a certain period are also believed to be fatal to seaweed culture.

Thermal Stratification Thermal stratification refers to stratum formation by light water in the upper stratum ad heavy water in the lower stratum.

Total Mercury (T-Hg) Total mercury refers to the aggregate of mercury compounds, both organic and inorganic.

Total Organic Carbon (TOC) Total organic carbon in water and sediment is primarily of natural origin. However, due to its strong tendency to absorb contaminants, it may often be used as an indicator of the degree of sediment or water contamination. TOC indicates a total amount of all organic substances, expressed by an amount of organic carbons (mg) contained in 1 litre of water.
Organic substances that contaminate water consist of mainly carbon, as well as hydrogen and oxygen; therefore, the degree of water contamination by organic substances can be gauged by measuring a carbon content in water.

Total Oxygen Demand (TOD) Total oxygen demand is an indicator of the degree of contamination in rivers, lakes, marshes, the sea and various types of waste water. TOD, a total amount of oxygen consumption required for complete oxidation of all types of pollutants existing in water, both organic and inorganic, is obtained by the actual combustion of a sample at 900^0C with the aid of a catalyst.
BOD and COD, similar indicators in use for some time, have the tendency of measuring only a portion of organic substances since they are not completely oxidized in some cases. Compared to these indicators, TOD has the advantages of full measurement of oxidizing matter made possible by complete combustion and a measuring time reduced to several minutes.

TPH Total Petroleum Hydrocarbons

Toxic Pollutant Pollutants, or combinations of pollutants, including disease-causing agents, that after discharge and upon exposure, ingestion, inhalation, or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will cause death, disease, behavioural abnormalities, cancer, genetic mutations, physiological malfunctions, or physical deformation in such organism or their offspring.

Toxic Substance Substances which cause harm to living organisms.

Toxic Substances Any chemical or material that has evidence of an acute or chronic health hazard; causes cancer or reproductive effects in animals at any dose level.

Toxicity The degree of danger posed by a substance to animal or plant life. Level of mortality by a group of organisms that have been affected by the properties of a substance, such as contaminated water, sediment, or dredged material.

	A term describing the limit of intolerance of organisms to survive lethal chronic or short-term subjection to certain chemical and contaminating substances, or physical and environmental conditions.
Transient Impacts	Defined in this study as those observed during short duration wet weather events where stormwater runoff can have significant impacts.
Transparency (Secchi Disk)	Transparency is an indicator of the degree of water contamination as expressed by its clarity. To measure transparency, a white-painted circular plate 30 cm in diameter (called Secchi Disk) is submerged, and a depth of water (length of a rope attached to the disk) at which the disk becomes invisible from above is expressed as transparency.
Tributylxin (TBT) (Organotin)	An extremely toxic marine anti-fouling agent. Concentrations as low as two parts per trillion can affect marine life. Banned in most European countries for use on boats greater than 25 m in length.
Turbidity	Turbidity, a unit indicating a degree of impurities in water, is used in tests of water and waste water turbidness. The turbidity of 1 litre of water containing 1 mg of kaoline is set at 1 degree of turbidity.
Water Quality Criteria	A scientific requirement on which a decision or judgement may be based concerning the suitability of water quality to support a designated use.
Water Users	Water is used *by* a number of users: Public and municipal sectors, agriculture and fisheries, industry, transport and energy.
Water Uses	Water is used *for* a number of purposes: Water supply for drinking water, irrigation, and industry (including food production), as a recipient of waste water from the public sector, industry and agriculture, for transport, for energy production, for recreation, riverine and other ecosystems, and Biodiversity.
Wetland	A periodically inundated wooded area. Land that has the water table at, near or above the land surface or that is saturated for a long enough time to promote wetland or *aquatic* processes and various kinds of biological activity that are adapted to the wet *environment*. Includes fen, bog, swamp, marsh and shallow open water.

*Many of the definitions have been adapted from PIANC (2000) *Glossary of Selected Environmental Terms,* Supplement to Bulletin No. 104, 2000, Report of Working Group No 3 of the Permanent Environmental Commission.

APPENDIX C

CATCHMENT DETAILS

Table C1: Mill Pond Catchment Details

Subcatchment	Area (ha)	Catchment Land Use	Catchment Length (km)	Max Height (m)	Min Height (m)	Catch Slope (%)	Impervious (%)	Impervious Area (ha)	Pervious area (ha)
M1	58.90	Residential	1.053	110.0	60.0	4.75%	50	29.45	29.45
M2	53.92	Grassed	0.645	78.0	44.0	5.27%	5	2.70	51.22
M3	68.51	SCG	1.128	71.0	49.9	1.87%	50	34.26	34.26
M4	35.57	Moore Park	1.049	56.0	44.0	1.14%	10	3.56	32.01
M5	43.19	Moore Park	0.63	60.0	40.0	3.17%	20	8.64	34.55
M6	41.55	Grassed	0.867	46.0	36.0	1.15%	20	8.31	33.24
M7	9.54	Grassed	0.9	41.0	35.0	0.67%	5	0.48	9.06
M7-1	8.15	Grassed	0.9	41.0	35.0	0.67%	5	0.41	7.74
M7-2	4.55	Grassed	0.9	41.0	35.0	0.67%	30	1.37	3.19
M7-3	12.63	Grassed	0.9	41.0	35.0	0.67%	30	3.79	8.84
M7-4	7.86	Grassed	0.9	41.0	35.0	0.67%	30	2.36	5.50
M7-5	19.21	Grassed	0.9	41.0	35.0	0.67%	5	0.96	18.25
M8	14.35	Grassed	0.726	60.0	37.0	3.17%	10	1.44	12.92
M8-1	27.96	Residential	0.726	60.0	37.0	3.17%	50	13.98	13.98
M9	36.21	Queens Park	0.87	91.8	47.0	5.15%	10	3.62	32.59
M10	29.59	Residential	0.891	87.0	47.0	4.49%	50	14.80	14.80
M11	29.16	Residential	0.851	60.0	50.0	1.18%	50	14.58	14.58
M11-1	10.04	Grassed	0.544	47.0	37.0	1.84%	5	0.50	9.54
M12	18.84	Residential	0.839	60.0	30.0	3.58%	50	9.42	9.42
M12-1	38.19	Residential	0.839	60.0	30.0	3.58%	50	19.10	19.10
M13	32.16	Grassed	0.94	41.0	31.0	1.06%	10	3.22	28.94
M14	38.95	Residential	1.472	40.0	30.0	0.68%	50	19.48	19.48
M14-1	18.64	Residential	1.472	40.0	30.0	0.68%	50	9.32	9.32
M15	56.90	Racecourse	1.053	31.0	30.0	0.09%	5	2.85	54.06
M16	24.65	Grassed	0.946	50.0	30.0	2.11%	5	1.23	23.42
M17	36.47	Residential	0.808	77.0	60.0	2.10%	50	18.24	18.24
M18	46.29	Residential	0.862	57.0	29.0	3.25%	50	23.15	23.15
M19	84.82	Residential	1.377	30.0	20.0	0.73%	50	42.41	42.41
M20	29.84	Residential	1.25	30.0	20.0	0.80%	50	14.92	14.92
M20-1	47.05	Golf Course	1.25	30.0	20.0	0.80%	1	0.47	46.58
M21	44.08	Residential	0.992	73.0	45.0	2.82%	50	22.04	22.04
M22	53.99	Residential	0.769	80.0	42.0	4.94%	50	27.00	27.00
M23	93.52	Residential	1.14	40.0	22.0	1.58%	50	46.76	46.76
M24	59.97	Residential	1.013	30.0	23.0	0.69%	50	29.99	29.99
M25	33.46	Residential	1.212	24.0	12.0	0.99%	50	16.73	16.73
M26	23.51	Grassed	0.424	20.0	12.0	1.89%	10	2.35	21.16
M26-1	31.64	Grassed	0.424	20.0	12.0	1.89%	9	2.85	28.79
M26-2	51.69	Park	0.424	20.0	12.0	1.89%	5	2.58	49.11
M27	78.04	Residential	0.795	23.0	12.0	1.38%	50	39.02	39.02
M28	98.73	Residential	0.992	12.0	8.0	0.40%	50	49.37	49.37
M29	41.78	Grassed	0.915	12.0	8.0	0.44%	5	2.09	39.69
M29-1	23.25	Residential	0.915	12.0	8.0	0.44%	30	6.98	16.28

Subcatchment	Area (ha)	Catchment Land Use	Catchment Length (km)	Max Height (m)	Min Height (m)	Catch Slope (%)	Impervious (%)	Impervious Area (ha)	Pervious area (ha)
M30	63.87	Golf Course	1.425	30.0	6.6	1.64%	5	3.19	60.68
M30-1	30.33	Industrial	1.425	30.0	6.6	0.10%	50	15.17	15.17
M31	39.02	Residential	0.564	6.6	5.0	0.28%	50	19.51	19.51
M32	22.38	Grassed	1.225	5.0	0.0	0.41%	5	1.12	21.26

Table C2: Springvale and Floodvale Catchment Details

Subcatchment	Area (ha)	Catchment Land Use	Catchment Length (km)	Max Height (m)	Min Height (m)	Catchment Slope (%)	Imperv Fraction (%)	Impervious Area (ha)	Pervious area (ha)
Springvale Drain									
S1	20.29	Residential	0.597	22.8	21.0	0.30%	60	12.17	8.12
S2	10.66	Golf Course	0.454	30.0	21.5	1.87%	10	1.07	9.59
S3	27.57	Golf Course	0.596	30.0	20.0	1.68%	10	2.76	24.81
S4	18.33	Residential	0.66	30.0	13.5	2.50%	60	11.00	7.33
S5	9.25	Mixed	0.491	30.0	13.6	3.34%	50	4.63	4.63
S6	16.57	Industrial	0.573	19.1	10.0	1.59%	60	9.94	6.63
S7	13.53	Industrial	0.324	16.9	12.9	1.23%	50	6.77	6.77
S8	10.27	Industrial	0.387	12.6	8.7	1.01%	18	1.85	8.42
S9	7.37	Industrial	0.289	10.0	8.0	0.69%	50	3.68	3.68
S10	12.99	Industrial	0.542	13.0	4.3	1.61%	60	7.79	5.20
S11	13.67	Industrial	0.415	13.6	8.8	1.16%	65	8.89	4.78
S12	10.91	Industrial	0.348	8.8	5.0	1.09%	30	3.27	7.64
S13	5.36	Industrial	0.368	5.5	5.0	0.14%	30	1.61	3.75
S14	10.27	Industrial	0.318	13.7	8.0	1.79%	80	8.22	2.05
S15	14.17	Industrial	0.467	7.7	4.8	0.62%	20	2.83	11.34
S16	3.63	Grassed	0.293	5.6	4.8	0.27%	10	0.36	3.27
S17	3.42	Industrial	0.211	10.0	5.0	2.37%	80	2.74	0.68
S18	4.81	Residential	0.239	5.0	3.7	0.54%	90	4.33	0.48
S19	2.98	Residential	0.23	4.7	3.7	0.43%	90	2.68	0.30
S20	6.17	Industrial	0.331	6.0	3.0	0.91%	80	4.94	1.23
S21	3.46	Industrial	0.257	3.0	2.9	0.04%	80	2.77	0.69
S22	6.95	Industrial	0.276	3.6	3.0	0.22%	95	6.60	0.35
S23	7.09	Grassed	0.226	3.0	2.9	0.04%	10	0.71	6.38
S24	1.64	Grassed	0.166	3.0	3.0	0.00%	10	0.16	1.47
Floodvale Drain									
F1	18.99	Residential	0.618	34.0	18.0	2.59%	70	13.29	5.70
F2	11.25	Industrial	0.228	19.0	14.0	2.19%	70	7.88	3.38
F3	15.86	Industrial	0.464	13.0	10.0	0.65%	50	7.93	7.93
F4	19.65	Industrial	0.518	10.0	6.0	0.77%	70	13.76	5.90
F5	10.14	Industrial	0.479	10.5	5.5	1.04%	80	8.11	2.03
F6	10.39	Industrial	0.283	10.0	6.0	1.41%	55	5.71	4.68
F7	10.7	Industrial	0.196	5.7	4.7	0.51%	70	7.49	3.21
F8	7.24	Industrial	0.395	8.0	4.0	1.01%	60	4.35	2.90
F9	5.15	Industrial	0.182	3.0	2.7	0.16%	70	3.60	1.54
F10	4.89	Industrial	0.323	6.0	4.6	0.43%	60	2.94	1.96
F11	3.78	Grassed	0.221	3.3	3.1	0.09%	10	0.38	3.40

Table C3: Foreshore Beach Catchment Details

Subcatchment	Area (ha)	Catchment Land Use	Catchment Length (km)	Max Height (m)	Min Height (m)	Catchment Slope (%)	Imperv Fraction (%)	Impervious Area (ha)	Pervious area (ha)
D1	10.53	Residential	0.45	27.3	9.0	4.07%	70	7.37	3.16
D2	23.93	Residential	0.389	9.0	6.8	0.57%	70	16.75	7.18
D3	13.68	Residential	0.294	7.0	4.0	1.02%	50	6.84	6.84
D4	15.86	Residential	0.53	6.8	4.5	0.43%	70	11.10	4.76
D4-1	14.91	Residential	0.35	6.8	4.5	0.66%	70	10.44	4.47
D5	20.97	Residential	0.65	26.0	8.0	2.77%	60	12.58	8.39
D6	14.75	Industrial	0.38	10.0	6.0	1.05%	70	10.33	4.43
D7	21.01	Industrial	0.53	10.0	4.0	1.13%	80	16.81	4.20
D8	15.48	Industrial	0.54	4.0	2.0	0.37%	80	12.38	3.10
D9	10.18	Industrial	0.77	2.0	0.0	0.26%	60	6.11	4.07
D10	28.85	Industrial	0.7	2.0	0.0	0.29%	65	18.75	10.10
D11	23.63	Residential	0.54	2.0	0.0	0.37%	50	11.82	11.82
D12	14.12	Industrial	0.53	12.0	4.0	1.51%	90	12.71	1.41
D13	9.06	Industrial	0.64	12.0	4.0	1.25%	90	8.15	0.91
D14	16.25	Residential	0.33	12.0	4.0	2.42%	70	11.38	4.88
D15	19.16	Residential	0.432	10.0	4.0	1.39%	70	13.41	5.75
D16	22.22	Grassed	0.6	4.0	0.0	0.67%	30	6.67	15.55
D17	27.88	Grassed	0.52	2.0	0.0	0.38%	30	8.36	19.52
D18	16.80	Grassed	0.5	2.0	0.0	0.40%	20	3.36	13.44

APPENDIX D

SUMMARY OF MUSIC MODEL PARAMETERS

Table D1: Catchment Parameters

Catchment Element/Parameter	Residential Mill Pond Catchment	Residential Floodvale/ Springvale and Foreshore Beach Catchments	Industrial Floodvale/ Springvale and Foreshore Beach Catchments	Grassed Mill Pond Catchment	Grassed Springvale, Floodvale and Foreshore Beach Catchments	Mixed Mill Pond Catchment
Impervious/pervious ratio (%)	From topographic features	From topographic features	From topographic features	From topographic features	From topographic features	From topographic features
Shallow/deep soil percentage for pervious area	% deep = % shallow	% deep = % shallow	% deep = % shallow	% deep = % shallow	% deep = % shallow	% deep = % shallow
Example Catchments	M27 25% : 25%	S1 20% : 20%	S12 35:35	M26-2 47:47	S16 45:45	S5 25:25
Field Capacity (mm)	100	100	100	100	100	100
Infiltration capacity coefficient 'a'	100	100	100	100	50/100	100
Infiltration capacity exponent 'b'	0.25	0.25	0.25	0.25	0.25	0.25
Rainfall threshold (mm)	2	0	0	2	0	0
Shallow soil area capacity (mm)	150	150	150	150	150	150
Shallow soil area initial storage (% of Capacity)	50	50	50	50	50	50
Deep soil area capacity (mm)	300	300	300	300	350	350
Deep soil initial storage (% of Capacity)	50	50	50	50	50	50
Daily recharge rate (%)	90	90	90	90	90	90
Daily drainage rate (%)	2	2	2	2	2	2
Initial depth (mm)	100	100	100	100	100	100
Storm flow Mean TSS (log)	1.3	1.7	1.7	1.3	1.7	1.7
Storm flow Std Dev (log)	0.2	0.2	0.2	0.467	0.2	0.2
Storm flow TSS Estimation method	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated
Base flow Mean TSS (log)	1.3	1	1	1.352	1	1
Base flow Std Dev (log)	0.2	0.2	0.2	0.4	0.2	0.2
Base flow TSS Estimation method	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated

Catchment Element/Parameter	**Residential**	**Residential**	**Industrial**	**Grassed**	**Grassed**	**Mixed**
	Mill Pond Catchment	**Floodvale/ Springvale and Foreshore Beach Catchments**	**Floodvale/ Springvale and Foreshore Beach Catchments**	**Mill Pond Catchment**	**Springvale, Floodvale and Foreshore Beach Catchments**	**Mill Pond Catchment**
Storm flow Mean TP (log)	-1	-0.6	-0.6	-1	-0.6	-0.6
Storm flow Std Dev (log)	0.2	0.2	0.2	0.45	0.2	0.2
Storm flow TP Estimation method	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated
Base flow Mean TP (log)	-1	-1	-1	-0.882	-1	-1
Base flow Std Dev (log)	0.2	0.2	0.2	0.4	0.2	0.2
Base flow TP Estimation method	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated
Storm flow Mean TN (log)	-0.1	0.3	0.3	-0.1	0.3	0.3
Storm flow Std Dev (log)	0.2	0.2	0.2	0.2	0.2	0.2
Storm flow TN Estimation method	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated
Base flow Mean TN (log)	-0.1	0.2	0.2	-0.1	0.2	0.2
Base flow Std Dev (log)	0.2	0.2	0.2	0.2	0.2	0.2
Base flow TN Estimation method	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated	Stochastically generated

Table D2: Swale/Ponds Parameters

Treatment Feature	Swales*	Swales* (Foreshore Beach Drains)	Ponds
Length (=overland flow length) & bed slope (= overland flowpath slope)	From topographic features	From topographic features	NA
Base width (m)	2	1	NA
Top width (m)	5	5	NA
Depth (m)	0.5	0.5	NA
Vegetation height (m)	0.25	0.25	NA
Number of CSTR cells	10	10	2
k for TSS	0	0	100
c* for TSS	30	2	7
c** for TSS	13.6	2.6	N/A
k for TP	0	0	50
c* for TP	0.18	0.18	0.06
c** for TP	0.143	0.143	N/A
k for TN	0	0	50
c* for TN	0.8	1.5	0.5
c** for TN	1.68	1.68	N/A
Threshold hydraulic loading for c** (m/yr)	3500	3500	N/A
Bypass flows in excess of (cumecs)	NA	NA	200
Inlet pond volume (cubic metres)	NA	NA	0
Surface area (sq metres)	NA	NA	Literature
Extended depth (m)	NA	NA	Average or maximum depth
Permanent pool volume (cubic metres)	NA	NA	Half or one tenth of capacity
Outlet pipe diameter (m)	NA	NA	Adapted from actual structure
Overflow weir width (m)	NA	NA	Adapted from actual structure

*Swales used in model schematisation to route flow only (ie no treatment function incorporated).

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