Metropolitan Region Scheme

Amendment No. 1010/33

PORT CATHERINE
ENVIRONMENTAL REVIEW

VOLUME 2
APPENDICES I - VIII

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(M.P. Rogers & Associates)

October 2000

Port Catherine Developments Pty Ltd

Port Catherine Development Coastal Engineering Study

M P ROGERS & ASSOCIATES

Coastal & Port Engineers

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1. Introduction

Port Catherine Developments Pty Ltd has prepared a concept plan for the development of a large residential and recreational project known as the Port Catherine Development. It is located between the old South Fremantle Power Station and Coogee Beach (see Figure 1.1).

As shown on Figure 1.2, the proposed development includes the following:

- Conventional residential estate,
- Residential canal estate,
- A marina for about 150 to 170 recreational boats, and
- Water front commercial development.

Port Catherine Developments Pty Ltd engaged Bowman Bishaw & Gorham (BBG) to prepare the necessary environmental report and obtain the environmental approval for the proposed development. To assist in this process, BBG engaged M P Rogers & Associates Pty Ltd (MRA) to complete investigations on the coastal engineering aspects of the development. This work included assessment of the following items:

- Meteorological and oceanographic conditions,
- Water quality in the waterways, and
- Coastal stability and harbour siltation.

The investigations, results and recommendations of this work are presented in this report.

2. Met-Ocean Conditions

2.1 Wind Regime

The seasonal weather patterns at Fremantle are largely controlled by the position of the so called Subtropical High Pressure Belt. This is a series of discrete anticyclones that encircle the Earth at mid-latitudes (20 to 40 degrees). Throughout the year, these high pressure cells are continuously moving from west to east across the southern portion of the Australian continent. A notional line joining the centres of these cells is known as the High Pressure Ridge.

In winter, this ridge lies across Australia typically between 25 to 30 degrees south and is to the north of Fremantle at 32 degrees 03 seconds south. Consequently, the migrating low pressure systems, which exist to the south of the High Pressure Ridge, are located sufficiently northward to bring a westerly wind regime to the southwest of Western Australia and the adjacent waters. Cold fronts associated with these low pressure systems frequently pass over the Fremantle region during this season. These can bring storm force winds with directions from northwest, through west, to southwest.

During summer, the High Pressure Ridge moves south of Fremantle and lies between 35 and 40 degrees south. Under these circumstances, the Fremantle region comes under the influence of the high pressure cells of the High Pressure Ridge. These cells cause anti-cyclonic winds that rotate anti-clockwise in the Southern Hemisphere. At Fremantle, these winds arrive from the southeast to east as the high pressure cell approaches from the west. The winds then rotate through northeast to north as the high pressure cell passes to the Great Australian Bight.

In addition to these synoptic scale effects, which cause seasonal variations, the meso-scale phenomenon of a land / sea-breeze system is commonly experienced during summer at Fremantle and adjacent coastal regions. This causes variations on a daily time scale. Breezes initially come from the land (east and southeast) in the morning but then swing around to be blowing from the sea (southwest) in the afternoon.

The Fremantle Port Authority has recorded the wind speed and direction at Fremantle over several decades. The monthly wind roses for the 4 years from 1981 to 1983 are shown on Figure 2.1. These wind roses show the storm force winds from the northwest to southwest that occurs in the winter months of July to September. During this period, the wind speed often exceeds 15 m/s (30 knots) due to the passage of the cold fronts associated with the winter storms.

The wind roses for the months of October to March, show that the common wind directions during the spring and summer months is from southwest through south to east. The wind speeds are typically between 5 and 12 m/s (10 to 25 knots). Because of the land / sea-breeze effect, the winds commonly come from the east and southeast in the mornings and from the southwest to south in the afternoons during spring and summer.

Occasionally in late summer, dissipating tropical cyclones may pass through the region. These have a pronounced, short term effect on the regional weather patterns.

The wind regime influences coastal processes through the generation of ocean waves and currents as well as feeding dune systems with wind blown beach sand. The action of wind will play an important role in the mixing of the enclosed waters of the proposed Port Catherine Development.

2.2 Wave Climate

Wave measurements and observations taken in the deep water offshore from Fremantle indicate that the area experiences reasonably high wave energy. The main elements of the offshore wave climate are as follows.

- Seas generated locally by the passage of cold fronts during winter. The wave heights and periods vary markedly from storm to storm. Often the wave heights exceed 4 metres and the wave periods reach 6 to 10 seconds. The direction from which these storm waves approach can range from northwest to southwest during the passage of the storm.

- Swell waves from distant storms in the Southern Indian Ocean continually reach the offshore area throughout the year. The swell waves often exceed 2 metres in height, and typical periods are between 8 and 16 seconds. The swell waves commonly approach from the southwest, and tend to be slightly smaller and more southerly in summer compared to winter.

- Seas produced by the sea-breeze. The generation of these waves is limited by the duration and the offshore extent of the sea-breeze system, with heights typically 0.5 to 1.5 metres high and periods of 3 to 6 seconds. The direction of these waves is generally from the southwest to south.

- Severe waves caused by dissipating tropical cyclones. These storms are infrequent at Fremantle, however, when they do occur they cause severe conditions for short periods of time.

As the offshore waves travel toward the shore, they are greatly affected by the nearshore bathymetry and the reefs extending from Garden Island to Rottnest Island. The bathymetry of the area, the islands and reefs are shown on Figure 2.2. Waves travelling to the shores of Owen Anchorage are modified by the following physical processes.

- Reflection off the reef faces,
- Depth limited breaking on the reef tops and in shallow areas,
- Diffraction through the gaps in the reefs,
- Attenuation due to hydraulic turbulence as the waves travel over the reefs and other areas of shallow water, and
- Refraction and shoaling.

These processes act in varying degrees, and significantly modify and attenuate the waves as they approach the shores of Owen Anchorage.

Computer modelling of the nearshore wave conditions has been completed for other projects in Owen Anchorage and Cockburn Sound (Rogers & Associates, 1995 and Rogers & Associates, 1996). Figure 2.3 shows a spatial plot of the wave conditions in the Fremantle area during the initial part of a typical winter storm. The contours show the significant wave height at 0.5 metre intervals and the arrows indicate the wave direction and period. Offshore, the waves are approaching from the west-northwest with significant wave heights of about 3 metres and periods in the range of 6 to 12 seconds. These waves are greatly attenuated by the time they reach the eastern shores of Owen Anchorage. At the Port Catherine site, the waves during the storm are about 0.5 metres in height and arrive from the west-northwest. This would tend to move beach sand along the coast towards the south.

Figure 2.4 shows the wave patterns for a commonly occurring background swell event. Offshore, the swell waves are about 3 metres high with periods in the order of 10 to 14 seconds, and are approaching from the west-southwest. At the Port Catherine site, the swell is less than 0.5 metres high are arriving from the west. Such conditions would also tend to move sediment in a southerly direction along the shore.

The wave conditions during a sea-breeze event are shown in Figure 2.5. Offshore, the seas are about 1.5 metres high with periods of about 4 to 6 seconds, and are approaching from the southwest. At the proposed development site, the waves are less than 0.5 metres high and coming from the southwest. These wave conditions would tend to move sediment in a northerly direction along the shore.

The reefs and nearshore bathymetry provide Owen Anchorage with significant protection from the offshore waves. Nevertheless, the resultant waves that break on the beach are believed to be the most important mechanism in the transport of sand in the littoral zone at the Port Catherine site.

2.3 Water Level Fluctuations

The astronomical tides at Fremantle are described in the Australian National Tide Tables (Commonwealth of Australia, 2000). They are predominantly diurnal (one tidal cycle each day) and relatively small in amplitude. The daily range is typically about 0.5 metres during spring tides and less than 0.3 metres during neap tides. Other tidal characteristics at Fremantle are listed below.

- Mean High High Water (MHHW) = 0.9 metres above Chart Datum.
- Mean Sea Level (MSL) = 0.7 metres above Chart Datum.
- Mean Low Low Water (MLLW) = 0.2 metres above Chart Datum.

Seasonal shifts in the sea level occur due to the Leeuwin Current and meteorological effects. Typically, the mean sea level at Fremantle rises 0.1 metre during winter and falls 0.1 metre during summer.

During storms events (both winter storms and cyclones) barometric and wind effects can cause significant storm surges. In rare storms, the surge can exceed 1 metre above the astronomical tide level.

Other than astronomical tidal variations, fluctuations in the mean water level can also be caused by the effects of atmospheric pressure systems and winds. Water level fluctuations due to atmospheric pressure and winds have been observed to be in the order of 1 metre with periods of 3 to 8 days around the southern parts of Australia. Fluctuations observed at Fremantle have been around 0.3 to 0.5 metres with similar periods of 3 to 8 days (Provis & Radok, 1976). A practical significance of these atmospheric water level fluctuations is the role they play in promoting the water exchange between the ocean and enclosed bodies of water.

Given the small astronomical tides, the height of the still water level would generally have a secondary effect on the sand transport along the beaches, except during storm events when high water levels would enable the waves to attack the rear of the sandy beaches.

The astronomical tidal movements will be important in the exchange of water between the enclosed waters of the development and the adjacent ocean. Atmospheric effects over a 3 to 8 day time frame will also assist in the water exchange process.

2.4 Currents in Owen Anchorage

Studies conducted during the Perth Coastal Waters Study found that the nearshore currents of the Perth coastal region (which includes Owen Anchorage) are predominantly driven by local winds, and the seasonal distribution of currents reflects the seasonal changes in the wind field. This study found that during the spring and summer months, up to 60% of the variance in the current field may be explained by the wind field, and wind speeds greater than 3 to 5 m/s are sufficient to dominate the flow dynamics in the nearshore waters where the depths are less than 10 metres.

The direction of current flow during spring and summer in the Owen Anchorage area is typically northwards due to the predominance of southerly winds. Data recorded by WNI Science Engineering at Success Bank in Owen Anchorage during the summer of 1995 shows that typical current speeds of around 0.2 to 0.3 m/s could be expected during the sea-breeze (Rogers & Associates, 1997).

During the winter months there is a weaker correlation between the wind and the currents compared to the summer months in the coastal waters of Perth. The weaker correlation during winter is due to the variation in wind direction and the currents also being more variable (Lord & Hillman, 1995). However, current speeds of around 0.1 to 0.3 m/s during winter would not be unusual.

3. Water Quality

3.1 General

Water Quality is a term used to describe the chemical, physical, and microbiological characteristics of a water body. In general, the quality of a waterway depends on three external factors:

- The quality of the source water,
- The management of nutrient and pollutant inflow; and
- The mixing and exchange processes.

In addition to these, the physical, chemical, and biological processes occurring within the water body may either enhance or degrade the quality of its water. The extent to which such internal processes influence water quality depends on the interaction between the aquatic ecosystem and the external factors. In general, these internal processes are only significant in water bodies characterised by long residence times, such as lakes and reservoirs.

The intended uses of the proposed waterways are:

- Direct contact recreation (eg occasional swimming),
- Mooring and navigation of boats,
- Adjacent residential and commercial development, and
- Passive recreation (eg enjoying the scenery).

Guidelines pertaining to the water quality of fresh and marine water bodies in Western Australia have been published in draft form by the Environmental Protection Authority (EPA, 1993). Under these guidelines, the proposed use of the waterway falls in the category titled "Recreational Water Quality and Aesthetics - Primary Contact". A copy of the Water Quality Guidelines for Fresh and Marine Waters for Recreational Primary Contact is included in Appendix A. The marina and associated waterways will be designed and managed to meet these requirements for Recreational Primary Contact.

3.2 Source Water

In developments of this nature, the ability to achieve a certain level of water quality is dependent on the quality of the source water. As such, it is only reasonable to expect that water quality as good as that of the existing source water be maintained.

The source water for the proposed waterway development will be the waters of the northern portion of Owen Anchorage. This area of water has seen significant improvements in the nutrient-based water quality since the 1970's, when the water quality was at its worst. This improvement has largely been due to the recent relocation or closure of many nearby industrial plants and the use of sewerage by the remaining industries. These changes have led to the reduction of direct waste discharges into Owen Anchorage, and therefore, the reduction in nutrient loading (Department of Environmental Protection, 1996). Nevertheless, this area of Owen Anchorage has been used for recreational pursuits including Recreational Primary Contact for a number of decades.

Based on this subjective information, it is taken that the source water is suitable for the intended development use of Recreational Primary Contact.

3.3 Management of Nutrient and Pollutant Inflow

The influx of nutrients and pollutants into the waterways will be minimised by careful design and management of the water bodies.

Measurements of the groundwater flowing towards the coast in the vicinity of the proposed Port Catherine Development site by Bowman Bishaw Gorham (BBG) shows elevated levels of nitrogen. Empirical calculations and computer modelling indicates that without appropriate management techniques, the level of DIN in the proposed waterway will be unacceptable and would greatly increase the probability of algal blooms. As such, groundwater extraction involving the use of a cut-off drain is proposed to reduce the amount of groundwater flow into the development waterway. However, results of extensive borehole monitoring by BBG suggest that the elevated levels of DIN currently in the groundwater adjacent to the proposed Port Catherine Development site is only a medium term problem. BBG has estimated that the elevated concentration of DIN in the groundwater is likely to completely pass through the system in around 7 to 12 years. After the depletion of the elevated levels of nitrogen in the groundwater, it is predicted that the groundwater extraction will not be required.

In addition to the groundwater extraction system, the design elements will also include the development of a reticulated sewerage system, and the collection and piping of all storm water runoff into soakage areas and only allow overflow into the waterways from major rainfall events.

The ongoing management of nutrient and pollutant inputs will include the following:

- Rubbish disposal and effluent discharge into the waterways will be banned and policed by the waterways manager,

- The use of plant species that require minimal watering and fertilising will be encouraged and required by the waterway manager, and

- The use of tributyl tin oxide antifouling on boats is prohibited under State Law.

In addition, the waterway manager will establish a comprehensive fuel and oil spill response plan to minimise any impacts from any accidental spills in the waterway. A key element of this will be the rapid deployment of floating barriers across the waterway entrance channel. This will prevent the spill moving out into Owen Anchorage. Skimmers and oil dispersants would then be deployed to treat and remove the spilt fuel or oil.

3.4 Mixing & Exchange

The water in the various waterways will be mixed by the action of tides, winds, waves, and boat traffic. All of these mechanisms will ensure that the water bodies are regularly and well mixed.

There are several physical processes that cause water exchange between harbours and the adjacent source waters. These include:

- Tidal fluctuations,

- Density currents,

- Inflow of ground water, and

- Wind induced currents.

In small waterways such as those in the proposed development, horizontal density currents are most likely to be set up from groundwater inflow. Other processes that may generate density currents include evaporation, and atmospheric heating and cooling of the surface waters. In the proposed development though, the surface area of the waterway limits the extent of significant longitudinal variations in density that can be created by these processes.

It should be noted that over the years, the operation of nearby market gardens has caused large quantities of nitrogen to leach into the groundwater that flows into the development site. Borehole tests completed by Bowman Bishaw Gorham suggest that the average concentration of Dissolved Inorganic Nitrogen (DIN) in the groundwater is around 4.4 mg/L. However, it is predicted that the concentration of DIN will decrease to 1 mg/L in around 7 to 12 years after this elevated nutrient load in the groundwater has completely passed through the system (pers comm Richard Gorham, BBG).

A detailed study of the likely water exchange and water quality of the proposed Port Catherine Development has been investigated in detail using 3-dimensional hydrodynamic and transport modelling techniques by Rogers & Associates (2000). The 3-dimensional hydrodynamic and transport model used accounts for the dominant water exchange mechanisms (ie tidal fluctuations, density currents, the inflow of groundwater and nutrients, and wind induced currents).

The investigations completed by Rogers & Associates (2000) examined the management techniques required to keep the nutrient levels to an acceptable level before and after the depletion of the elevated DIN levels. In addition, Rogers & Associates (2000) also investigated the water quality between the proposed Port Catherine Development and other established harbours in the Perth metropolitan area. A summary of the results from this study is outlined below in §3.5.

3.5 Resultant Water Quality

The results from Rogers & Associates (2000) indicates that the proposed Port Catherine Development can achieve acceptable water quality similar to the harbours already established in the Perth metropolitan area which have good water quality. The results also show that with the proposed management techniques, the water quality in the waterway of the proposed Port Catherine Development will be comparable to both Hillarys and Success Harbours (which are generally regarded as having acceptable water quality). The proposed management techniques will involve extracting nitrogen rich groundwater (allowing only 310 m^3/day throughflow) for the next 7 to 12 years. The groundwater extraction can be ceased in about 7 to 12 years when the elevated levels of nitrogen in the groundwater have completely passed through the system (refer also to Rogers & Associates, 2000).

In addition to the proposed groundwater extraction scheme to actively manage the inflow of nutrient rich groundwater, Rogers & Associates (2000) suggests that it would be appropriate to develop practical and detailed contingency plans. These contingency plans should be sufficiently developed and implemented to allow a rapid response should they be required. These contingency plans could include:

- Increased groundwater extraction rates,
- Enhanced water exchange with the ocean using pipes and pumps, and

- Enhanced mixing using pumps or propeller wash.

4. Coastal Stability & Harbour Siltation

4.1 Sediment Transport Mechanisms

It is believed that the dominant mechanisms responsible for the transport of sediment within the nearshore zone of Owen Anchorage are associated with the waves breaking on the beach. Other possible driving forces, such as wind and background currents, are likely to only play a minor role in sediment transport. Waves can move sediment on a beach in both a cross-shore and longshore direction. These two processes are outlined below.

4.1.1 Onshore Transport

Sediment is typically moved onshore by persistent background swell. Long period swell waves are able to penetrate deeper into the water column, enabling sediment to be moved at greater depths, in contrast to shorter period local sea waves. In addition, the swell waves in Owen Anchorage are substantially more consistent in direction and persistent in duration than the wind-sea portion of the wave energy.

Over time, an equilibrium beach profile can be reached under the action of the background swell. However, the establishment of such a beach profile requires a sufficient off-shore depth such that the oscillatory wave currents acting on the sediment is negligible. This off-shore depth depends on the sediment characteristics as well as the height and period of the background swell.

Estimations based on the typical swell wave climate reaching the shores of Owen Anchorage (significant wave height ~ 0.5 metre and period 10-15 seconds) using the methods outlined by Swart (1976) suggest that this depth is in the order of 10 metres. In view of this, there is unlikely to be significant onshore transport of sand at the proposed development site, as the nearshore waters are about 7 to 10 metres deep in this region.

Onshore transport is most significant in the shallows of Catherine Point and Woodman Point where Success and Parmelia Banks meet the shore. The onshore feed of sand would then be moved along the coast by longshore transport.

4.1.2 Offshore Transport

During significant storm events, the strong winds generate high steep waves and an increase in water level known as storm surge. These factors acting in concert, allow the waves to attack the higher portion of the beach that is not normally vulnerable. The initial width of the surf zone can be insufficient to dissipate the increased wave energy of the storm waves and the residual energy is often spent in eroding the beach, the beach berm and sometimes the dunes. The eroded sand is carried offshore with return water flow to deeper water, where it is deposited and can form an offshore bar. Such bars can eventually grow large enough to break the incoming waves further offshore, causing the wave energy to be spent in a wider surf zone. Figure 4.1 was taken from the Shore Protection Manual (CERC, 1984) and diagrammatically illustrates storm attack on beaches and dunes.

4.1.3 Longshore Transport

The transport of sand along the coast is one of the fundamental mechanisms in beach dynamics. A simplistic description of this mechanism is that in the surf zone of sandy beaches, the breaking waves agitate the sand and place it in suspension. If the waves are approaching at an angle to the beach, then a longshore current can form and this can transport the suspended sand along the beach. This suspended load is accompanied by bed-load transport where sand is rolled over the bed by the shear of the water motion.

There can be considerable variation in the magnitude and direction of the longshore transport from season to season and from year to year. Generally, the mean nearshore wave climate in Owen Anchorage is more southerly in summer than during the winter months. This is due to the combined effects of a shift in the background swell direction and the onset of regular afternoon sea-breezes, driving a northward longshore current in summer. The seasonal change in the mean wave direction causes seasonal fluctuations in the longshore sediment drift. As a result, the beaches to the north of the development site tend to rotate between their summer and winter alignments. Shorter beaches, such as those confined between two groyne structures, react more quickly to these changes, as a smaller volume of longshore transport is required before a stable alignment is achieved.

The southern beaches, Coogee Beach and Quarantine Beach, are more protected from the sea-breeze waves by Woodman Point and do not rotate significantly from winter to summer. These beaches are dominated by the nearshore direction of the persistent background swell.

4.2 Shoreline Movement Plans

4.2.1 Shoreline Movement Calculations

The Department of Marine & Harbours has produced a number of plots showing the position of the coastal vegetation line from Fremantle to Woodman Point. These plans were prepared using aerial photographs and controlled photogrammetry techniques. The resultant accuracy is expected to be about ±2 metres in the horizontal plane. Consequently, these shoreline movement plans are ideal for examining the trends in erosion and accretion occurring over a number of decades.

The publicly available plans show the position of the summer vegetation line taken from aerial photographs dated 1942, 1976, 1980, 1987 and 1994.

Using these shoreline movement plans, accretion and erosion rates were calculated along the Owen Anchorage coastline for the various periods between the photographs to assess the coastal stability (see Table 4.1). The sections of the coast described in Table 4.1 are shown on Figure 4.2.

Table 4.1 – Accretion and Erosion Rates along the Owen Anchorage Coastline

Coastal Segment	Accretion / Erosion Rates (m^3/yr)			
	1942-76	**1976-87**	**1987-94**	**1976-94**
Fremantle Harbours	-	~0	~0	~0
South Beach	-4,110	-	-	3,680
Northern Dog Beach	4,850	-	-	3,440
Southern Dog Beach	13,760	26,350	32,260	28,910[3]
Proposed Development Site	-7,120	7,430	1,540	4,880
Coogee Beach	2,770	670	-3,680	-1,210
Quarantine Beach	23,030	18,450	-1,140	9,960
Woodman Point	1,260	11,690	11,470	11,590
Totals	**34,440[2]**	-	-	**61,250**

Notes:
1. Positive values represent accretion, negative values erosion.
2. Insufficient data is available to accurately estimate the accretion of sand in the area of the Fishing Boat Harbour and Success Harbour prior to 1979. Consequently, this figure is an under-estimate of the total accretion.
3. This rate of accretion is likely to decrease in the near future due to the saturation of the Robb Road Groyne. Consequently, this amount of sediment is expected to move further southward.

4.2.2 Onshore Sediment Feed

Table 4.1 indicates that sediment was accumulating on the shores of Owen Anchorage at a mean rate of approximately 34,500 m^3/yr during 1942 to 1976 (not including accretion in the area of the Fremantle small boat harbours) and around 61,000 m^3/yr during 1976 and 1994. If it is assumed that all of the onshore feed from Success Bank has accreted on the shores to the north of Anchorage Butchers, and all of the sediment from Parmelia Bank has accumulated on the shores to the south, then the mean onshore sediment transport rates from the two banks between 1942 and 1976 is 11,900 m^3/yr (not including accretion in the area of the Fremantle small boat harbours) and 22,600 m^3/yr respectively, and 40,700 m^3/yr and 20,600 m^3/yr respectively for the period 1976-94.

The most likely reason for the apparent difference in the rate of accumulation near Success Bank is related to the construction of Success Harbour and Fishing Boat Harbour in the 1970's. The construction of the Fishing Boat Harbour and Success Harbour in the 1970's formed an arrangement of breakwaters which prevented sediment from being transported to the coastline to the north of South Beach. Consequently, it is reasonable to conclude that since 1979, the year Success Harbour was completed, essentially all of the onshore sediment feed from Success Bank has been accreting along the shores to the south of the Success Harbour breakwater. In light of this, it is to be expected that the sediment accretion rates of South Beach, the Dog Beaches, and the northern portion of the Proposed Development Site would be significantly greater in the 1980's and 1990's compared to their values prior to the 1970's.

In view of the above discussion, it is clear that the most recent estimate of the accretion adjacent to Success Bank, namely 40,700 m^3/yr for 1976-94, is the best estimate of the total onshore feed received from Success Bank. The mean annual onshore sediment feed from Parmelia Bank is likely to be in the order of 21,000 m^3/yr. Summaries of the estimated sediment fluxes for the 1970's-90's and the 1990's onwards are given in Figures 4.3 and 4.4 respectively. It should be noted that the saturation of the Robb Road Groyne (see §4.3.1) has been taken into account in Figure 4.4.

4.3 Coastal Stability

4.3.1 North of the Proposed Development Site

To the north of the proposed development, the shoreline has generally been accreting from 1942 to 1994. The only area to have experienced any erosion is South Beach, which eroded 27 metres from 1942 to 1976. Since 1976 though, this entire section of shoreline has been accreting.

The accretion of the shoreline north of the Port Catherine Development over the past half a century is due to the onshore feed of sand from Success Bank and the construction of 3 groynes (Catherine Point, Robb Road and the old Power Station). The effect of these groynes was to trap sediment to their northern side resulting in a rotation of the alignment of the enclosed beaches. This new alignment was such that the angle between the breaking swell waves and the shore was less, and hence the longshore sediment transport to the south was reduced.

The accumulation of sand to the north of the Catherine Point Groyne has been very rapid, resulting in a shoreline progression in the order of 3 m/yr. This was undoubtedly due to the onshore sediment feed from Success Bank.

Observations at the southern end of the Dog Beaches shows that the groyne to the south of these beaches (Robb Road Groyne) has become saturated with sand on its northern side. Because the Power Station groyne just south of Robb Road groyne has also become saturated, the sediment that would have previously been trapped by these structures is now likely to travel further south. Therefore, an increase of about 28,000 m^3/yr (from around 5,000 m^3/yr to 33,000 m^3/yr) of sediment is expected to be transported towards the proposed development site. This has an important consequence on harbour siltation at the Port Catherine site.

4.3.2 South of the Proposed Development Site

The shoreline to the south of the proposed development site has also generally been accreting over the past 53 years. Woodman Point, in particular, has advanced around 170 metres over this period of time. During this period, Coogee Beach was the only area south of the proposed development site to have experienced any erosion. This erosion is fairly recent, occurring between 1976 and 1994. However, the amount of shoreline retreat is small, around 2 metres, and equates to a very small annual loss of sediment, around 1,200 m^3/yr.

The rapid accretion of sediment at Woodman Point is most likely to have been caused by the onshore feed of sand from Parmelia Bank as well as the construction of the WAPET Groyne in 1967. The construction of the WAPET Groyne in 1967 caused sediment to rapidly accumulate on both sides of this structure. Initially, this is likely to have been caused by the groyne's interception of the onshore sediment feed, arriving with the background swell, from Parmelia Bank. Refraction effects cause swell waves to converge on Woodman Point, and, as a result, the WAPET Groyne location receives onshore sediment feed from both the northwest and southwest. In the absence of the WAPET Groyne, these two fluxes interact to form a net eastward onshore feed. The imposition of the groyne structure has prevented these two streams from interacting with each other. As a result, sediment has accumulated on both the northern and southern sides of the groyne. Over time, this accretion has become more extensive and significantly modified the seabed topography in the vicinity of the structure. It is possible that this has further enhanced the refraction of swell waves onto the point, and hence increased the proportion of the onshore feed that accumulates at Woodman Point rather than moving, in the form of longshore drift, towards Quarantine Beach.

4.3.3 At the Proposed Development Site

The shoreline of the proposed development site retreated during the period from 1942 to 1976. Since 1976 however, the shoreline in this region has been slowly advancing.

The early erosion was most likely due to the interception of the longshore sediment feed from Catherine Point by the construction of the groynes at Catherine Point, Robb Road and the old Power Station. As discussed in §4.3.1, the Robb Road and Power Station Groynes have in recent years become saturated with sand on their northern sides. This has allowed a substantial sediment flux to nourish the shoreline of the proposed development site. This is likely to be the dominant mechanism responsible for the progradation of the shoreline along this stretch of coast over the last 20 years or so.

4.4 Harbour Siltation and Management

As mentioned in §4.3.1, an increase in sediment flux towards the proposed development site of around 28,000 m^3/yr is expected, in the coming years, due to the saturation of the Robb Road and Power Station Groyne. This would mean that a net sediment flux of around 33,000 m^3/yr would be expected to be moved towards the proposed development (refer to Figure 4.4). It should be borne in mind that this is an estimated average annual figure of the net movement and as such, there will be significant seasonal and inter-annual fluctuations.

This sediment could initially be managed by allowing it to be trapped by the northern breakwater of the proposed development. It is estimated that to create a beach of around 50 metres in width between the northern breakwater and the Power Station breakwater, around 120,000 m^3 of sand would need to be trapped. Under the anticipated rate of sediment movement, it is estimated that it would take around 3 to 4 years to form this beach.

After the formation of this beach, the sediment trapping could be augmented by extending Robb Road Groyne. Provision should be made in the budget for the possible extension of this groyne. It is anticipated that this extension would trap around 800,000 to 900,000 m^3 of sand and would take around 2 to 3 decades to saturate under the estimated sediment transport rate.

Further management strategies would need to be implemented when the Robb Road Groyne becomes saturated with sediment. A range of methods would be possible and some of these are listed below in Table 4.2.

The net sediment movement at Coogee Beach is relatively minor at present. However, a net of about 1,000 m^3/yr could be made up of seasonal fluxes of 5,000 to 10,000 m^3 in either direction. This means that during the sea-breeze regime in spring and summer, 5,000 to 10,000 m^3 of sand could be moved northwards from Coogee Beach. At present, during the winter regime, a similar quantity could be moved south.

The southern breakwater of the proposed development is likely to create a small wave shadow for storm waves from the northwest. In addition, some of the sand trapped by the southern breakwater or entering the trap area may be moved offshore by local rip currents near the breakwater. Either or both of these features may result in a change in the beach dynamics at the northern end of Coogee Beach. Such changes, if they occur, could be managed by sand bypassing from the northern trap area or the construction of minor structures to limit the zone of influence of the southern breakwater. Other management strategies are listed below in Table 4.2.

Table 4.2 – Harbour Siltation Management Strategies

Time Frame	Management Strategy
Decades 0 to 3	Implement the following as required: • Trap sediment north of harbour. • Extend Robb Road Groyne. • Bypass sand to the south of the harbour using dredges, excavators or draglines. • Modify the coastal dynamics of the northern portion of Coogee Beach with minor coastal structures.
Decades 3 to 5	Implement one or more of the following: • Allow sand to pass around the Robb Road Groyne and be trapped by the northern breakwater. • Bypass sand to the south of harbour using dredges, excavators or draglines. • Remove $CaCO_3$ sands from the northern trap area for the manufacture of cement or lime.
Decade 5 onwards	Implement one or more of the following: • Allow the sand to pass around the northern breakwater and deposit around the western side of the northern breakwater. • Bypass sand to the south of harbour using dredges, excavators or draglines. • Remove $CaCO_3$ sands from the site for the manufacture of cement or lime. • Enlarge trap capacity to the north of the harbour using coastal structures between Catherine Point and the northern breakwater of the development.

5. Conclusions & Recommendations

The coastal and marine engineering aspects of the proposed development have been investigated for the purpose of concept planning and assessment of the environmental impacts. These investigations have been completed for the Port Catherine Developments Pty Ltd concept plan shown in Figure 1.2 and have resulted in the following conclusions and recommendations.

Water Quality

The development waterways have been designed and will be managed to ensure that there will be minimal inflow of pollutants and nutrients. In addition, the waterway manager will establish a comprehensive oil spill response plan and ensure that appropriate equipment and trained personnel are available for emergency response.

Results of detailed 3-dimensional hydrodynamic and transport modelling completed by Rogers & Associates (2000) suggests that with the proposed management techniques, the water quality in the waterway of the proposed Port Catherine Development will be comparable to both Hillarys and Success Harbours (which are generally regarded as having acceptable water quality). The proposed management techniques will involve extracting nitrogen rich groundwater (allowing only 310 m^3/day throughflow) for the next 7 to 12 years. The groundwater extraction can be ceased in about 7 to 12 years when the elevated levels of nitrogen in the groundwater have completely passed through the system. From the results of the detailed water quality investigations the waterway of the proposed Port Catherine Development is expected to comply with the Environmental Protection Authority (1993) criteria for "Recreational Primary Contact".

In addition to the proposed groundwater extraction scheme to actively manage the inflow of nutrient rich groundwater, Rogers & Associates (2000) suggests that it would be appropriate to develop practical and detailed contingency plans. These contingency plans should be sufficiently developed and implemented to allow a rapid response should they be required. These contingency plans could include:

- Increased groundwater extraction rates,
- Enhanced water exchange with the ocean using pipes and pumps, and
- Enhanced mixing using pumps or propeller wash.

Harbour Siltation

Sand movement from the north will initially be managed by the sand trap created by the northern breakwater. It is estimated that to create a beach of around 50 metres in width between the Power Station Breakwater and the northern breakwater it would be necessary to trap around 120,000 m^3 of sand. The net rate of sediment movement towards the proposed development site, from the north, is estimated to be around 33,000 m^3/yr. Under this rate of transport, it is estimated that it would take around 3 to 4 years to form this beach.

After the formation of this beach, the sediment trapping could be augmented by the extension of Robb Road Groyne. It is anticipated that this extension would trap around 800,000 to 900,000 m^3 of sand and would take around 2 to 3 decades to saturate under the estimated sediment transport rate. Provision should be made in the budget for the extension of Robb Road Groyne.

Further management strategies would need to be implemented when the Robb Road Groyne becomes saturated with sediment. A range of methods has been suggested in §4.4.

It is recommended that an adequate monitoring program be set up to assess the effectiveness of the spur groyne. If the spur groyne is allowing too much sediment to pass, it will be necessary to augment the sediment trapping by extending Robb Road Groyne. Provision should be made in the budget for the extension of Robb Road Groyne.

Further management strategies will need to be implemented when the spur groyne on the northern breakwater of the development becomes saturated with sediment. A range of methods have been suggested in §4.4.

The seasonal fluctuations in sand movement at Coogee Beach could be around 5,000 to 10,000 m^3 in either direction. Currently, the seasonal sand movements are almost in equilibrium. Therefore, Coogee Beach is experiencing a relatively minor annual net sediment movement. However, the construction of the southern breakwater may change the beach dynamics in this region by creating a small wave shadow for northwest storm waves as well as local rip currents near the breakwater. A range of management strategies have been suggested in §4.4 if these changes occur.

6. References

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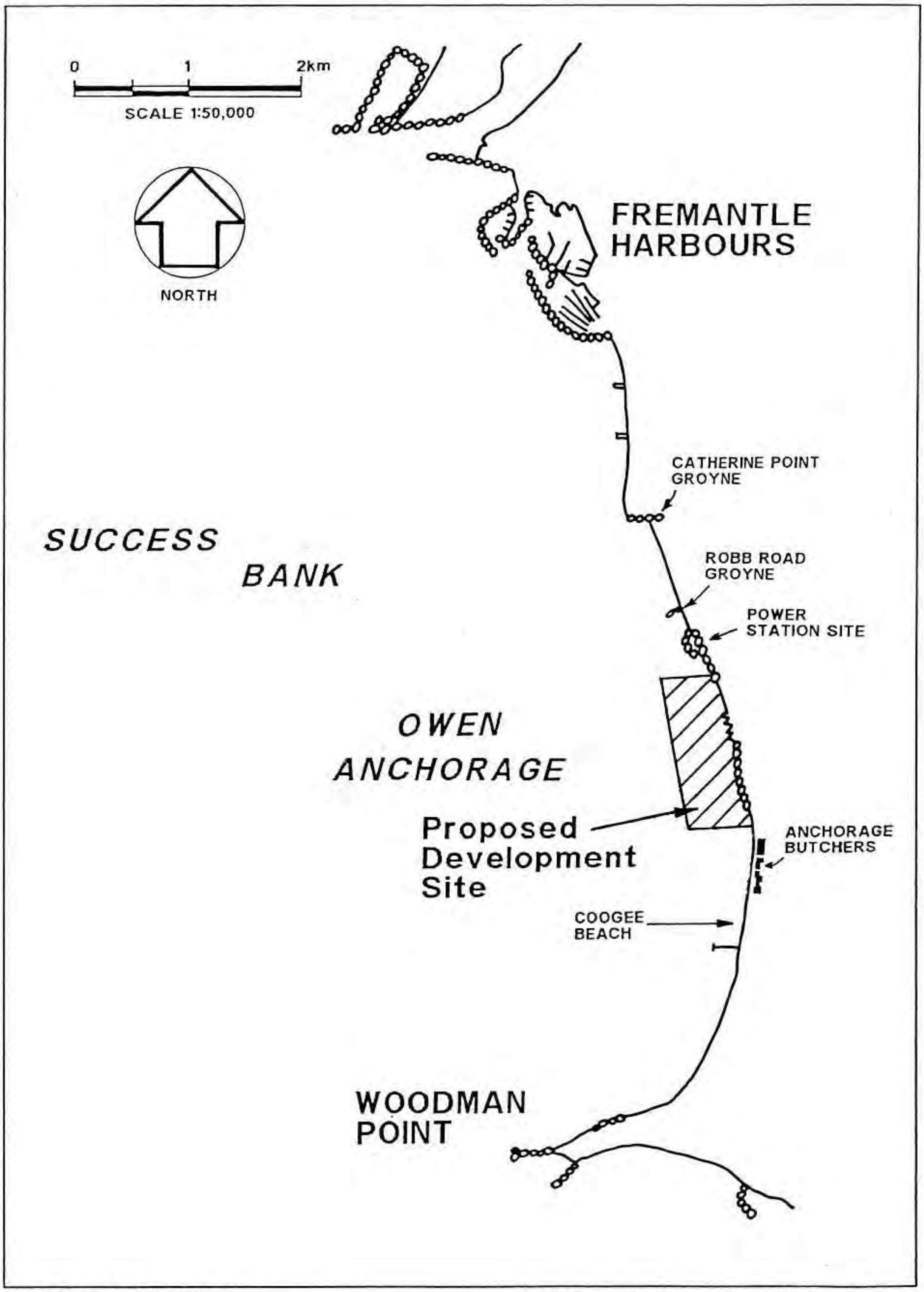
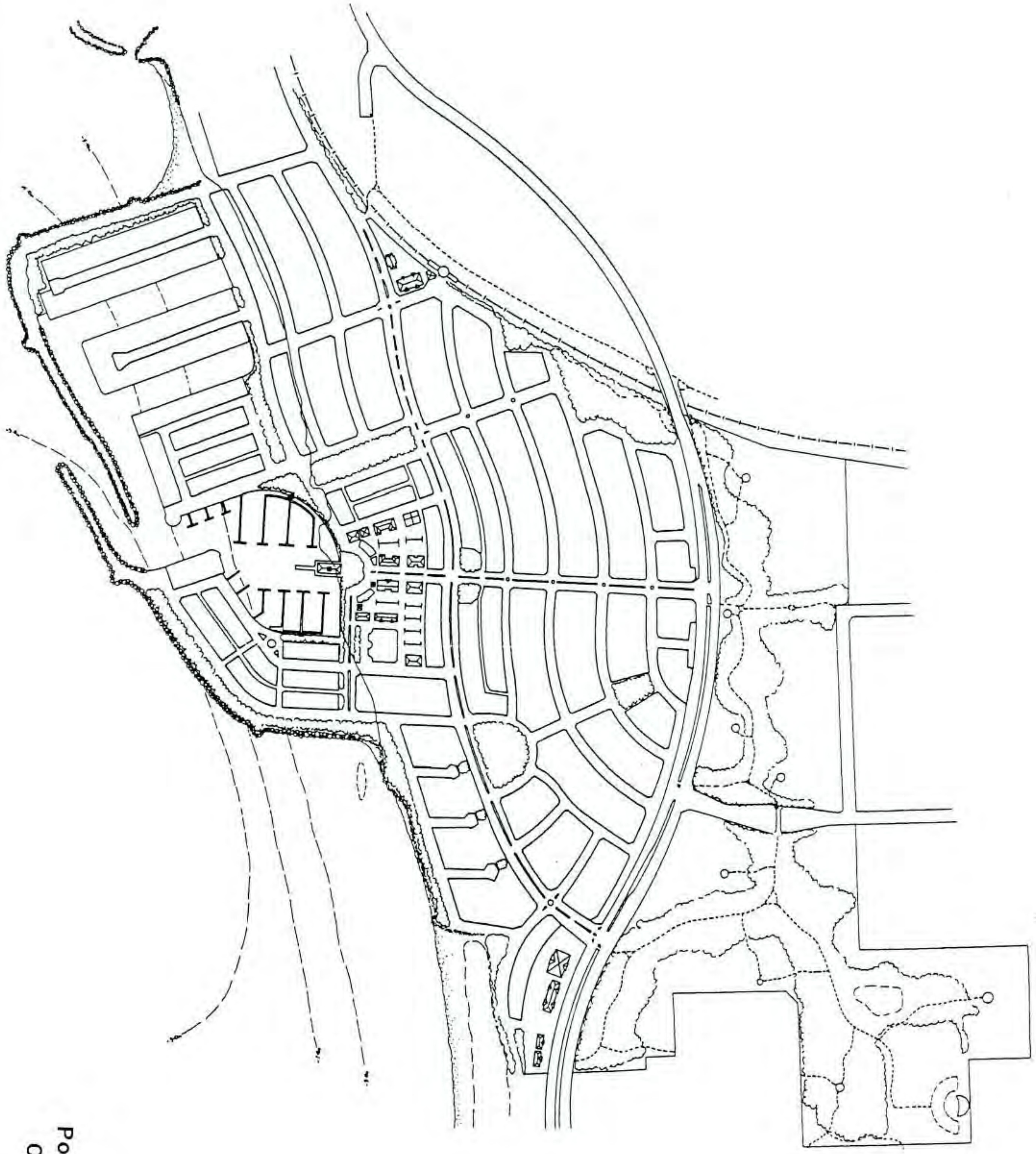
7. Figures

Figure 1.1 – Location Diagram



Port Catherine
Concept Plan
Figure 1.2



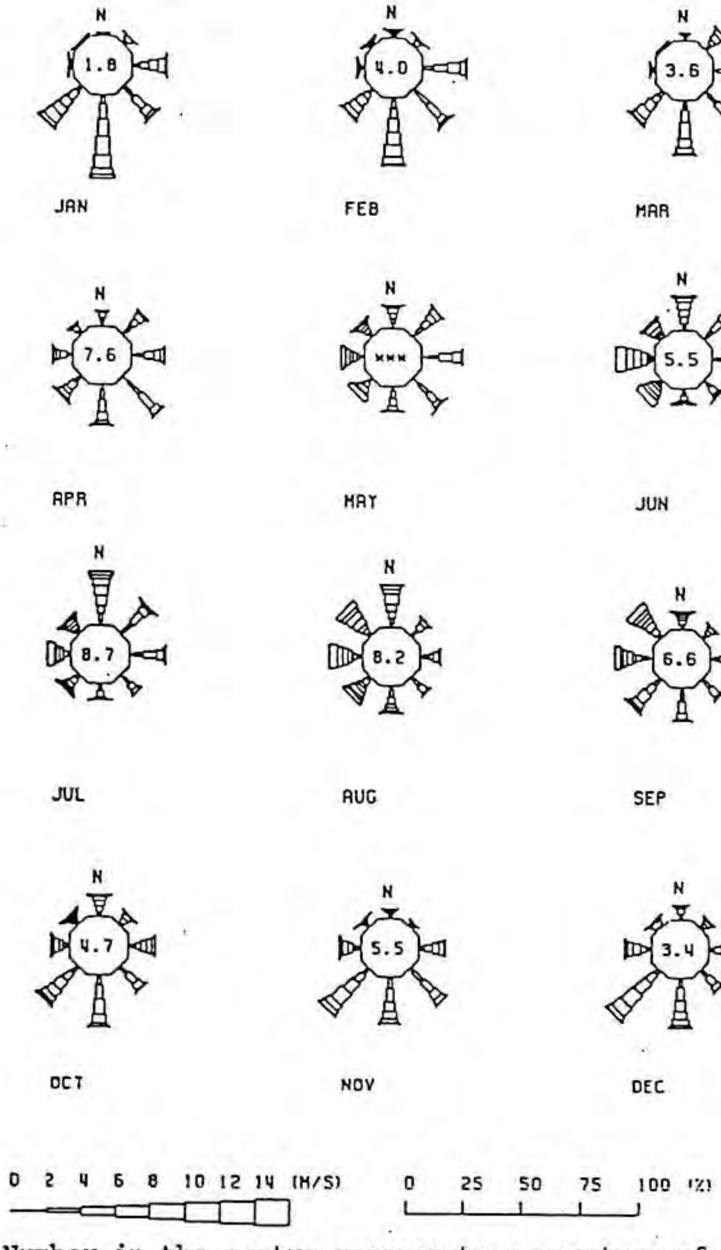
PORT CATHERINE
OUTLINE DEVELOPMENT PLAN

Client	Date	Plan No.	North
Australand	July, 2000	90/57/52	

Scale
0 50 100 150 200m

Taylor Burrell

Figure 2.1 – Fremantle Wind Roses (1981 – 1983)



Number in the centre represents percentage of calms

Figure 2.2 – Bathymetry of Owen Anchorage

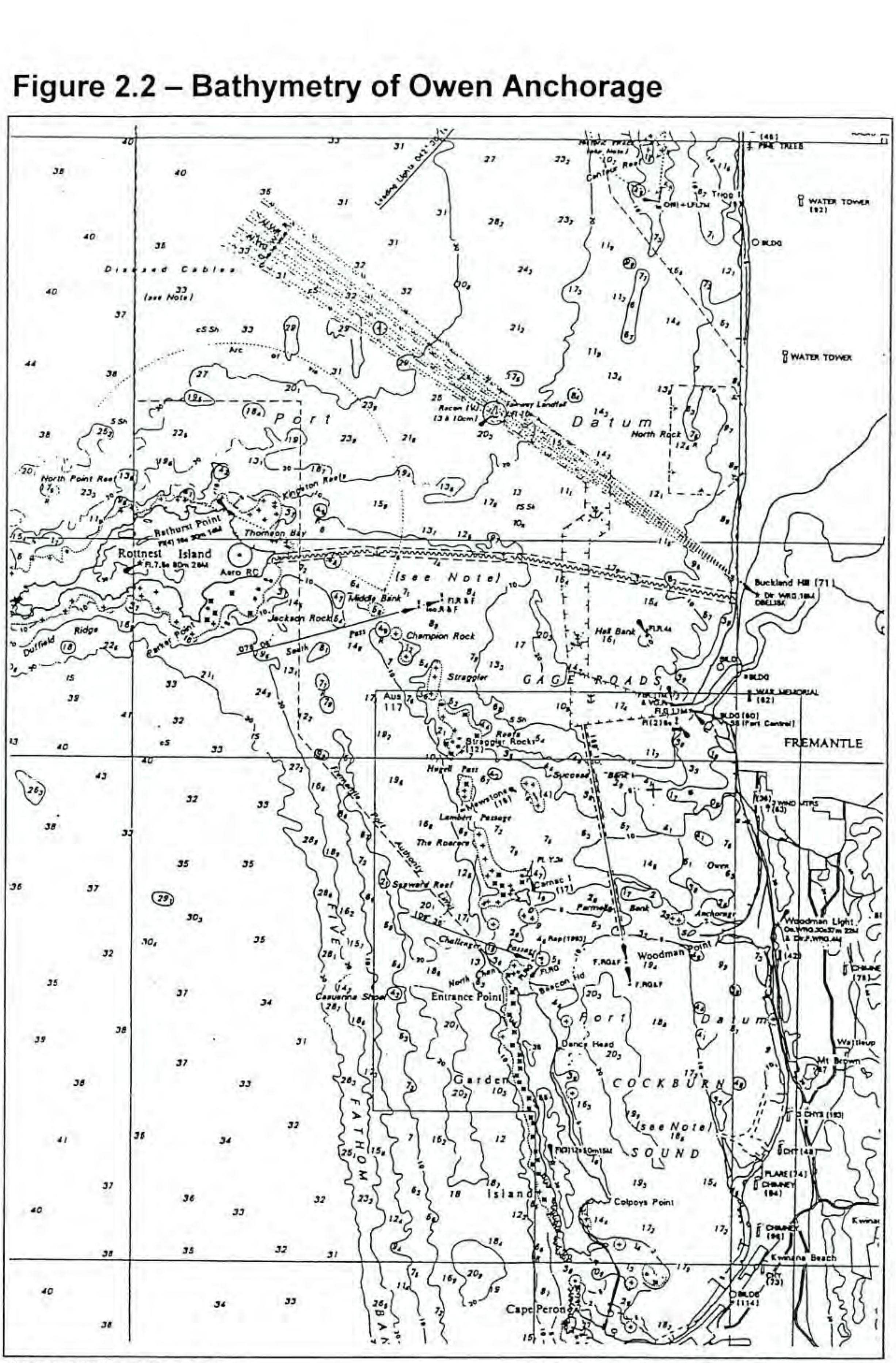


Figure 2.3 – Wave Conditions – Typical Winter Storm

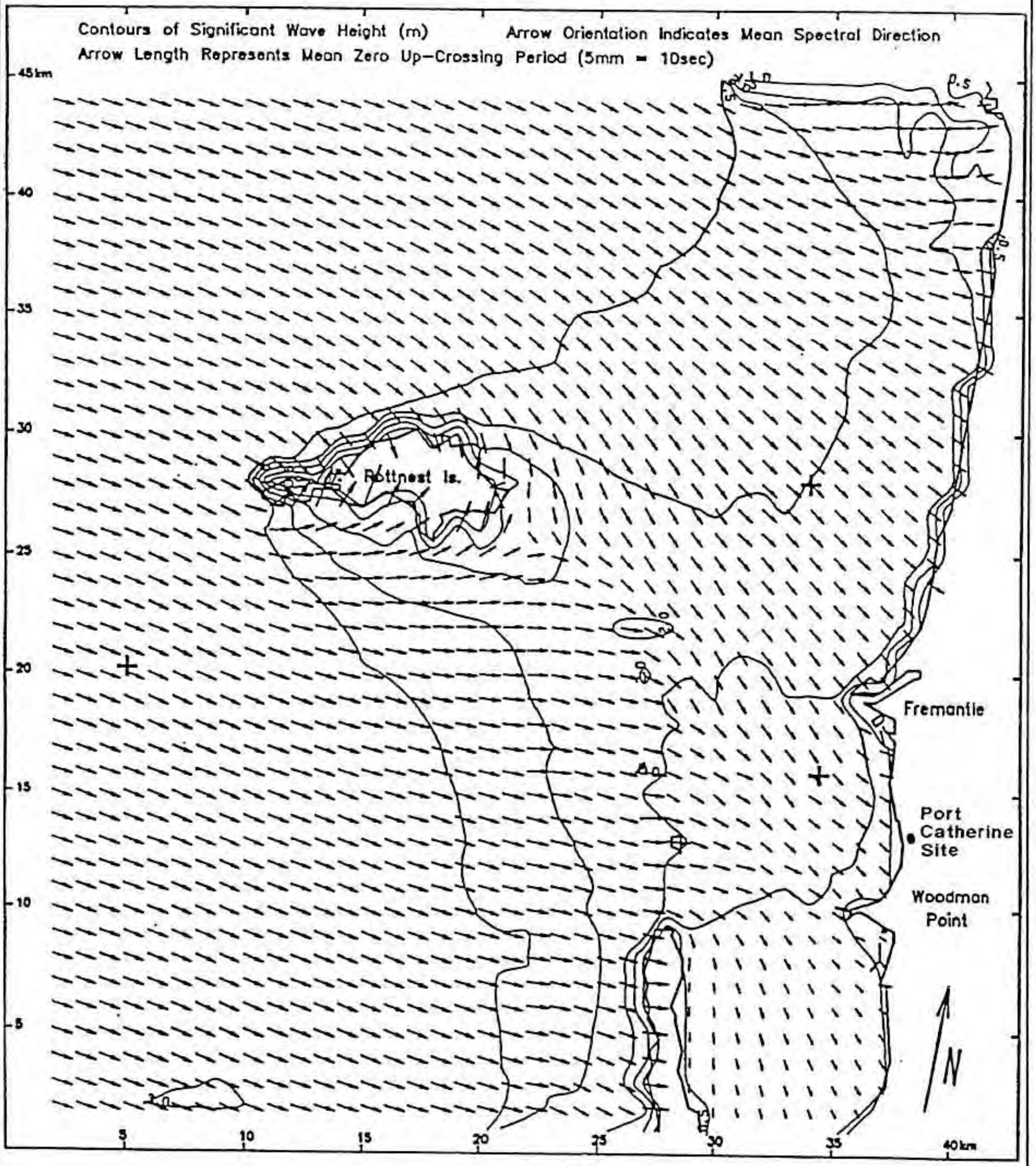


Figure 2.4 – Wave Conditions – Typical Swell

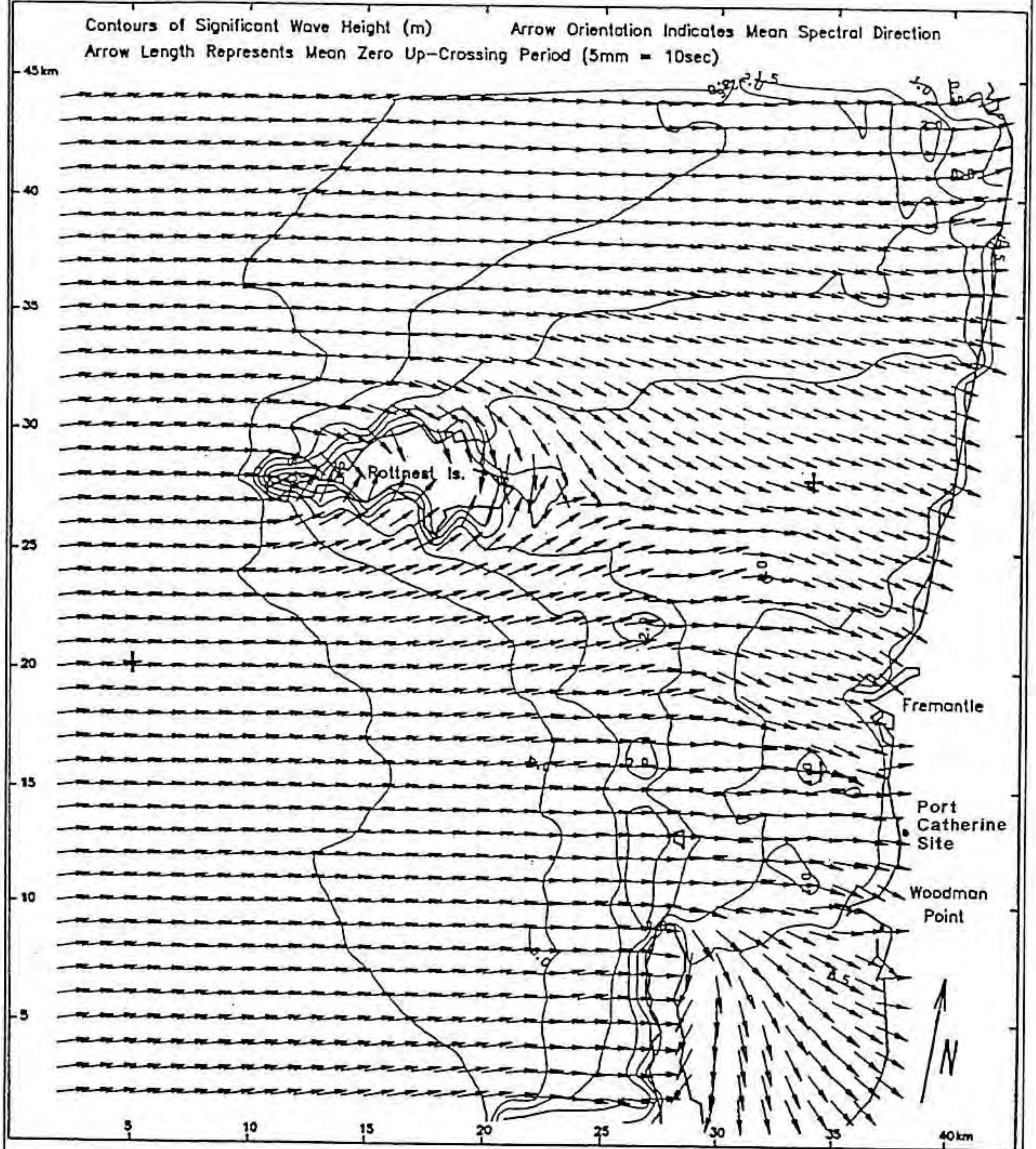


Figure 2.5 – Wave Conditions – Typical Sea-Breeze

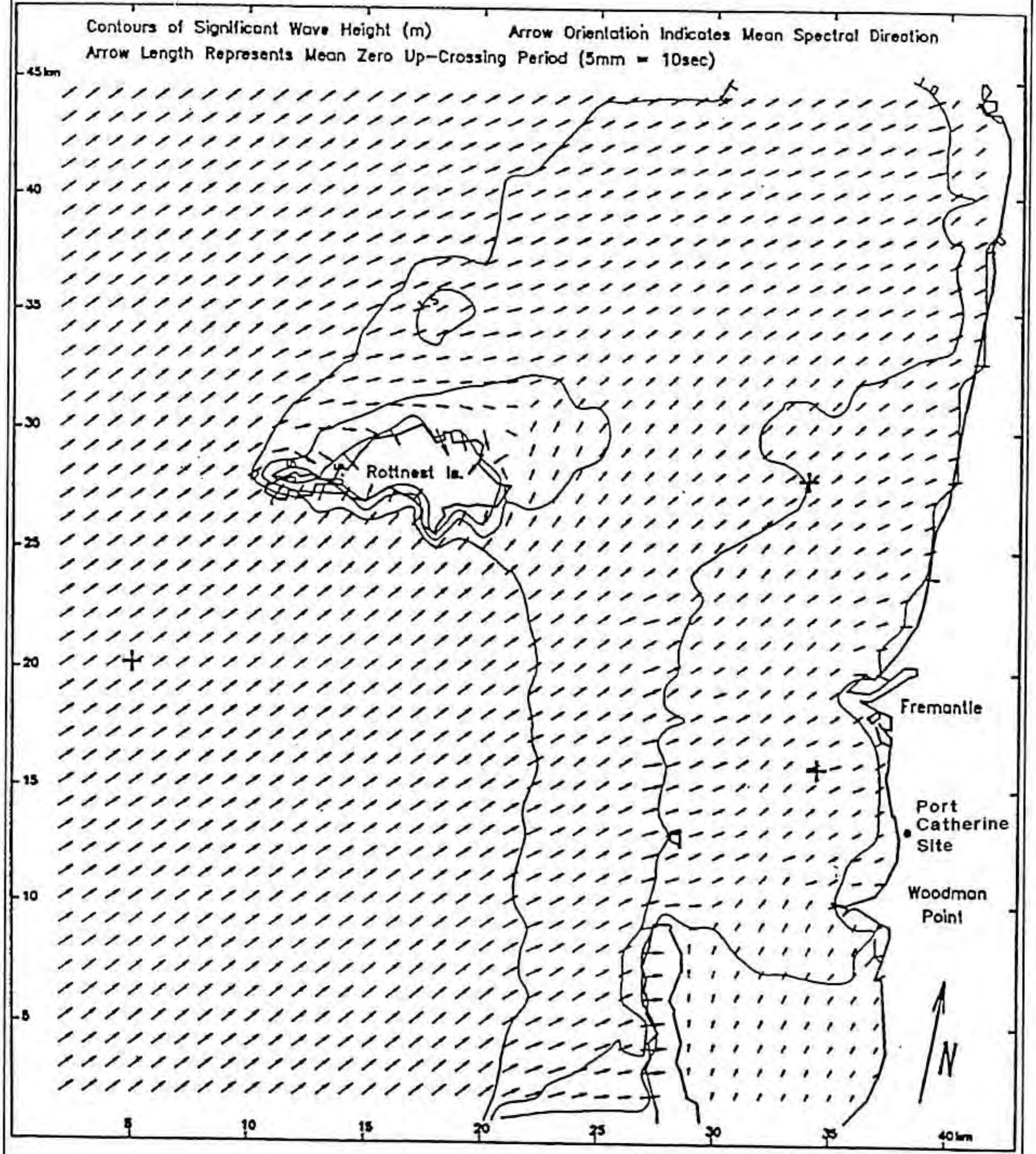
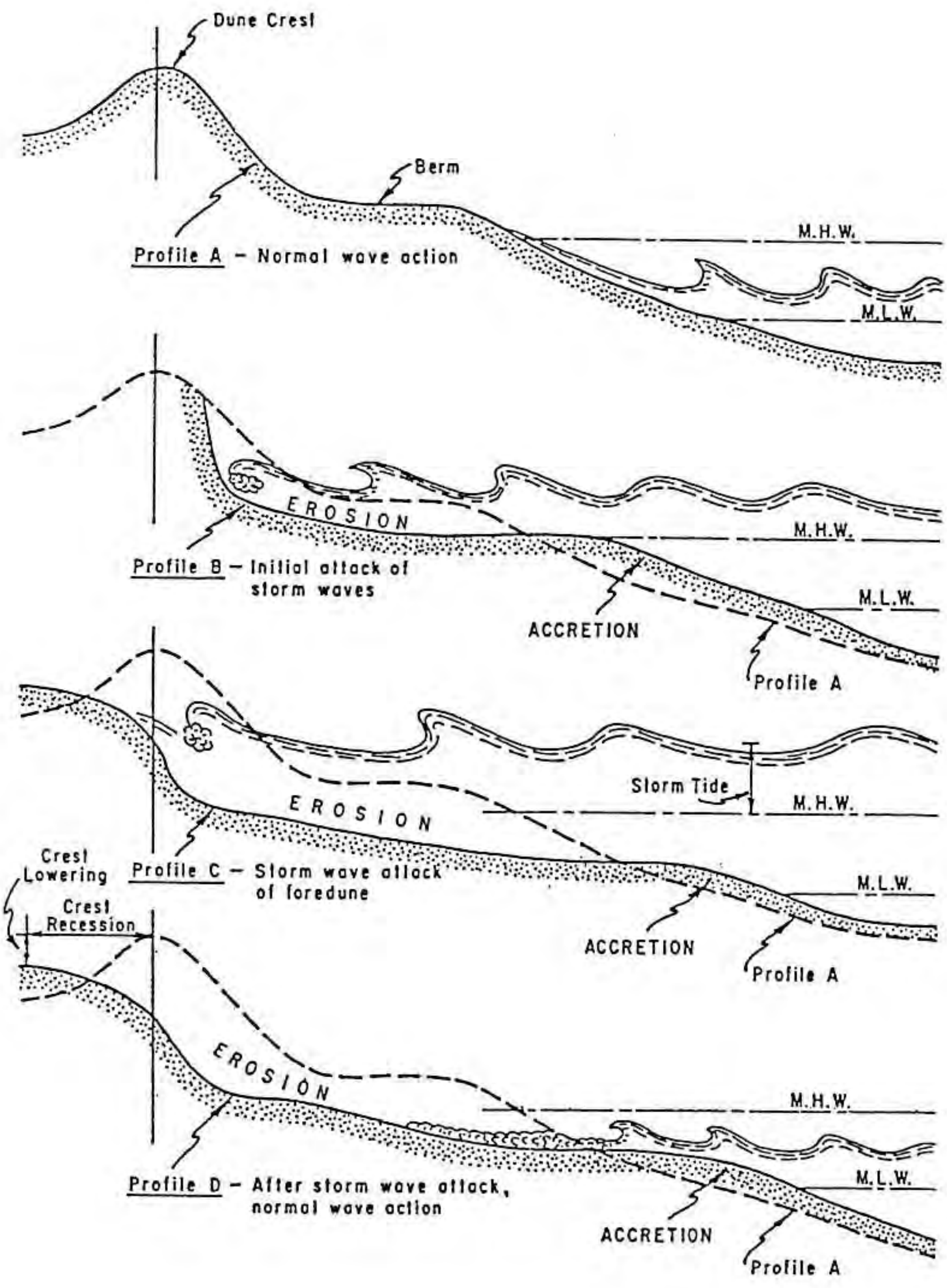


Figure 4.1 – Storm Wave Attack



Source: Shore Protection Manual (CERC, 1984)

Figure 4.2 – Locations of Coastal Regions

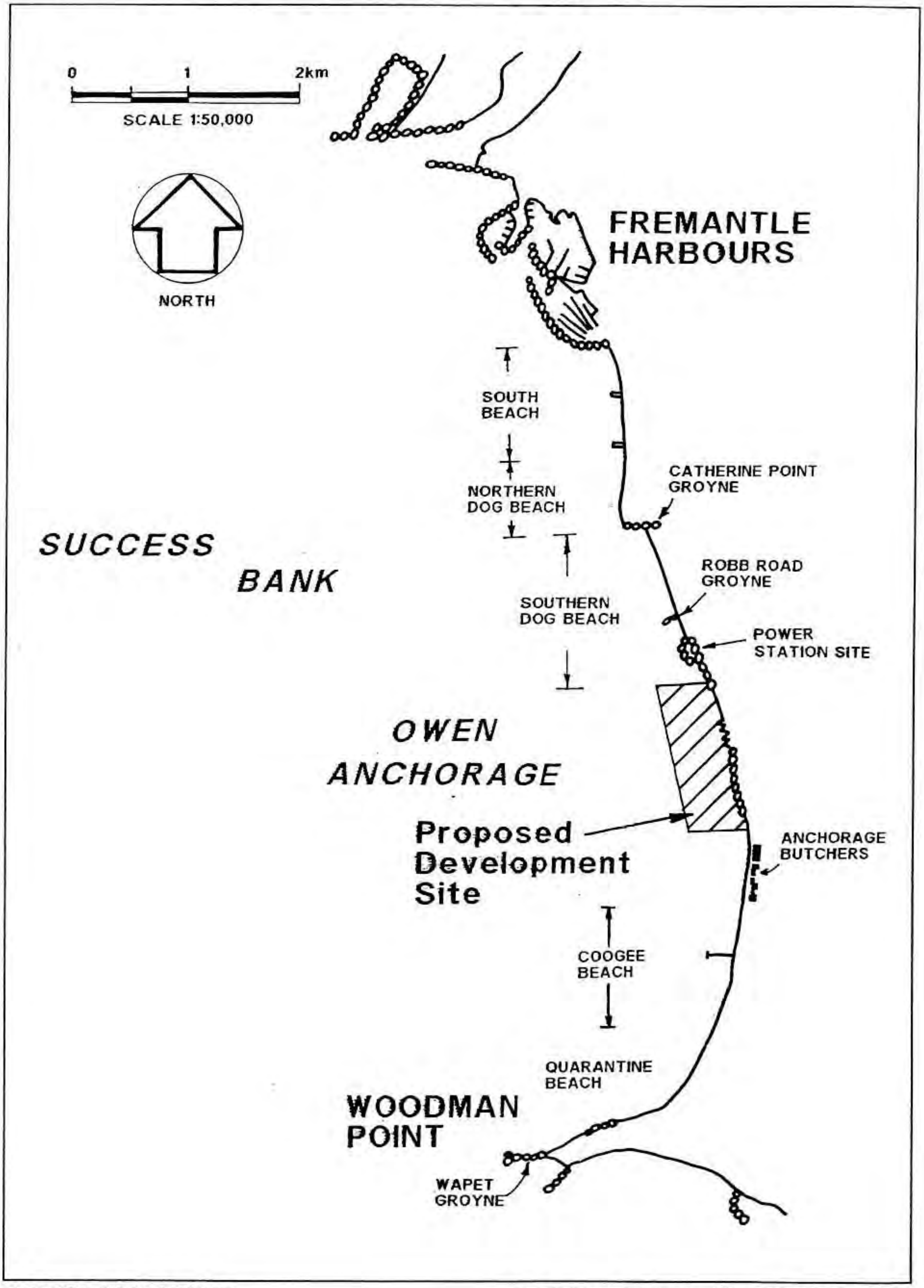


Figure 4.3 – Estimated Net Annual Sediment Fluxes 1970's – 90's

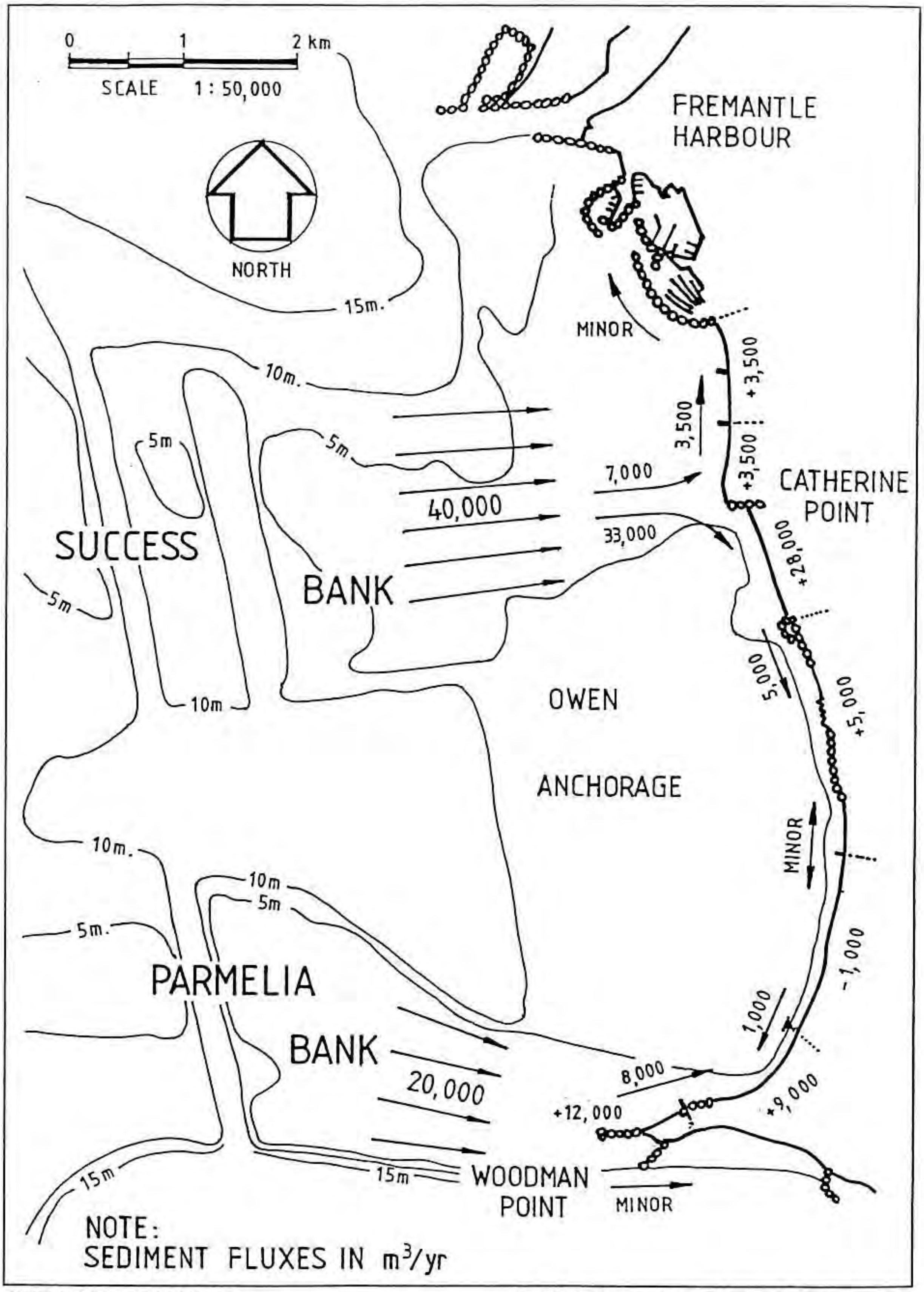


Figure 4.4 – Estimated Net Annual Sediment Fluxes 1990's Onwards

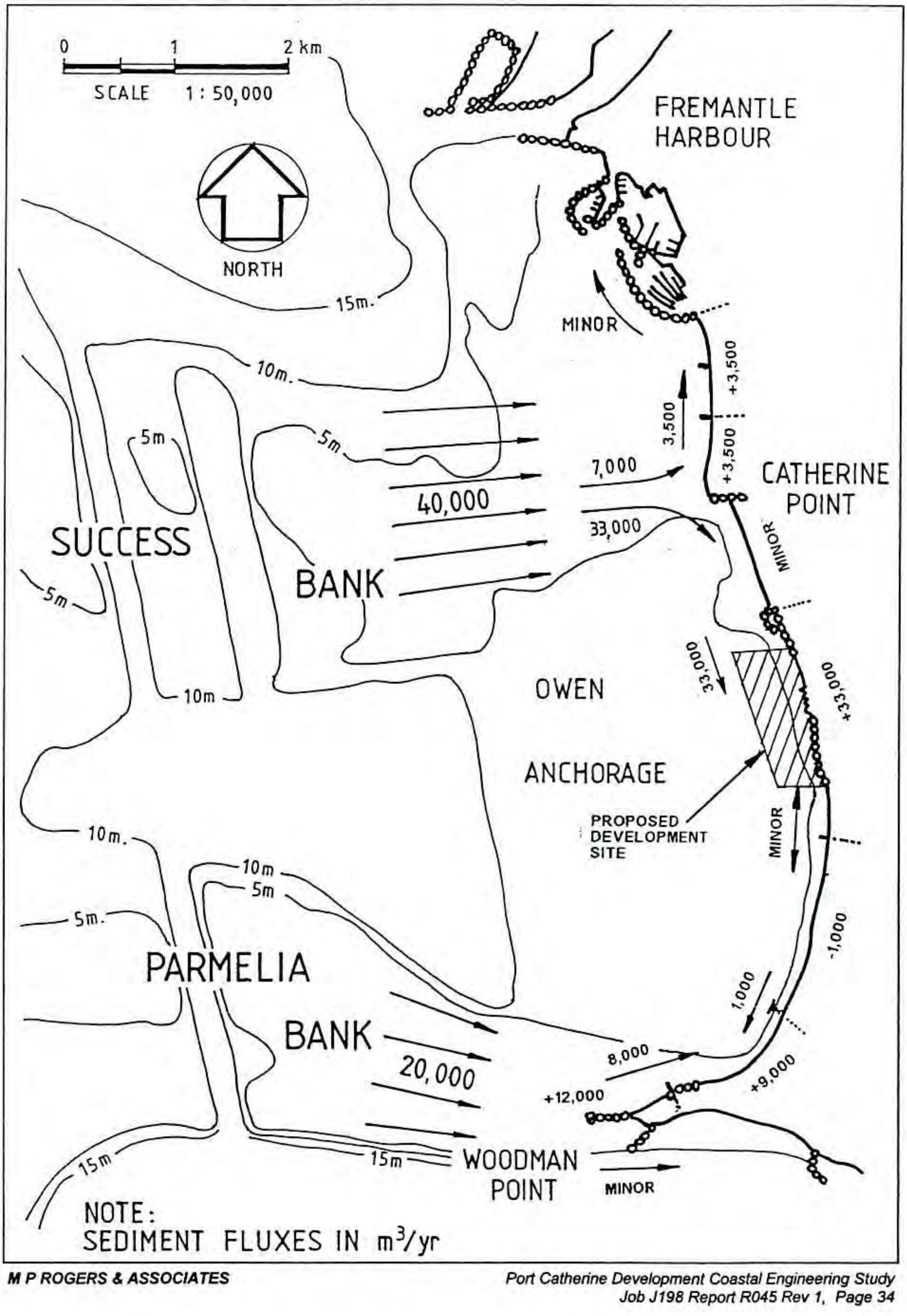
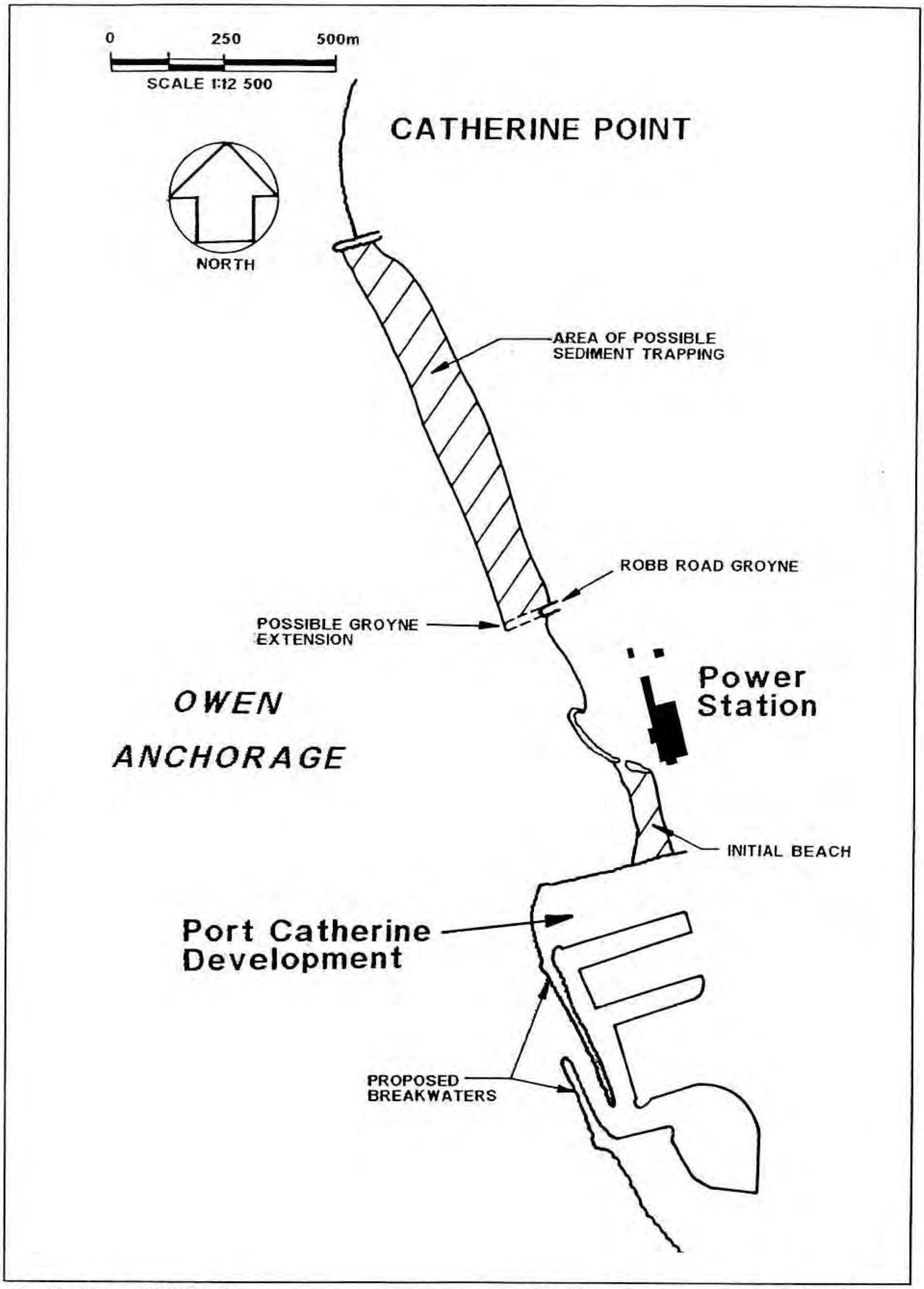


Figure 4.5 – Estimated Trap Capacity



8. Appendices

Appendix A Water Quality Guidelines

Appendix A Water Quality Guidelines

3. RECREATIONAL WATER QUALITY AND AESTHETICS

Water-based recreational activities are highly regarded by Australians. Water quality guidelines are therefore necessary to protect these waters for recreational activities, such as swimming and boating, and to preserve the waters' aesthetic appeal.

Sporting activities can be divided into two categories:

- sports in which the user comes into frequent direct contact with water, either as part of the activity or accidently; for example, swimming or surfing (primary contact);
- sports that generally have less-frequent body contact with the water; for example, boating or fishing (secondary contact).

A third recreational category concerns the passive recreational use of waterbodies, mainly as pleasant places to be near or to look at (no body contact). The relevance of the different water quality guidelines to the three recreational categories is shown in Table 3.1. The detailed water quality guidelines for recreational water are summarised in Table 3.2. The recommended guidelines rely on the guidelines developed by NHMRC (1990), with additional indicators included where appropriate.

Table 3.1: Water quality characteristics relevant to recreational use

Characteristics	Primary contact (e.g. swimming)	Secondary contact (e.g. boating)	Visual use (no contact)
Microbiological guidelines	x	x	
Nuisance organisms (e.g. algae)	x	x	x
Physical and chemical guidelines:			
Aesthetics	x	x	x
Clarity	x	x	x
Colour	x	x	x
pH	x		
Temperature	x		
Toxic chemicals	x	x	
Oil, debris	x	x	x

Table 3.2: Summary of water quality guidelines for recreational waters

Parameter	Guideline
Microbiological	
Primary contact	The median bacterial content in fresh and marine waters taken over the bathing season should not exceed 150 faecal coliform organisms/100 mL *(minimum of five samples taken at regular intervals not exceeding one month, with four out of five samples containing less than 600 organisms/100 mL);* or
	35 enterococci organisms/100 mL *(maximum number in any one sample: 60–100 organisms/100 mL.*
	Pathogenic free-living protozoans should be absent from bodies of fresh water.*
Secondary contact	The median value in fresh and marine waters should not exceed 1,000 faecal coliform organisms/100 mL *(minimum of five samples taken at regular intervals not exceeding one month, with four out of five samples containing less than 4,000 organisms/100 mL);* or
	230 enterococci organisms/100 mL *(maximum number in any one sample 450–700 organisms/100 mL).*
Nuisance organisms	Macrophytes, phytoplankton scums, filamentous algal mats, sewage fungus, leeches etc. should not be present in excessive amounts.
	Direct contact activities should be discouraged if algal levels of 15,000–20,000 cells/mL are present, depending on the algal species.
	Large numbers of midges and aquatic worms should also be avoided.
Physical and chemical	
Visual clarity & colour	To protect the aesthetic quality of a waterbody: • the natural visual clarity should not be reduced by more than 20%; • the natural hue of the water should not be changed by more than 10 points on the Munsell Scale; • the natural reflectance of the water should not be changed by more than 50%.
	To protect the visual clarity of waters used for swimming, the horizontal sighting of a 200 mm diameter black disc should exceed 1.6 m.
pH	The pH of the water should be within the range 5.0–9.0, assuming that the buffering capacity of the water is low near the extremes of the pH limits.
Temperature	For prolonged exposure, temperatures should be in the range of 15–35°C.
Toxic chemicals	Water containing chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreation. Toxic substances should not exceed levels given for untreated drinking waters.
Surface films	Oil and petrochemicals should not be noticeable as a visible film on the water nor should they be detectable by odour.

* *(It is not necessary to analyse water for these pathogens unless the temperature is greater than 24°C.)*

3.1 RECREATIONAL CATEGORIES

3.1.1 PRIMARY CONTACT

Water used for primary contact activities, such as swimming, bathing and other direct water-contact sports, should be sufficiently free from faecal contamination, pathogenic organisms and other hazards (e.g. poor visibility or toxic chemicals) to protect the health and safety of the user. The general guidelines desirable for aquatic scenery are also applicable for water used for primary contact.

3.1.2 SECONDARY CONTACT

Water used for secondary contact activities, such as boating and fishing, should also meet the guidelines suggested for aquatic scenery. Since there is less body contact with the water, the microbiological guidelines can generally be lower, although not in cases when shellfish might be taken from the waterbody. To protect water-skiers from injury and boating vessels from damage, the water should be free from floating or submerged logs and stumps and excessive growth of algae and other aquatic plants. The quality of the water should be maintained so that there is minimal alteration of the fish habitat (Chapter 2).

3.1.3 VISUAL USE

Surface waters used for visual recreational use (no-contact activity) should not be altered in any way that reduces their ability to support aesthetically valuable flora and fauna. Such alteration may be physical, such as dredging and dam construction, or may be due to addition of wastes to the water. Visual impact of the surface waters is important; they should be free from:

- floating debris, oil, grease and other objectionable matter;
- substances that produce undesirable colour, odour, taste or foaming;
- undesirable aquatic life, such as 'algal blooms', or dense growths of attached plants or insects.

All these factors have to be considered in areas used for aquatic scenery.

APPENDIX II
Groundwater and Soil Dissolved Inorganic Nitrogen Investigation
(Bowman Bishaw Gorham)

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1.0 INTRODUCTION AND PURPOSE

Port Catherine Developments Pty Ltd is proposing to develop a residential and marina estate on disused industrial land on the Coogee foreshore. The Port Catherine development site is situated at the western margin of the Jandakot Groundwater Mound (Davidson, 1995), with groundwater flowing west toward the coast.

Previous investigations indicated the occurrence of elevated levels of nitrogen (in the form of nitrate) in the groundwater at this locality (Appleyard, 1990 and Groundwater Technology, 1994). If not properly managed, groundwater inputs of nitrogen to the proposed marina development are of concern due to the potential for algal blooms within the enclosed waterways.

The construction of a groundwater drain to intercept groundwater upstream of the marina has been proposed to mitigate conditions conducive to excessive algae growth. The intercepted groundwater will be used to irrigate parks and reserves within and near the development. The excess groundwater will be injected back into the aquifer at locations north of the groundwater capture zone of the marina.

The objective of this investigation is to assess the length of time that nitrogen enriched groundwater is likely to continue to flow to the proposed intercept drain and require re-use or diversion, in order to maintain acceptable water quality in the marina. The length of time it will be necessary to intercept and divert the nitrogen enriched groundwater is an important issue with respect to the ongoing management of the intercept drain and associated irrigation and disposal network.

This report includes the following sections:

- Background and overview of previous groundwater investigations.
- Discussion of groundwater investigations.
- Discussion of soil investigations.
- Conclusions and management recommendations.

2.0 BACKGROUND

2.1 Historical Land Use

Historical activities at the site have predominantly been animal based industries including fellmongery, wool scouring and tanning. Land inland from the proposed development site was historically used for market gardens. Due to high irrigation and fertiliser application rates, market gardens are known to contribute nutrients, particularly nitrogen, to underlying aquifers (Appleyard, 1990 and Davidson, 1995).

Figure 1 shows a comparison of land uses inland of the site in 1965 and 1997. As regional development progressed after 1965, market garden areas were initially replaced by unsewered residential. However all new residential areas are now connected to reticulated sewage and, as part of the Government's backlog sewage program, unsewered areas are rapidly being connected to sewer.

A survey was conducted as part of this investigation to assess if the remaining market gardens in the area are operating. The survey results indicated that very few of the 1997 market gardens shown in Figure 1 remain operational; the majority have been or are being converted to residential land use.

2.2 Physical Setting

Soils in the area are of the Cottesloe soil formation, which extends inland from the coastline for approximately 5km. The soils are described as brown sands overlying limestone. The soil formation is characterised by frequent limestone outcropping (Churchward and McArthur, 1978).

Groundwater is present beneath the area in a superficial aquifer, which occurs in the Tamala Limestone Formation (Davidson, 1995). The superficial aquifer moves in a westerly direction normal to the coast.

The geology and hydrogeology at Port Catherine are described in Appendix C.

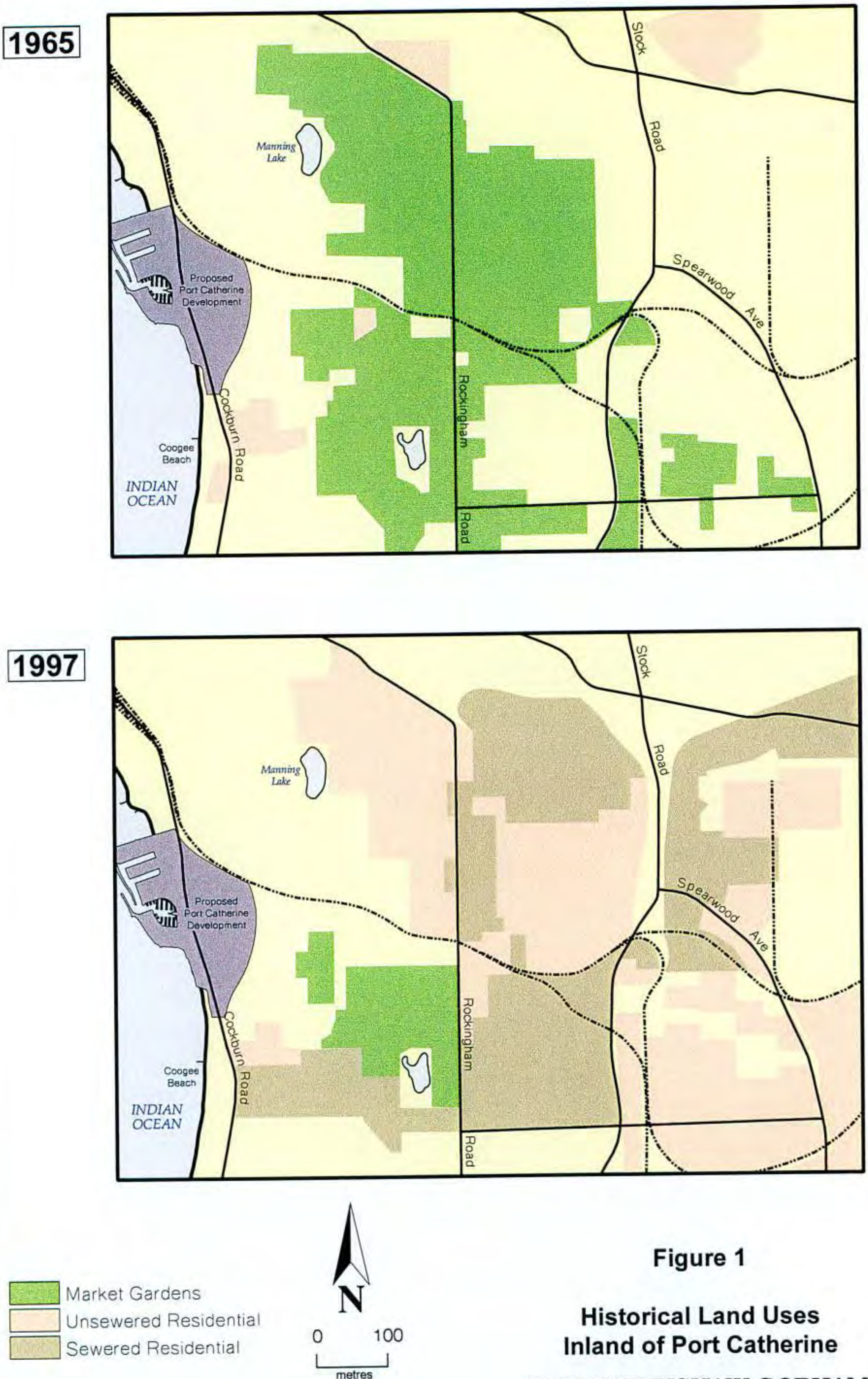

Figure 1

Historical Land Uses Inland of Port Catherine

BOWMAN BISHAW GORHAM

ENVIRONMENTAL MANAGEMENT CONSULTANTS

R97062-AB-FIG.1-30.11.00

3.0 GROUNDWATER INVESTIGATIONS

3.1 Previous Investigations

Previous investigations indicated the occurrence of elevated levels of nitrogen (in the form of nitrate) in the groundwater at this locality (Appleyard, 1990 and Groundwater Technology, 1994). These investigations were consistent with concern expressed regarding the potential for nitrogen enriched groundwater to flow to the proposed marina and provide conditions conducive to algal blooms, thus identifying the requirement for the investigations.

The groundwater investigations described herein comprised the following:

- The installation and sampling of monitor bores located adjacent to the shoreline and up to 1.6km inland.
- Groundwater sampling from 30 inland bores.
- Comparison of all available groundwater nutrient data.
- Predictive modelling of groundwater.

These investigations are discussed in the following sections.

3.2 Groundwater Bore Installation and Sampling

Groundwater sampling locations are shown on Figure 2. Bowman Bishaw Gorham installed deep groundwater monitoring bores in 1997 at two locations (MW2a and MW5a) adjacent to the shoreline and at two locations (MW10a and BBG4) 1km and 1.6km inland of the proposed Port Catherine marina. These bores were installed to assess the groundwater quality flowing toward the proposed marina site.

The former three bores were immediately adjacent to shallow bores MW2, MW5 and MW10 that had originally been installed by Groundwater Technology in 1994. Groundwater Technology had also installed MW1, MW3, MW4, MW6, MW7, MW8, MW9, MW11, MW12, and MW13 (Figure 2).

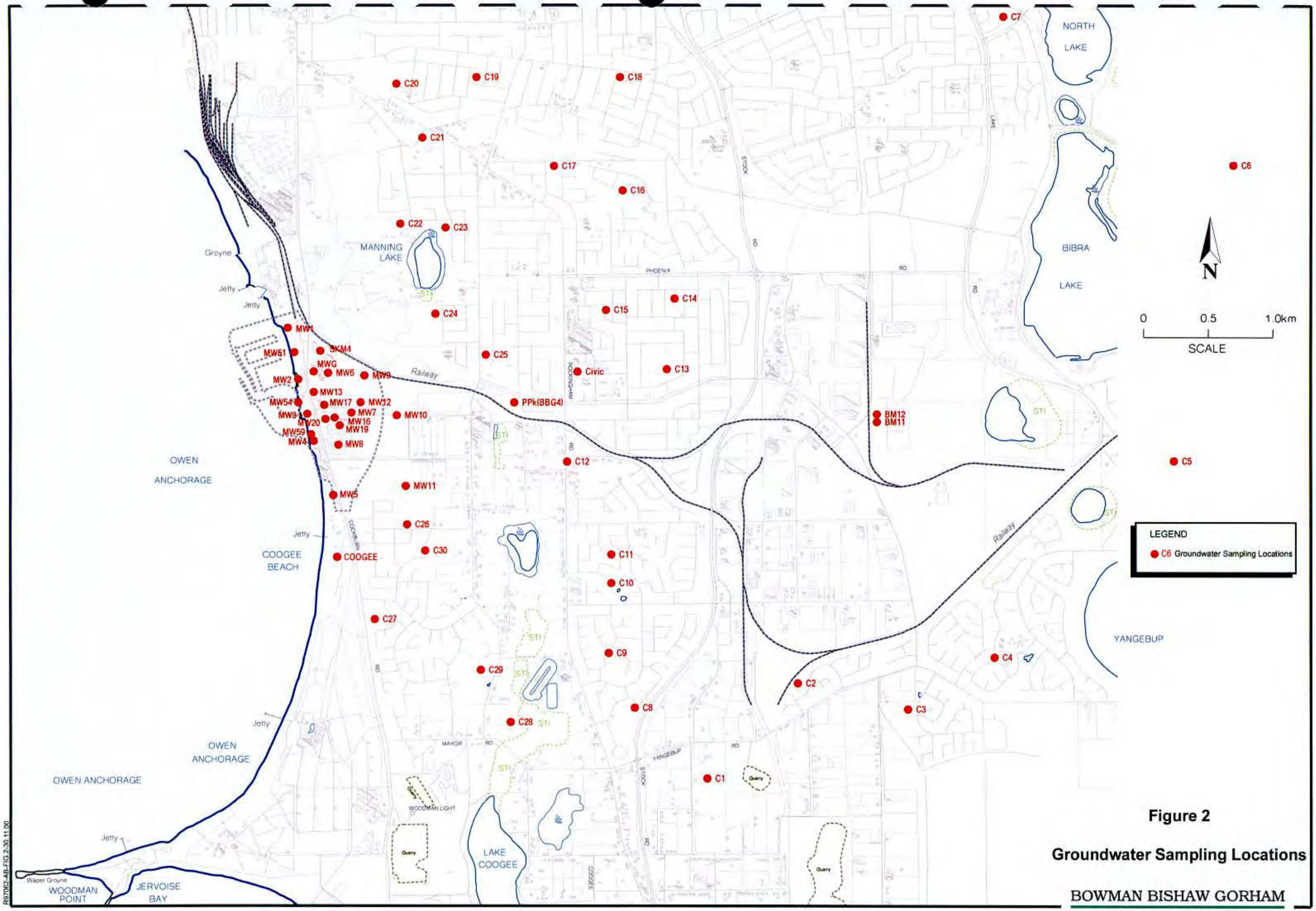

Figure 2

Groundwater Sampling Locations

BOWMAN BISHAW GORHAM

ENVIRONMENTAL MANAGEMENT CONSULTANTS

Groundwater monitoring bores were installed in 1997 at locations MW51, MW54 and MW59 by CMPS&F on behalf of the Western Australian Planning Commission (WAPC) as part of their site contamination investigation program being conducted in association with Port Catherine Developments.

The bores were drilled using a rotary air core drill. Bore MW2a was cased with slotted PVC to a depth of 8 metres. Bores MW51, MW54 and MW59 were screened over the lower two metres and cased to 0.5 m above ground level. Bore MW5a could not be cased due to collapse of the hole.

On each occasion that the groundwater quality in the bores was monitored, the bore was pumped to purge a minimum of three bore volumes of water. Samples were then collected in clean plastic bottles and stored on ice pending analysis at the laboratory.

A broadscale groundwater sampling program was undertaken by Bowman Bishaw Gorham in February 2000 to assess groundwater quality inland from the proposed marina site. On this occasion, groundwater samples were collected from 30 irrigation bores at City of Cockburn parks and reserves, spread over an area extending from approximately 0.5 km to 8 km inland from the proposed development site. City of Cockburn staff assisted with this survey. Sampling was conducted at locations C1 through C30, shown on Figure 2.

All of the irrigation bores sampled are known to draw water from the superficial aquifer. At the time of sampling (February 2000) the bores were in daily use. Sampling was conducted by collecting a sample from the sprinkler nearest the pump at each site after allowing the irrigation system to run for at least two minutes to purge any stagnant water from the sprinklers and pipelines.

Groundwater samples were stored on ice and delivered to the laboratory within eight hours of collection. All samples were analysed for ammonia nitrogen (NH_3-N), nitrate-nitrite nitrogen species (NO_x-N) and total Kjeldahl nitrogen (TKN).

3.3 Results

Table 1 provides the concentrations of the various forms of nitrogen measured in the groundwater samples from the City of Cockburn bores. The data show that with a few exceptions at inland locations, most of the nitrogen within the groundwater occurred as dissolved inorganic nitrogen (DIN), comprising ammonia nitrogen and nitrate-nitrite nitrogen. DIN is the most readily available nitrogen for algal growth in the coastal marine environment, and this is the critical nutrient of concern at Port Catherine.

Table 2 provides all available data for DIN concentrations measured in the groundwater samples during this and previous investigations within 8km of the coast within the City of Cockburn. The data mostly comprise those acquired for this investigation, but also include data acquired by others during the mid- to late-1990s.

The DIN concentrations ranged from 0.2mg/L to 11.2mg/L.

Figure 3 shows the concentration of dissolved inorganic nitrogen (DIN) measured in groundwater relative to the distance from the coast. The figure shows that groundwater concentrations of DIN are markedly higher within 2.5km of the coast. This boundary approximately coincides with the alignment of Rockingham Road (Figure 2).

Within 2.5km of the coast, the 95% upper confidence limit (UCL) on the mean DIN concentration is 4.4mg/L. In contrast, the 95% UCL on the mean concentration of DIN measured between 2.5km and 8km from the coast is approximately 1.0mg/L, indicating background conditions.

The data show that elevated nitrogen concentrations in groundwater extend to approximately 2.5km east of the proposed marina at Rockingham Road. Land use to the east of Rockingham Road is not substantially contributing to nitrogen enrichment of groundwater, relative to land use to the west of Rockingham Road. This is consistent with the broadscale change of land use from market gardens to residential development that has occurred east of Rockingham Road since 1965 (Figure 1).

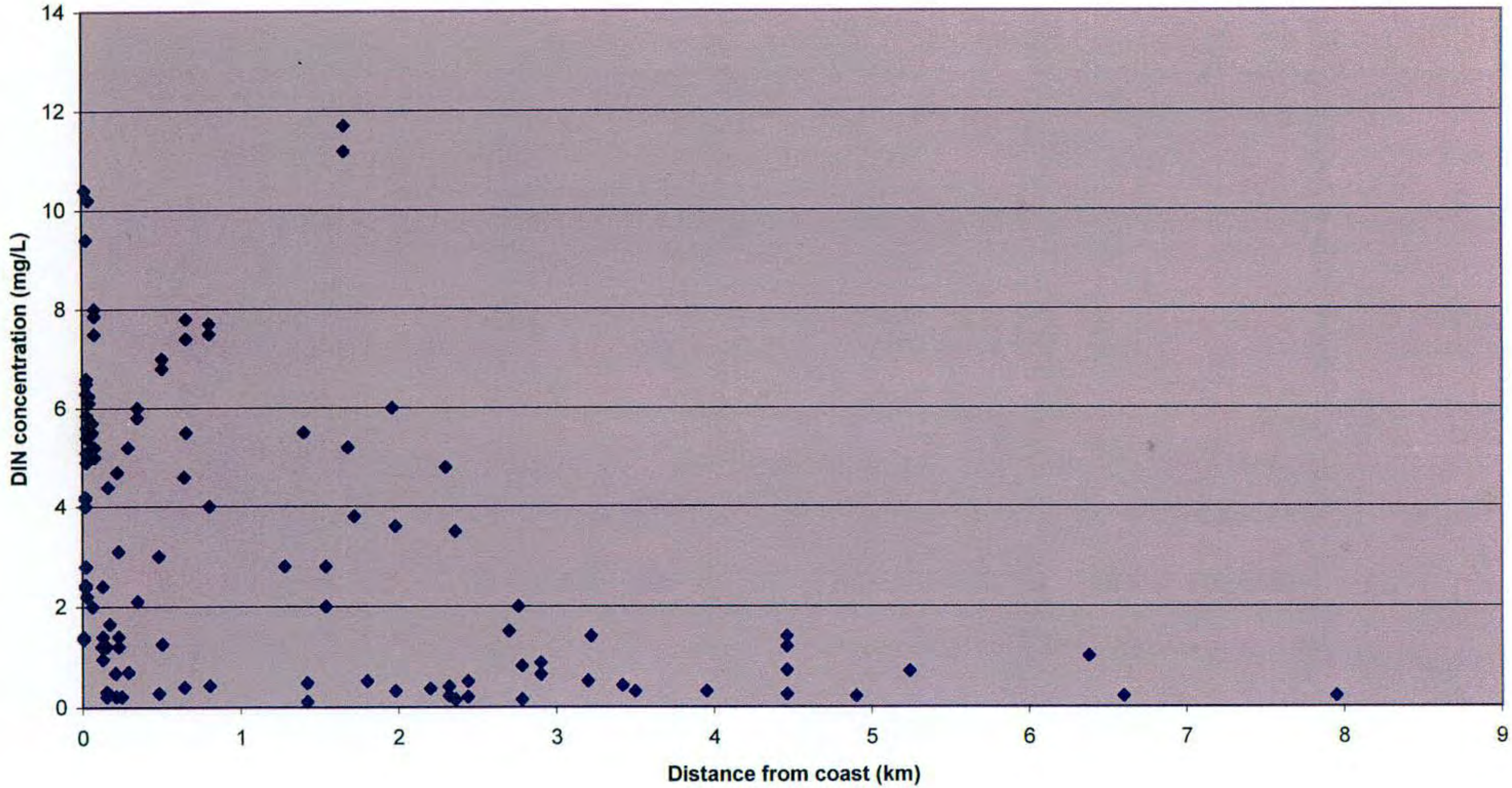

Figure 3

DIN Concentration (mg/L) with Distance from Coast

BOWMAN BISHAW GORHAM
ENVIRONMENTAL MANAGEMENT CONSULTANTS

R97062-A8-FIG.3-30.11.00

3.4 Predicted Groundwater Flow Rate

Rockwater used a numerical groundwater model (MODFLOW) to estimate the time that nitrogen enriched groundwater is likely to continue to flow into the proposed intercept drain at Port Catherine. The results indicate it will take approximately nine years for groundwater to travel the 2.5km distance from Rockingham Road to the proposed intercept drain (Rockwater, pers. com., May 2000).

Due to dilution of the plume during transport, it is anticipated that elevated concentrations of DIN in groundwater may continue to reach the intercept drain for a maximum period of twelve years. Nitrogen concentrations are expected to reduce to background concentrations (average 1.0 mg/L) during or by the end of this period.

4.0 SOIL INVESTIGATIONS

4.1 Objective

Investigations were undertaken to ascertain the potential for residual fertilizers in old market garden soils to act as a continuing source of nitrogen to the groundwater. The objective of the soil sampling and analysis was to assess the nitrogen status of the topsoils in operational and non-operational market gardens west of Rockingham Road, in terms of their residual capacity to leach DIN to the underlying groundwater. In view of the conversion to reticulated sewage in the area, it was assumed that market garden soils are the principal potential long-term source of nitrogen.

4.2 Background – Typical Nitrogen Contribution from Soil to Groundwater

The majority of nitrogen in a typical soil environment is contained in soil organic matter. However only a small percentage of this pool of nitrogen at any given time is plant available or in a leachable, inorganic (NH_3 and/or NO_x) form.

The process that transforms organically derived nitrogen to inorganic forms is generally referred to as mineralisation (Sylvia *et al*, 1996). Mineralisation is a process driven by microbes that occurs primarily in the surface soils and is enhanced by favourable environmental conditions such as high temperatures and available soil moisture.

When excess wetting occurs, mineralised nitrogen will leach to underlying soils, beyond the reach of crop roots and eventually to groundwater. In Western Australia's Mediterranean climate, all mineralised nitrogen will ultimately be flushed from the soil profile. On a seasonal basis, particularly with land uses such as market gardening, a peak of nitrogen concentration will occur in the underlying groundwater with the onset of winter rains.

An important factor in characterising the potential mineralisation rates of nitrogen in soils is the carbon to nitrogen (C:N) ratio. It is generally accepted that C:N ratios of around 25 will, assuming favourable soil conditions, result in mineralisation of soil organic nitrogen (Vlek *et al*, 1981).

Recent research conducted on deep sandy soil types in the Swan Coastal Plain has shown average mineralisation rates of 2% of total nitrogen (TN) content per annum (pers. com., G. Anderson, CSIRO, 2000).

4.3 Methods

Soils were collected from eighteen market garden sites that are or until recently were, under production. Two samples were also collected from native vegetation reserves to provide background data.

At each site, four soil samples were collected from the surface 50cm of the soil profile and composited. After thorough mixing of the composited samples, a representative sub-sample was collected into precleaned containers and stored on ice.

All samples were submitted to the laboratory within eight hours of collection and were analysed for ammonia (NH_3), nitrates (NOx), total Kjeldahl nitrogen (TKN) and organic carbon (OC) content. At each site, a separate core sample of soil was collected for determination of in-situ bulk density (BD).

4.4 Results

The results of analysis and subsequent calculations are shown in Table 3 and are summarised as follows:

- Compared with the background samples, the market garden soils did not contain large residual concentrations of TN. The TN content of the market garden soils ranged from 1,144kg/Ha to 8,050kg/Ha with an average of 3,732kg/Ha. The average TN concentration in the background soils was 2,917kg/Ha.

- The predominant occurrence of nitrogen at both market garden and background soils was as TKN, with relatively minor fractions of NO_x and NH_3, confirming that the majority of inorganic nitrogen had been flushed from the soil profile.

- Comparable concentrations of organic carbon were detected in market garden and background soils. The OC content of market garden soils ranged from 17,500kg/ha to 140,000kg/ha with an average of 79,576kg/ha. The background sites had a marginally higher average OC content of 85,313kg/ha.

- The average C:N ratio was 23 in market garden soils and 29 in background soils. These ratios are in a range that indicates that net mineralisation of TKN will occur.

- The average mineralisation rate (2% of TN per annum) was 74.6kg/ha in market garden soils and 58.3kg/ha in background soils.

If it is conservatively assumed that the measured surface concentrations of nitrogen are distributed throughout the surface 1m of the soil profile and that the soil has a porosity of 40% and is constantly saturated, then the maximum rate at which mineralised nitrogen may potentially leach from each soil type is as follows:

For market garden soils:

Mineralisation rate of 74.6 kg/ha/a	=	0.00746 $kg/m^2/a$
Potential leaching rate	=	0.00746 $kg/m^2/a$ x 1m x 0.4
	=	0.003 $kg/m^3/a$
	=	3 mg/L/a
	=	0.0082 mg/L/d

For background soils:

Mineralisation rate of 58.3 kg/ha/a	=	0.0058 $kg/m^2/a$
Potential leaching rate	=	0.0058 $kg/m^2/a$ x 1m x 0.4
	=	0.0023 $kg/m^3/a$
	=	2.3 mg/L/a
	=	0.0064 mg/L/d

4.5 Discussion

The market garden soils had similar TN and OC content to background soils. The low fraction of NO_x measured in these soils indicates that fertilisation using nitrate-based compounds is not a wide scale current practice in the area. This confirms that mineralisation of residual organic soil material will be the only major potential ongoing contributor to groundwater DIN content.

The annual mineralisation rate of 74.6kg/ha from market garden soils, which is only marginally higher than the background rate of 58.3kg/ha, suggests that the market garden soils in this area are unlikely to leach nitrogen to groundwater unless they receive additional fertiliser application and irrigation.

It is concluded that previous market gardening practices in the hinterland to the east of the proposed Port Catherine marina and groundwater intercept drain have not resulted in an ongoing potential for nitrogen leaching to groundwater. The maximum rate at which mineralised nitrogen may potentially leach from old market garden soils is estimated to be 0.0082mg/L/d. This rate is only 0.0018mg/L/d greater than might occur from background soils.

The conversion to residential development east of Rockingham Road that has resulted in the distinct demarcation of nitrogen enriched groundwater to the west of Rockingham Road (Figure 3) is also likely to halt the leaching of nitrogen to groundwater. Grass species have reported uptake rates of 53% of soil derived nitrogen (Anderson *et al,* 1998) and are a dominant feature as urban lawns in the area.

5.0 CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

5.1 Conclusions

Historical market gardening activities inland of the proposed Port Catherine marina have resulted in the plume of nitrogen enriched groundwater that is currently present in the area. The cessation of horticultural activities and the conversion to residential development will effectively reduce the leaching of nitrogen. The soil investigation has shown that the market garden soils west of Rockingham Road are unlikely to continue to contribute nitrogen to groundwater.

The groundwater investigations defined a plume of groundwater with a mean concentration of up to 4.4mg/L DIN beneath the Port Catherine site and extending to about 2.5km inland. Groundwater located from 2.5km to 8km inland contains a reduced DIN concentration that approaches background (mean concentration up to 1.0mg/L).

Numerical groundwater modelling indicates that the eastern edge of the elevated DIN plume will reach the proposed intercept drain within nine to twelve years. The eastern edge of the plume will be followed by groundwater containing background concentrations of DIN.

5.2 Management Measures

Port Catherine Development plans to prevent nitrogen-enriched groundwater from reaching the proposed marina and thereby contributing to algal blooms by implementing the following management measures:

- Constructing a drain within the proposed development area to intercept nitrogen enriched groundwater, thus preventing this groundwater from reaching the proposed marina and decreasing marina water quality.

- Pumping of the intercepted groundwater for irrigation of public open space and park areas within the proposed development.

- Pumping of excess intercepted groundwater north of the proposed development, outside of the capture zone for the proposed marina. Excess water will be re-injected to groundwater.

On the basis of the investigations described herein, the drain is required to intercept groundwater for up to 12 years. The maximum mean concentration of DIN in groundwater reaching the drain during that time is expected to be 4.4mg/L.

Beyond 2012 the maximum mean DIN concentration in groundwater reaching the marina will decrease to a background concentration of 1.0mg/L and pumping from the intercept drain will no longer be required.

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TABLES

Table 1
Results of Groundwater Analysis
February 2000

Sample Details				Results				
Sample ID	Park	Location	Distance from coast	NH_3	NOx	TKN	TN	DIN
C1	Radonich Park	Ivancovich Rd	3.5	0.3	0.01	0.6	0.61	0.31
C2	Warthwyke Park	Magnolia Cr	3.95	0.3	0.01	0.6	0.61	0.31
C3	Ronsard Reserve	Ronsard Pl	4.9	0.2	0.01	0.6	0.61	0.21
C4	Perena Rochi Park	Moorhen Rd	5.24	0.7	0.01	1.4	1.41	0.71
C5	Hop Bush Park	Elderberry Dr	6.6	0.2	0.01	0.3	0.31	0.21
C6	Meller Park	Hope Rd	7.95	0.2	0.01	0.3	0.31	0.21
C7	Richard Angeloni Park	Gilbertson Rd	6.38	1	0.01	1.6	1.61	1.01
C8	Santich Park	Shelley Wy	2.78	0.2	0.62	0.3	0.92	0.82
C9	Hagan Park	Dryden Str	2.44	0.2	0.31	0.3	0.61	0.51
C10	Smart Park	Barrett Str	2.32	0.2	0.02	0.4	0.42	0.22
C11	Bishop Park	Huxley Pl	2.36	1	2.5	1.3	3.8	3.5
C12	Watsons Oval	Reserve Rd	1.98	0.2	3.4	0.4	3.8	3.6
C13	McFaull Park	Falstaff Rd	2.9	0.6	0.05	1	1.05	0.65
C14	Dubove Park	Bohemia Str	3.22	1.4	0.01	1.7	1.71	1.41
C15	Bavich Park	Lancaster Str	2.7	1.5	0.01	1.8	1.81	1.51
C16	Goodchild Park	Cade Str	3.2	0.5	0.02	0.8	0.82	0.52
C17	Isted Reserve	Isted Ave	2.76	0.2	1.8	0.3	2.1	2
C18	Enright Reserve	Healy Rd	3.42	0.4	0.03	0.6	0.63	0.43
C19	Baker Square	Dianne Str	2.3	0.2	4.6	0.3	4.9	4.8
C20	Dixon Reserve	Hurford rd	1.72	0.2	3.6	0.3	3.9	3.8
C21	Davilac Oval	Lucius rd	1.96	0.2	5.8	0.3	6.1	6
C22	Manning Park (1)	Janson Rd	1.4	0.2	5.3	0.3	5.6	5.5
C23	Manning Park (2)	Glenister Rd	1.68	0.2	5	0.3	5.3	5.2
C24	Manning Park (3)	Gorham Rd	1.28	0.2	2.6	0.2	2.8	2.8
C25	Beale Park	Hamilton Rd	1.54	0.2	2.6	0.3	2.9	2.8
C26	Rotary Lookout	King Str	0.64	0.2	4.4	0.3	4.7	4.6
C27	Powell Reserve	Parakeet Wy	0.48	0.2	2.8	0.3	3.1	3
C28	Kevin Bowman Reserve	Kotisina Grdns	1.8	0.2	0.32	0.3	0.62	0.52
C29	Poole Reserve	Hamilton Rd	1.42	0.2	0.28	0.3	0.58	0.48
C30	Piccatee Reserve	Duchart Wy	0.8	1.5	2.5	2	4.5	4

Notes:
All results in mg/L
Distance in km

TKN total Kjeldahl nitrogen
NOx oxygenated nitrogen species (nitrates)
NH_3 ammonia
TN total nitrogen

Table 2
Summary of DIN in Groundwater
(0-8 km from coast)

Bore Name	Km from coast	DIN (mg/L)	Date	Source
Beale	1.54	2	Jul-97	ARL MI 7063
Bishop	2.36	0.15	Jul-97	ARL MI 7063
BM11	4.46	1.2	Aug-93	WAWA
BM11	4.46	0.73	Oct-97	WAWA
BM12	4.46	0.248	Aug-93	WAWA
BM12	4.46	1.402	Oct-97	WAWA
C01	3.5	0.31	Feb-00	BBG Monitoring
C02	3.95	0.31	Feb-00	BBG Monitoring
C03	4.9	0.21	Feb-00	BBG Monitoring
C04	5.24	0.71	Feb-00	BBG Monitoring
C05	6.6	0.21	Feb-00	BBG Monitoring
C06	7.95	0.21	Feb-00	BBG Monitoring
C07	6.38	1.01	Feb-00	BBG Monitoring
C08	2.78	0.82	Feb-00	BBG Monitoring
C09	2.44	0.51	Feb-00	BBG Monitoring
C10	2.32	0.22	Feb-00	BBG Monitoring
C11	2.36	3.50	Feb-00	BBG Monitoring
C12	1.98	3.60	Feb-00	BBG Monitoring
C13	2.9	0.65	Feb-00	BBG Monitoring
C14	3.22	1.41	Feb-00	BBG Monitoring
C15	2.7	1.51	Feb-00	BBG Monitoring
C16	3.2	0.52	Feb-00	BBG Monitoring
C17	2.76	2.00	Feb-00	BBG Monitoring
C18	3.42	0.43	Feb-00	BBG Monitoring
C19	2.3	4.80	Feb-00	BBG Monitoring
C20	1.72	3.80	Feb-00	BBG Monitoring
C21	1.96	6.00	Feb-00	BBG Monitoring
C22	1.4	5.50	Feb-00	BBG Monitoring
C23	1.68	5.20	Feb-00	BBG Monitoring
C24	1.28	2.80	Feb-00	BBG Monitoring
C25	1.54	2.80	Feb-00	BBG Monitoring
C26	0.64	4.60	Feb-00	BBG Monitoring
C27	0.48	3.00	Feb-00	BBG Monitoring
C28	1.8	0.52	Feb-00	BBG Monitoring
C29	1.42	0.48	Feb-00	BBG Monitoring
C30	0.8	4.00	Feb-00	BBG Monitoring
Civic	2.2	0.37	Jul-97	ARL MI 7063
Coogee	0.12	1.2	Jul-97	ARL MI 7063
Hagen	2.44	0.2	Jul-97	ARL MI 7063
McFall	2.90	0.88	Jul-97	ARL MI 7063
MW01	0.04	10.2	Jul-94	Groundwater Technology - South Coogee Hydrogeological Assessment
MW01	0.04	6.25	na	CMPS&F and Ministry for Planning
MW01	0.04	6.1	Jun-97	W:\ENVIRON\JOBS\VW1043\GWORIG.DOC
MW02	0.026	5.4	Jul-94	Groundwater Technology - South Coogee Hydrogeological Assessment
MW02	0.026	5.85	Nov-97	ARL - MI 7062
MW02	0.026	6.5	Jul-97	R97062/ Drilling Results
MW02	0.026	9.4	Jul-97	R97062/ Drilling Results
MW02	0.026	5.6	Jul-94	R97062/nitrate in shallow bores
MW02	0.026	6.6	Jul-97	R97062/nitrate in shallow bores
MW02	0.026	2.2	Jun-97	W:\ENVIRON\JOBS\VW1043\GWORIG.DOC
MW03	0.062	5.7	Jul-94	Groundwater Technology - South Coogee Hydrogeological Assessment
MW03	0.062	5.2	Jul-94	R97062/nitrate in shallow bores
MW03	0.062	2	Jun-97	W:\ENVIRON\JOBS\VW1043\GWORIG.DOC
MW03	0.062	5.5	Nov-97	ARL - MI 7062
MW04	0.024	5.1	Jul-94	Groundwater Technology - South Coogee Hydrogeological Assessment
MW04	0.024	4.9	Jul-94	R97062/nitrate in shallow bores
MW04	0.024	6.3	Jul-97	R97062/nitrate in shallow bores
MW04	0.024	2.8	Oct-97	R97062/nitrate in shallow bores

Table 2
Summary of DIN in Groundwater
(0-8 km from coast)

Bore Name	Km from coast	DIN (mg/L)	Date	Source
MW05	0.076	5	Jul-94	Groundwater Technology - South Coogee Hydrogeological Assessment
MW05	0.076	7.86	Jul-97	R97062/ Drilling Results
MW05	0.076	7.5	Jul-97	R97062/ Drilling Results
MW05	0.076	5.2	Jul-94	R97062/nitrate in shallow bores
MW05	0.076	8	Jul-97	R97062/nitrate in shallow bores
MW06	0.226	1.2	Jul-94	Groundwater Technology - South Coogee Hydrogeological Assessment
MW06	0.226	1.4	Jul-94	R97062/nitrate in shallow bores
MW06	0.226	3.1	Jun-97	W:\ENVIRON\JOBS\VW1043\GWORIG.DOC
MW07	0.288	5.2	Jul-94	Groundwater Technology - South Coogee Hydrogeological Assessment
MW07	0.288	5.2	Jul-94	R97062/nitrate in shallow bores
MW07	0.288	0.7	Jun-97	W:\ENVIRON\JOBS\VW1043\GWORIG.DOC
MW08	0.15	1.2	Jul-94	Groundwater Technology - South Coogee Hydrogeological Assessment
MW08	0.15	0.31	Jul-94	R97062/nitrate in shallow bores
MW08	0.15	0.21	Jun-97	W:\ENVIRON\JOBS\VW1043\GWORIG.DOC
MW09	0.502	6.8	Jul-94	Groundwater Technology - South Coogee Hydrogeological Assessment
MW09	0.502	1.25	na	CMPS&F and Ministry for Planning
MW09	0.502	7	Jul-94	R97062/nitrate in shallow bores
MW10	0.8	7.5	Jul-94	Groundwater Technology - South Coogee Hydrogeological Assessment
MW10	0.8	7.7	Jul-97	R97062/ Drilling Results
MW10	0.8	0.43	Jul-94	R97062/nitrate in shallow bores
MW11	0.654	7.8	Jul-94	Groundwater Technology - South Coogee Hydrogeological Assessment
MW11	0.654	7.4	Jul-94	R97062/nitrate in shallow bores
MW11	0.654	5.5	Jun-97	W:\ENVIRON\JOBS\VW1043\GWORIG.DOC
MW12	0.346	6	Jul-94	Groundwater Technology - South Coogee Hydrogeological Assessment
MW12	0.346	5.8	Jul-94	R97062/nitrate in shallow bores
MW12	0.346	2.1	Jun-97	W:\ENVIRON\JOBS\VW1043\GWORIG.DOC
MW13	0.126	1.4	Jul-94	Groundwater Technology - South Coogee Hydrogeological Assessment
MW13	0.126	0.95	Jul-94	R97062/nitrate in shallow bores
MW13	0.126	2.4	Jun-97	W:\ENVIRON\JOBS\VW1043\GWORIG.DOC
MW16	0.21	0.21	1997	R97062/inland nitrogen 31 Jan
MW17	0.218	4.7	1997	R97062/inland nitrogen 31 Jan
MW19	0.244	0.21	1997	R97062/inland nitrogen 31 Jan
MW20	0.16	4.4	1997	R97062/inland nitrogen 31 Jan
MW51	0.018	4.15	Jan-98	CMPS&F ARL Lab No. 21184
MW51	0.018	4.2	Dec-97	Appendix G Page 9
MW51	0.018	10.4	Jul-94	R97062/nitrate in shallow bores
MW51	0.018	4	Dec-97	R97062/nitrate in shallow bores
MW54	0.006	1.35	Jan-98	CMPS&F ARL Lab No. 21184
MW54	0.006	1.35	Dec-97	Appendix G Page 9
MW54	0.006	1.4	1997	R97062/inland nitrogen 31 Jan
MW59	0.02	2.38	Jan-98	CMPS&F ARL Lab No. 21184
MW59	0.02	2.43	Dec-97	Appendix G Page 9
MW59	0.02	2.8	1997	R97062/inland nitrogen 31 Jan
MWG	0.17	1.65	na	CMPS&F and Ministry for Planning
Poole	1.42	0.11	Jul-97	ARL MI 7063
Powell	0.48	0.28	Jul-97	ARL MI 7063
PPk (BBG4)	1.66	11.7	Jul-97	R97062/ Drilling Results
PPk (BBG4)	1.66	11.18	1997	R97062/inland nitrogen 31 Jan
Rotary	0.64	0.4	Jul-97	ARL MI 7063
Santich	2.78	0.15	Jul-97	ARL MI 7063
SKM4	0.206	0.68	Jun-97	W:\ENVIRON\JOBS\VW1043\GWORIG.DOC
Smart	2.32	0.41	Jul-97	ARL MI 7063
Watsons	1.98	0.32	Jul-97	ARL MI 7063

Table 3
Soil Characteristics

Market Garden Sites												
	Results of Analysis											
Sample ID	TKN	NOx	NH_3	TN	OC	BD	OC	OC	C:N	TN	NOx	N min rate
	mg/kg	mg/kg	mg/kg	mg/kg	%	g/cm^3	mg/kg	kg/Ha		kg/Ha	kg/Ha	kg/Ha/yr
PC1	920	0.6	<1	920.6	1.60	1.75	16,000	140,000	17	8,050	5.25	161.0
PC2	590	0.2	<1	590.2	1.10	1.75	11,000	96,250	19	5,176	1.75	103.5
PC3	300	1.0	<1	301.0	0.70	1.76	7,000	61,250	23	2,640	8.75	52.8
PC4	310	0.1	<1	310.1	0.64	1.74	6,400	56,000	21	2,698	0.88	54.0
PC5	670	1.1	<1	671.1	0.79	1.76	7,900	69,125	12	5,896	9.63	117.9
PC6	140	1.6	<1	141.6	0.25	1.75	2,500	21,875	18	1,228	14.00	24.6
PC7	130	1.1	<1	131.1	0.20	1.76	2,000	17,500	15	1,144	9.63	22.9
PC8	240	0.4	<1	240.4	0.62	1.74	6,200	54,250	26	2,093	3.50	41.9
PC9	200	0.1	<1	200.1	0.47	1.75	4,700	41,125	24	1,750	0.88	35.0
PC10	220	1.3	<1	221.3	0.67	1.75	6,700	58,625	30	1,925	11.38	38.5
PC11	240	0.9	<1	240.9	0.58	1.75	5,800	50,750	24	2,100	7.88	42.0
PC12	250	0.9	<1	250.9	1.00	1.75	10,000	87,500	40	2,188	7.88	43.8
PC13	360	0.6	<1	360.6	0.95	1.75	9,500	83,125	26	3,150	5.25	63.0
PC14	800	3.1	2.0	803.1	1.50	1.75	15,000	131,250	19	7,000	27.13	140.0
PC15	360	5.9	<1	365.9	1.10	1.75	11,000	96,250	31	3,150	51.63	63.0
PC16	670	5.0	2.0	675.0	1.40	1.75	14,000	122,500	21	5,872	43.75	117.4
PC17	680	4.7	<1	684.7	1.50	1.73	15,000	131,250	22	5,876	41.13	117.5
PC18	600	3.2	<1	603.2	1.30	1.76	13,000	113,750	22	5,250	28.00	105.0
Average	*427*	*1.8*	*<1*	*428.4*	*0.91*	*1.75*	*9,094*	*79,576*	*23*	*3,732*	*15.46*	*74.6*
Background Sites												
PCC1	340	4.1	<1	344.1	1.00	1.75	10,000	87,500	29	2,980	35.88	59.6
PCC2	330	2.9	<1	332.9	0.95	1.73	9,500	83,125	29	2,854	25.38	57.1
Average	*335*	*3.5*	*<1*	*338.5*	*0.98*	*1.74*	*9,750*	*85,313*	*29*	*2,917*	*30.63*	*58.3*

Abbreviations:

TKN total Kjeldahl nitrogen
NOx oxygenated nitrogen species (nitrates)
NH_3 ammonia
TN total nitrogen
OC organic carbon
BD insitu bulk density
C:N carbon to nitrogen ratio
OC organic carbon
BD insitu bulk density
C:N carbon to nitrogen ratio

N min rate minimum rate of nitrogen leaking

APPENDIX III
Groundwater Modelling to Predict the Effects of Planned Cut-off Drain
(Rockwater Pty Ltd)

Rockwater
PROPRIETARY LIMITED

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PORT CATHERINE DEVELOPMENT PTY LTD
BOWMAN BISHAW GORHAM

GROUNDWATER MODELLING TO PREDICT THE EFFECTS OF PLANNED CUT-OFF DRAIN

NOVEMBER 2000

221.2/00/2

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Rockwater
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PORT CATHERINE DEVELOPMENT PTY LTD
BOWMAN BISHAW GORHAM

GROUNDWATER MODELLING TO PREDICT THE EFFECTS OF PLANNED CUT-OFF DRAIN

NOVEMBER 2000

1. INTRODUCTION

Groundwater flowing towards the coast in the vicinity of the planned Port Catherine development has elevated nitrogen concentrations (average 4.4 mg/L) that could cause algal blooms in the marina and canals which will form part of the development. A cut-off drain is proposed up-gradient of the development to capture most of the groundwater throughflow in summer, and possibly in winter (if necessary). Water pumped from the drain will be used to irrigate areas of public open space (POS) that are within several kilometres of the drain. Surplus water will be injected back into the aquifer near the coast, north of the project site.

As part of the environmental review, Rockwater was engaged to carry out numerical modelling to predict the required elevation of the drain, groundwater inflow rates and effects; as well as calculating residual groundwater flows to the coast and marina.

The results of the modelling have been used by others:

- to design the drain, and a conceptual irrigation scheme (Sinclair Knight Merz, Bowman Bishaw Gorham)
- for solute transport and fate modelling (Bowman Bishaw Gorham); and,
- for modelling nitrogen levels in Owen Anchorage and the marina (MP Rogers & Associates).

This report describes the method and results of the numerical groundwater modelling.

2. DRAIN REQUIREMENTS

Initial calculations by MP Rogers & Associates indicated that nitrogen input to the planned marina would need to be reduced by about 80 to 90 percent in summer for nitrogen concentrations to be at an acceptable level.

In the numerical model the level of water in the drain ("drain level") was varied until the flow to the marina was reduced to the required rate (300 to 640 m^3/d) in summer. If in practice the permeability of the aquifer, drain conductance and groundwater levels (Section 4.1.1) are more or less than the values adopted in the modelling, the drain level can be adjusted until groundwater flow to the to the marina/canals is at an acceptable rate.

It is unlikely that groundwater discharge to the marina and canals will need to be regulated in winter. In the modelling it was assumed that groundwater would continue to flow past the drain, towards the coast.

3. GEOLOGY AND HYDROGEOLOGY

The Tamala Limestone of Quaternary age crops out inland of the coast at Port Catherine. It is a variably-cemented calcareous eolianite. Along the coast, the limestone is overlain by the Safety Bay Sand, a fine to medium grained sand composed of shell fragments and minor quartz. The sand generally extends to less than one metre below mean sea level (or AHD).

The Tamala Limestone contains karstic features and is generally highly permeable, with hydraulic conductivities of between about 100 and 1,000 m/d (Davidson, 1995). The Safety Bay Sand is less permeable, with a hydraulic conductivity of about 8 m/d (Davidson, 1995). Analysis of tidal fluctuations in the groundwater suggests that the effect of the Safety Bay Sand and other restrictions to flow have reduced hydraulic conductivity within 30 m of the coast at Port Catherine to 50 m/d or less (Coffey Partners International, 1997). The Coffey analysis also indicated a hydraulic conductivity of about 500 m/d at distances of 30 m to 200 m from the coast, and that the hydraulic conductivity is likely to vary over short distances.

Groundwater level measurements made in monitoring bores at and inland of the site in July/August 1994 (GTA, 1994) indicate water levels ranging from 0.16 m to 0.26 m AHD (average 0.2 m) along Cockburn Road, 100 m from the coast, rising to 0.5 m AHD at a distance of 500 to 600 m east of the coast (Fig. 1). They show a relatively steep hydraulic gradient at the coast and a lower gradient inland, supporting the findings of the Coffey tidal analysis. Recent water level measurement by Bowman Bishaw Gorham indicate end-of-summer water levels of 0.41 to 0.56 m AHD along Cockburn Road (Fig. 2). These high levels are attributed to the effects of unusually high tides that have occurred since March 1999 (Fig. 3).

Groundwater levels have been monitored regularly by the Water and Rivers Commission in bore CSG2, situated alongside Cockburn Road in the project area. They have been affected by tides, but the average water level in the bore has ranged from about 0.2 m AHD in summer to about 0.4 m AHD in winter (Fig. 3).

A wedge of saltwater extends inland from the coast, with the depth to the top of the wedge generally increasing with distance from the coast although there is a high degree of variability. Six monitoring bores constructed for the Port Catherine project have intersected the saltwater wedge. The thickness of fresh water in these and two other bores is shown in Table 1.

TABLE 1

THICKNESS OF FRESH GROUNDWATER VERSUS
DISTANCE FROM COAST

Bore	Distance From High Water Mark (m)	Thickness of Groundwater (m) (of less than 2,000 mg/L TDS)
MW54	8	3
MW59	8	>10
MW51	10	9
MW2	23	5
MW4	24	8
MW5	80	13
PC1	240	17
MW10	780	21 (to base of aquifer)

Variations in the relationship between distance from the coast and thickness of low-salinity groundwater result from variations in hydraulic conductivity: the thickness is less where hydraulic conductivity is higher.

4. GROUNDWATER FLOW MODELLING

4.1 METHOD

The modelling was undertaken using Processing Modflow version 5.1.7, a recent version of the industry-standard finite difference groundwater modelling software Modflow (McDonald and Harbaugh, 1988).

The model consists of two layers of 58 rows and 46 columns covering an area of 7,500 m (east-west) by 6,200 m (north-south). Both layers represent the Superficial aquifer above the saltwater interface: Layer 1 extends down to –5m AHD and is used in representing the cut-off drain.

Cell sizes range from 50 m x 50 m in the project area, to 600 m x 500 m in some marginal areas (Fig. 4).

4.1.1 Model Parameters

The parameters used in the model are as follows:

- The base of the aquifer ranges in elevation from –30 m AHD inland of the coast to –20 m AHD at the eastern boundary of the model (Plate 49, Davidson, 1995). Along the coast, the base was taken to be the top of the saltwater wedge, ie. the base of the flow system. The slope of the interface was represented by four steps corresponding with model columns. The zone covered by each column, and the adopted elevation of aquifer base, are as follows:

  40 m west, to 10 m east of coast, – 5 m AHD
  10 to 60 m east of coast, – 10 m AHD
  60 to 110 m east of coast, – 20 m AHD, and
  110 to 160 m east of coast, – 30 m AHD

- A fixed head boundary was set at average groundwater level (15 m AHD) in the east; and a general head boundary was used to represent the ocean in the west. Heads representing the ocean range from an average summer sea level of –0.06 m AHD to an average winter level of +0.07 m AHD.

- The northern and southern boundaries were assumed to be no-flow, as they are parallel to the groundwater flow direction.

- A high value of 700 m/d was adopted for the hydraulic conductivity of the Tamala Limestone inland of the coast, in calibrating the model to measured groundwater levels. This is higher than the value of 500 m/d that was estimated from tidal measurements by Coffey Partners International (1997), and so should represent a worst-case with respect to pumping requirements from the cut-off drain and the movement of nitrogen and other constituents in groundwater towards the ocean and the marina.

- Other values of horizontal hydraulic conductivity adopted in model calibration are 90 m/d for the Tamala Limestone (and Safety Bay Sand) along the coast; values of 100 to 200 m/d for the Tamala Limestone/Sand to at least 600 m inland of the coast; and 15 to 25 m/d for the Tamala Sand.

- Vertical hydraulic conductivity was assumed to be one tenth of horizontal hydraulic conductivity. This is a relatively high ratio, but measurements by Bowman Bishaw Gorham offshore at Port Catherine indicate that most groundwater discharge is within 40 m of the shore. This implies that there is high vertical hydraulic conductivity within the Tamala Limestone.

- A specific yield of 0.2 was used. Groundwater flows calculated by the model are insensitive to the value of this parameter.

- Recharge adopted in calibrating the model was 0.9 mm/d over the months May to September. This is equivalent to 138 mm/year or 16% of annual rainfall, and is almost the same as the value of 15% used by Davidson (1995) in a flow-net analysis of the Jandakot groundwater mound.

4.1.2 Calibration, and Validity of Model

The model was calibrated to average groundwater levels, taken to be those given in Figure 27 of Davidson (1995), and to an average summer water level of about 0.2 m AHD at Cockburn Road (eg. bore CSG2). The calculated end-of-summer levels, used as initial water levels in the model (Fig. 5) are similar but slightly lower than the July/August 1994 (mid-season) groundwater levels measured at the project site (Fig. 1).

Model-predicted groundwater flows to the ocean north and south of the project site, without the cut-off drain, range from 4,000 – 4,200 m^3/d/km in winter, to 2,500 – 3,000 m^3/d/km in summer (annual average 3,300 – 3,600 m^3/d). The average value is slightly higher (by 6 to 12 percent) than an average flow of 3,100 m^3/d/km that was derived from a flow-net analysis of the Jandakot Mound (Davidson, 1995), for the flow channel which includes Port Catherine. The flow channel is about 17 km wide at the coast, and so the flow calculated by Davidson represents an average for an aquifer that has variable permeability and hydraulic gradients.

The comparison of the calculated groundwater flows again shows that the model is conservative for calculating flows to the planned marina and cut-off drain, and should allow for any zones of higher-than-average hydraulic conductivity in the Tamala Limestone at the project site.

Consideration was given to installing test bores or sumps and conducting pumping tests to determine hydraulic conductivity of the Tamala Limestone and the hydraulic response to pumping, but it was decided that testing was not warranted because:

(i) Even with tests on several bores or sumps, it is unlikely that the results would represent the variability of the limestone, and

(ii) It is very difficult to obtain interpretable test data for the Tamala Limestone because almost all of the drawdown occurs within the first minute of testing, and drawdowns measured in observation bores that are at the required distance from the pumped bore (ie. at least 1.5 times aquifer thickness) are usually too small to be analysed.

4.1.3 Simulating Effects of Drain and Injection Bores

Modflow's drain package was used to simulate the cut-off drain, and the well package was used to simulate infiltration via injection bores.

The drain is planned to be about 150 m inland of the present coastline, close to Cockburn Road (Fig. 6). The position was selected to minimise pumping requirements, and to reduce the possibility of up-coning of saline groundwater (Section 5).

A conductance term is used in the drain package to allow for the hydraulic conductivity of the aquifer and the bed of the drain, and head losses between the aquifer and the drain. Values of hydraulic conductance can only be determined by calibration of the model to drain flows, but for prediction of flows a value of 25,000 m^2/d was adopted. This is equivalent to an effective hydraulic conductivity (after allowing for restrictions to inflow to the drain and head losses) of 500 m/d (= 71 percent of the aquifer hydraulic conductivity).

The drain water level was varied in the model until the residual groundwater flow to the planned marina was at the target level (minimum of 300 m^3/d) in summer. A drain water level of -0.02 m AHD was indicated. The drain would be constructed at a lower elevation, -1 m to -2 m AHD, so that its water level can be lowered further if the hydraulic conductivity of the aquifer or the drain conductance are lower than the values adopted. The water level would be varied by controlling the flow from the drain.

Once the drain is operating, the groundwater model can be re-calibrated to flows, drain level, and groundwater levels down-gradient of the drain; and then run to reassess groundwater flows to the marina and any variation in drain water level required.

The position and layout of injection bores have yet to be finalised, but there could be about six bores, spaced 100 m to 200 m apart on the western side of the old Robb's Jetty freight terminal, north of the disused South Fremantle power station (Fig. 6).

4.2 MODELLING RESULTS

Groundwater flows to be pumped from the cut-off drain are indicated to be about 6,000 m^3/d in summer (without any injection of surplus water) for a residual flow to the marina of 300 m^3/d. Actual flows to the drain are likely to be less, as the aquifer hydraulic conductivity is probably lower than the adopted value, as discussed in Section 4.1.1.

The water pumped from the drain will be used for irrigation of Public Open Space (POS), as much as possible. An irrigation specialist (A Ogden, Western Irrigation) has indicated that 7 mm/day could be applied to grassed areas in summer without infiltration of excess water to the water table. Fifty-seven hectares of POS have been identified for irrigation that will require a water supply of 4,000 m^3/d. The remaining 2,000 m^3/d (or less) will be infiltrated via injection bores.

With mounding of groundwater from the injection of surplus water and the capture of a wide section of groundwater flow by the drain, the rate needed to be pumped from the drain to limit groundwater flow to the marina to 300 m^3/d is indicated to be 6,400 m^3/d, requiring injection of about 2,400 m^3/d.

Model-predicted flows in summer with re-injection of surplus water, and no pumping from the drain in winter, are summarised in Table 2.

TABLE 2

MODEL-PREDICTED FLOWS
(m^3/d)

	Summer	Winter
To Marina (with Pumping From Drain in summer)	300	2,000
Pumped From Drain	6,400	0
Pumped To Injection Bores	2,400	0
To Coast, 0 – 1 km south of Marina	2,400	5,800
To Coast, 0 – 1 km north of Marina	2,100	4,700

The drainage would lower the water table: by the end of summer, measurable drawdowns (0.05 m or more) would extend to 3.5 km east of the coast.

Model-predicted end-of-summer water levels with the proposed cut-off drain and injection bores operating, and end-of-winter water levels, are shown in Figures 6 and 7, respectively.

4.3 SENSITIVITY ANALYSIS

Groundwater flows to the planned marina, the ocean, and to the cut-off drain are most sensitive to values of hydraulic conductivity. As discussed in Section 4.1.1, the value of 700 m/d adopted for the Tamala Limestone near the coast is probably higher than the average value, and so is taken to be the upper limit.

A low value of 100 m/d was also tested in the model; with 90 m/d above the saltwater wedge along the coast; and values of 10 to 15 m/d for the Tamala Sand (the latter values were reduced in an attempt to lower water levels near the coast to as close as possible to observed values). Model-calculated end-of-summer groundwater levels near the coast (Fig. 8) are about 0.3 m above observed values, and so the actual (average) hydraulic conductivity of the Tamala Limestone must be greater than 100 m/d.

If the hydraulic conductivity of the Tamala Limestone did average 100 m/d, the modelling results indicate that the water level in the cut-off drain would still need to be lowered to about –0.02 m AHD to reduce groundwater discharge to the marina in summer to 300 m^3/d; but the flow to the drain would only be about 3,600 m^3/d, which could all be used for irrigation.

5. UP-CONING OF SALINE WATER

Pumping from the cut-off drain could cause up-coning of saline groundwater from the saltwater wedge that extends inland from the coast.

The cut-off drain is planned to be about 150 m inland of the present coastline, where the end-of-summer groundwater level (without extraction from the drain) is expected to be about 0.23 m AHD (= 0.3 m above mean sea level). From the Ghyben-Herzberg relationship:

$$z = 40h$$

where z = thickness of fresh groundwater below sea level, and
h = height of the water table above sea level

The thickness of fresh groundwater (below sea level) at the drain location could, therefore, be 40 x 0.3 = 12 m. The actual thickness of freshwater is generally greater than predicted by the relationship because the dynamics of groundwater flow modify the hydrostatic conditions (Freeze and Cherry, 1979).

From the measured thicknesses of freshwater given in Table 1, there is estimated to be about 17 m thickness of fresh groundwater at the position of the drain, on average.

The method of Schmorak and Mercado (1969) was used to assess the possibility of saltwater up-coning to the cut-off drain. This method calculates up-coning beneath a production bore, and uses the formula:

$$Zt = \frac{\rho_f Q}{2\pi (\rho_s - \rho_f) K_x L} \left(1 - \frac{2\rho_f n L}{2\rho_f n L + (\rho_s - \rho_f) K_z t}\right)$$

Where Zt = rise (m) of saltwater cone beneath the bore at time t
Q = bore discharge (m^3/d)
L = depth of saltwater interface below base of bore prior to pumping
= 16 m (if drain extends down to –1 m AHD)
n = porosity of aquifer = 0.2
ρ_s = density of saltwater = 1.025
ρ_f = density of freshwater = 1.000
t = time since start of pumping = 180 days, say
K_x = horizontal hydraulic conductivity = 700 m/d
K_z = vertical hydraulic conductivity = 70 m/d

The critical cone height when some saltwater could be drawn to the bore is between 0.4 L and 0.6 L (Schmorak and Mercado, 1969). Assuming a worst-case of 0.4 L, = 6.4 m, the equation becomes:

$$6.4 = \frac{Q}{1,759} \quad (1 - \frac{6.4}{6.4 + 315})$$

i.e. $11,258 = 0.98\ Q$

and $Q = 11,487\ m^3/d$

This indicates that a bore could, in theory, produce 11,847 m^3/d without up-coning of saltwater. A line-source such as the cut-off drain which will extend across the groundwater flow, should be capable of a higher pumping rate without causing up-coning than a bore which draws from a single point.

6. CONCLUSIONS

The results of groundwater flow modelling indicate that a cut-off drain located up-gradient of the planned Port Catherine marina and canals can be used to intercept most of the groundwater that would discharge to them, thereby greatly reducing the input of nitrogen.

Water from the drain would be used, as much as possible, for irrigating areas of Public Open Space in and around the Port Catherine development. Surplus water would be put back into the superficial aquifer (Tamala Limestone) via injection bores. The calculations indicate that up to 6,400 m^3/d may be extracted from the drain in summer, reducing groundwater discharge to the marina and canals to about 300 m^3/d. 4,000 m^3/d of the water extracted would be used for irrigation, and 2,400 m^3/d would be injected back into the aquifer. Actual flows may be lower, if the Tamala Limestone is less permeable than has been assumed.

The drain will be constructed to a depth of at least 1 m below the predicted drain water level that is required to reduce groundwater discharge to the marina and canals to 300 m^3/d. The water level in (or above) the drain can then be varied by controlling flow from the drain to achieve the required reduction in groundwater levels.

Monitoring bores will be needed between the drain and the marina/canals for monitoring water levels, in order to determine the rate of groundwater flow the marina/canals, and also to monitor the position of the saltwater interface.

DATED: 24 NOVEMBER 2000 ROCKWATER PTY LTD

P H WHARTON
PRINCIPAL HYDROGEOLOGIST

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FIGURES

Figure 1

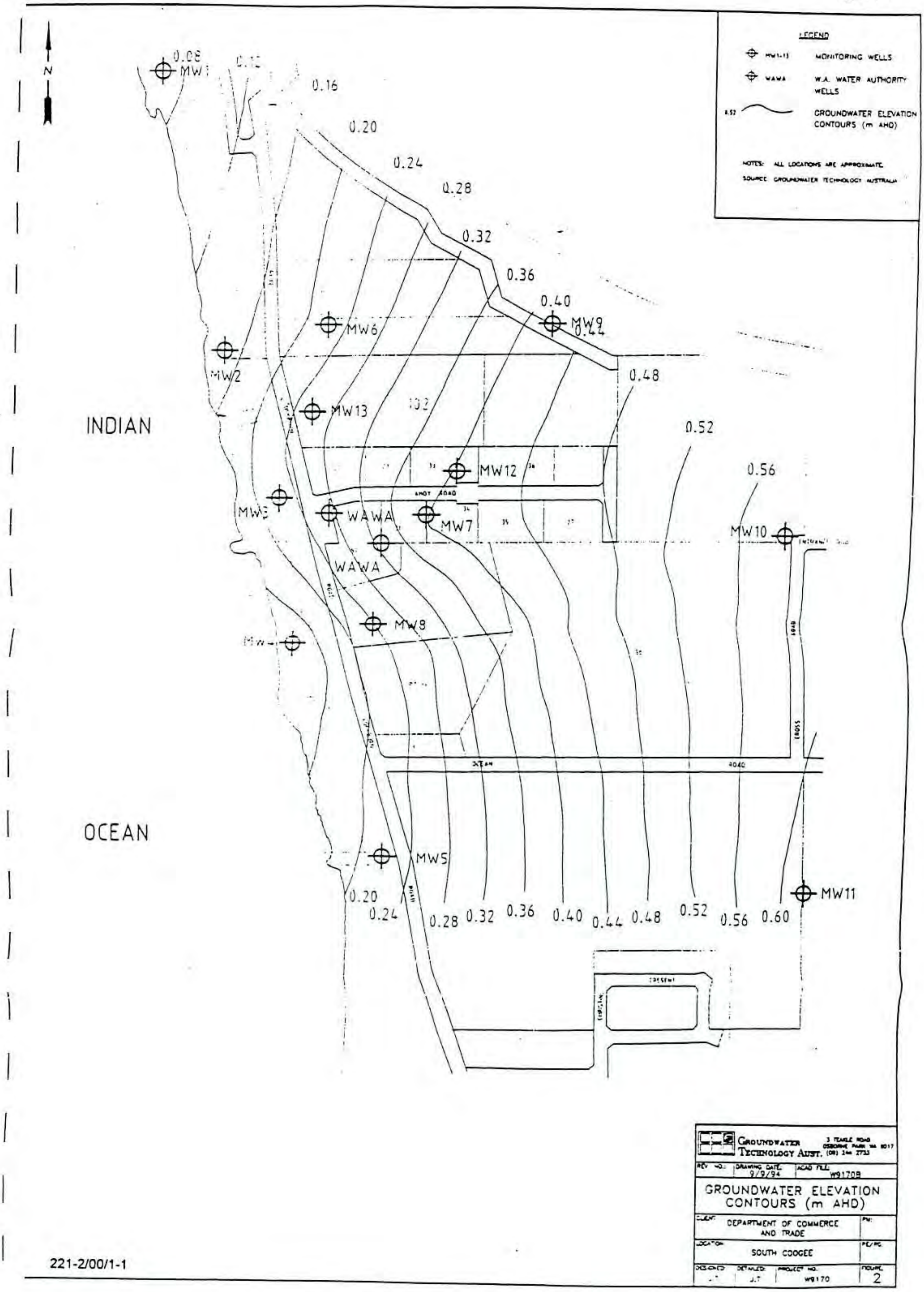

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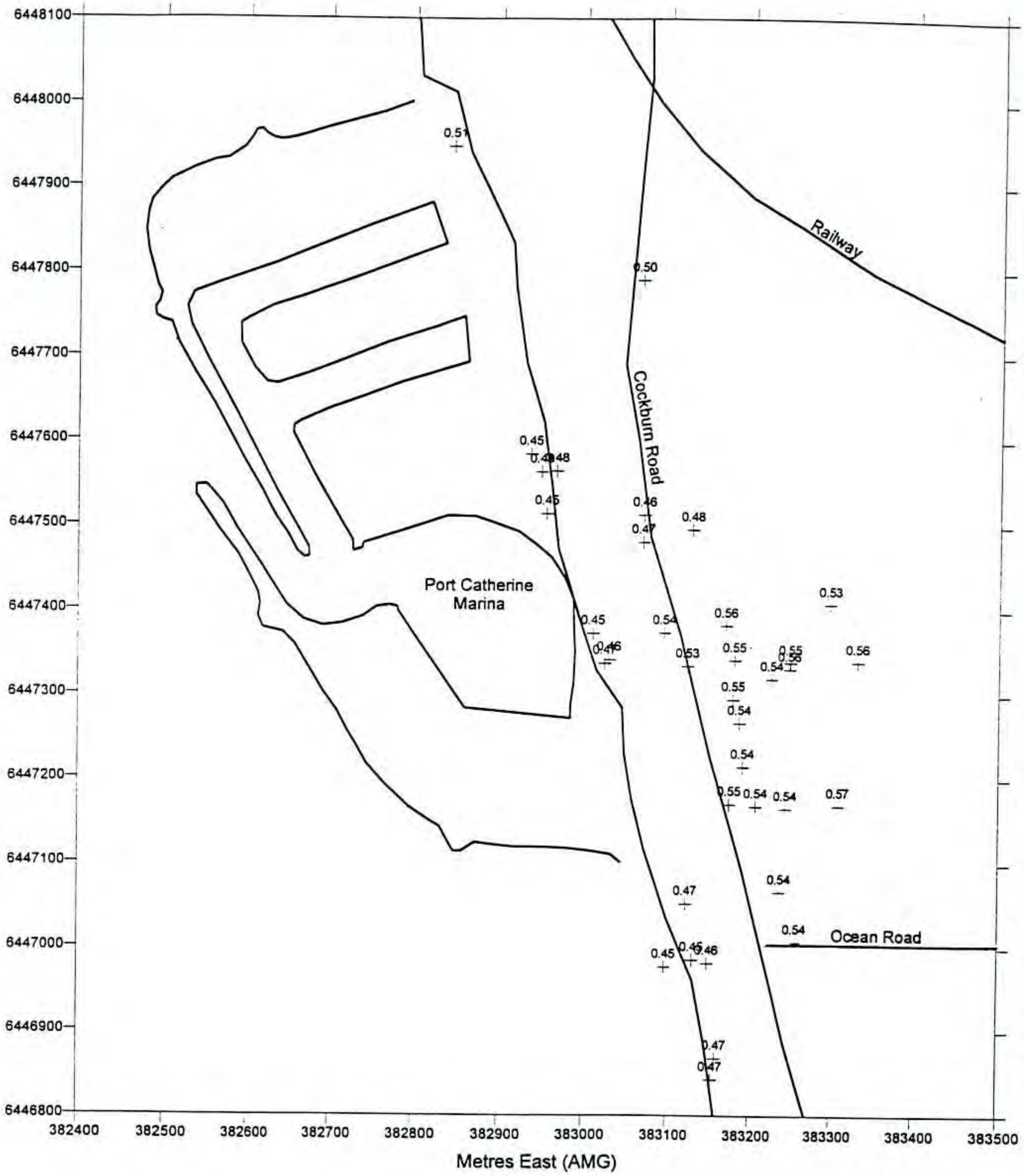
FIGURE 2



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CLIENT: Port Catherine

PROJECT:Port Catherine Development

DATE: July 2000

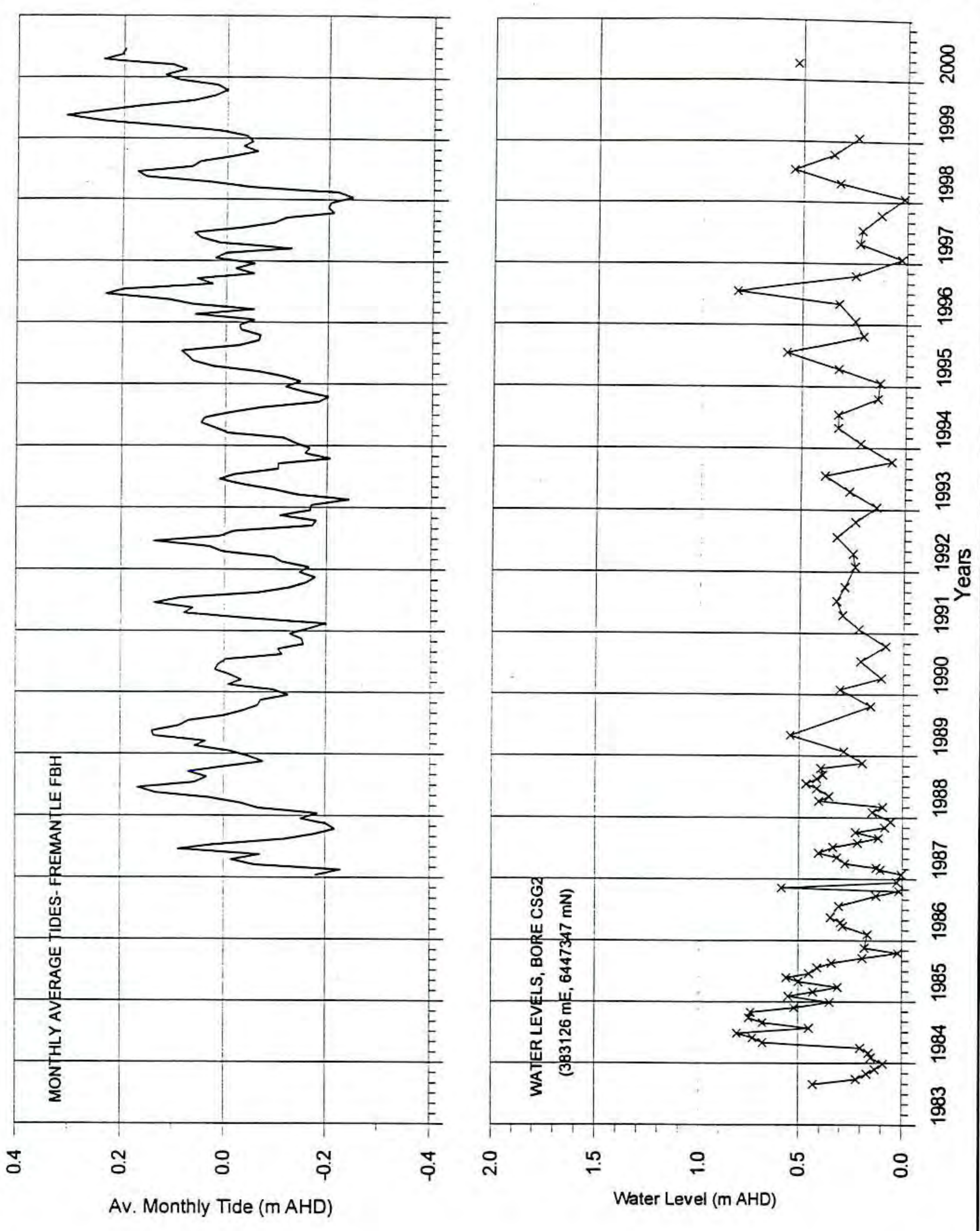
Dwg No: 221-2/00/1-2

GROUNDWATER LEVELS (m AHD)

MEASURED 12 APRIL 2000

Rockwater Pty Ltd

FIGURE 3



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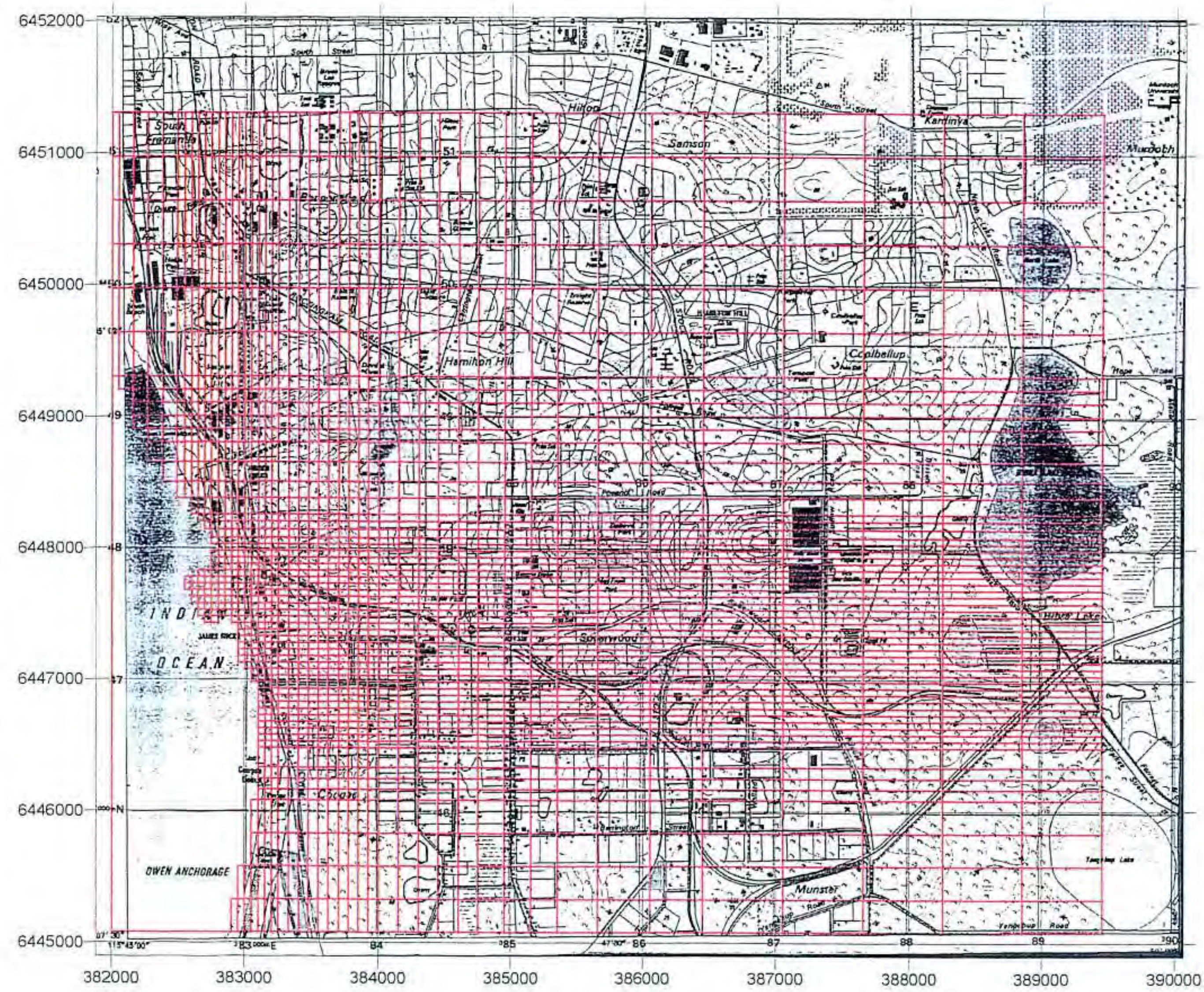
Client: Port Catherine Development Project: Port Catherine Date: July 2000 Dwg. No: 221-2/00/1-3	TIDES AT FREMANTLE, AND GROUNDWATER LEVELS AT PORT CATHERINE Rockwater Pty Ltd

FIGURE 4



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PROJECT: Port Catherine

DATE: July 2000

Dwg No: 221-2/00/1-4

LAYOUT OF MODEL GRID

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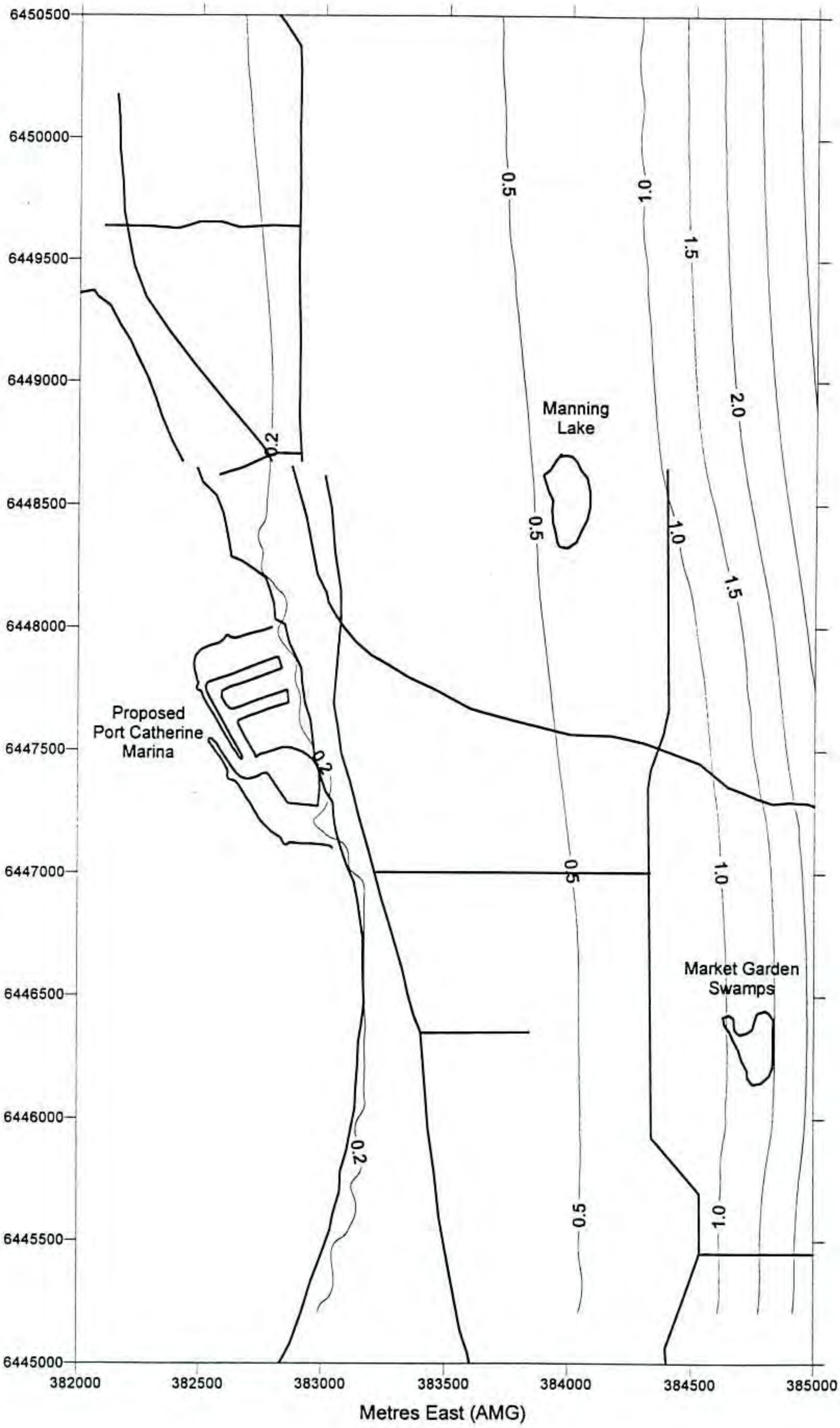
FIGURE 5



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CLIENT: Port Catherine

PROJECT: Port Catherine Development

DATE: November 2000

Dwg No: 221-2/00/1-5

INITIAL (END OF SUMMER) WATER LEVELS (m AHD) ADOPTED IN MODEL

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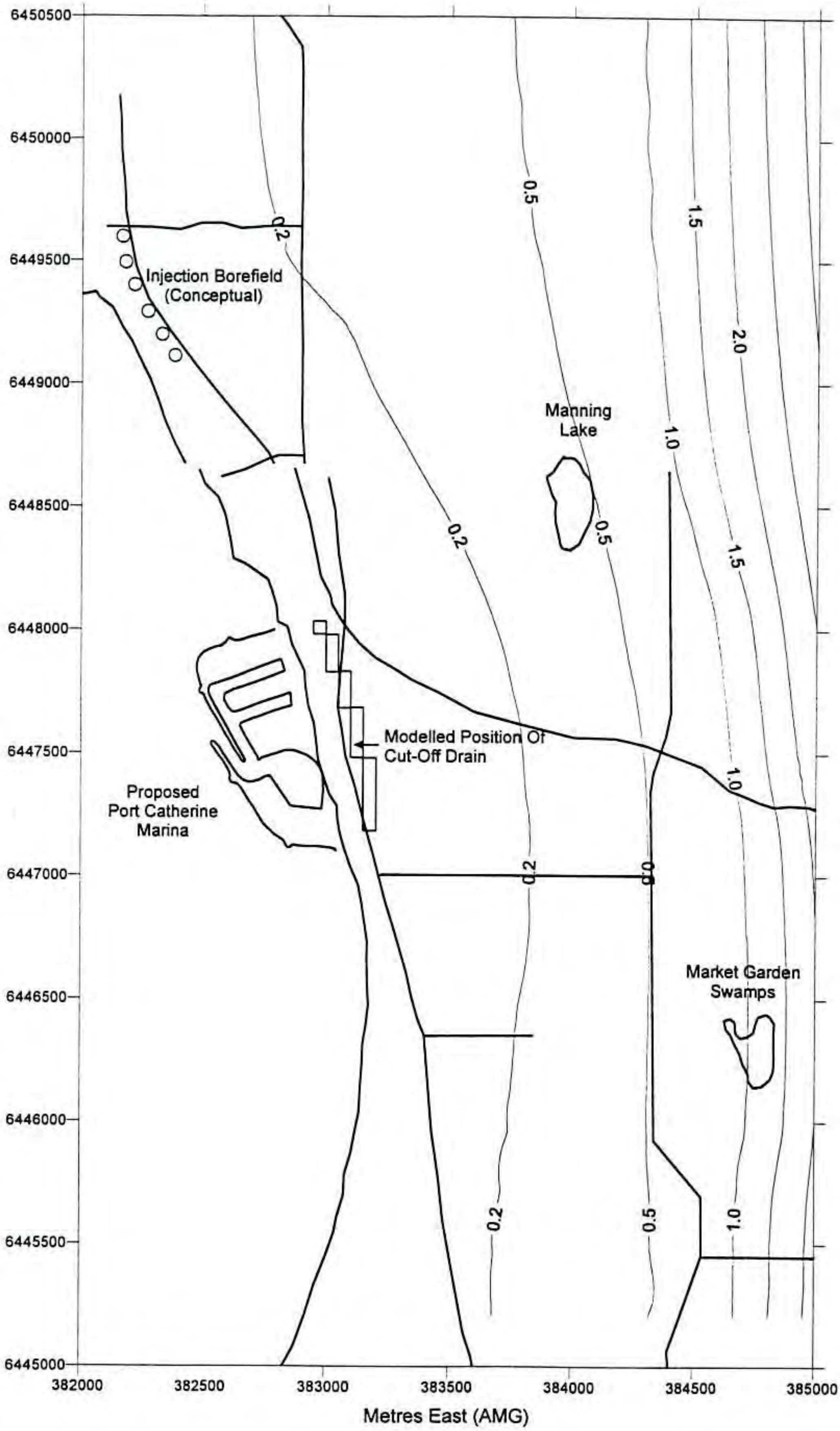
FIGURE 6



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CLIENT: Port Catherine

PROJECT: Port Catherine Development

DATE: November 2000

Dwg No: 221-2/00/1-6

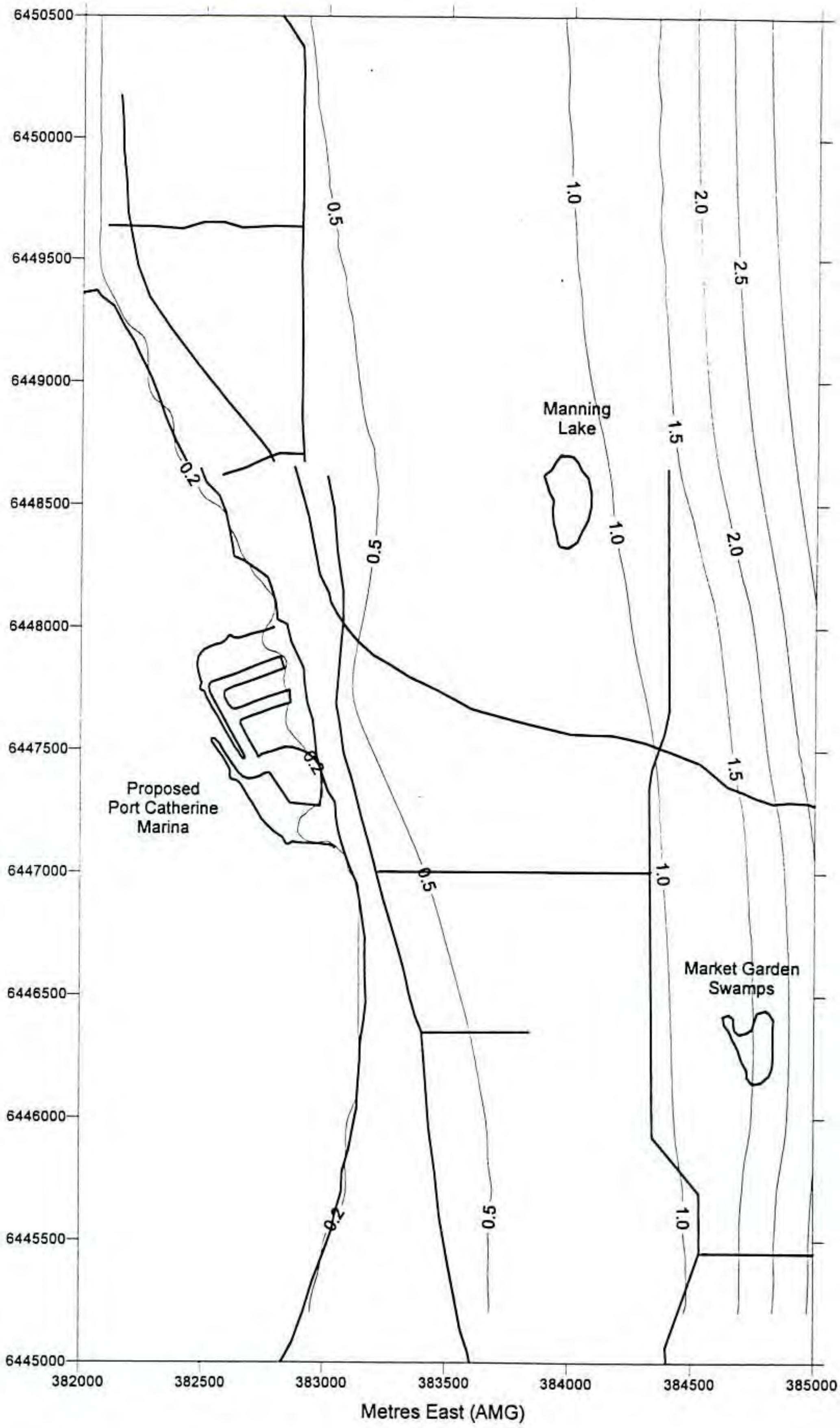
MODEL-CALCULATED END-OF-SUMMER

WATER LEVELS (m AHD)

(DRAIN & INJECTION BORES OPERATING)

Rockwater Pty Ltd

FIGURE 7



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CLIENT: Port Catherine

PROJECT: Port Catherine Development

DATE: November 2000

Dwg No: 221-2/00/1-7

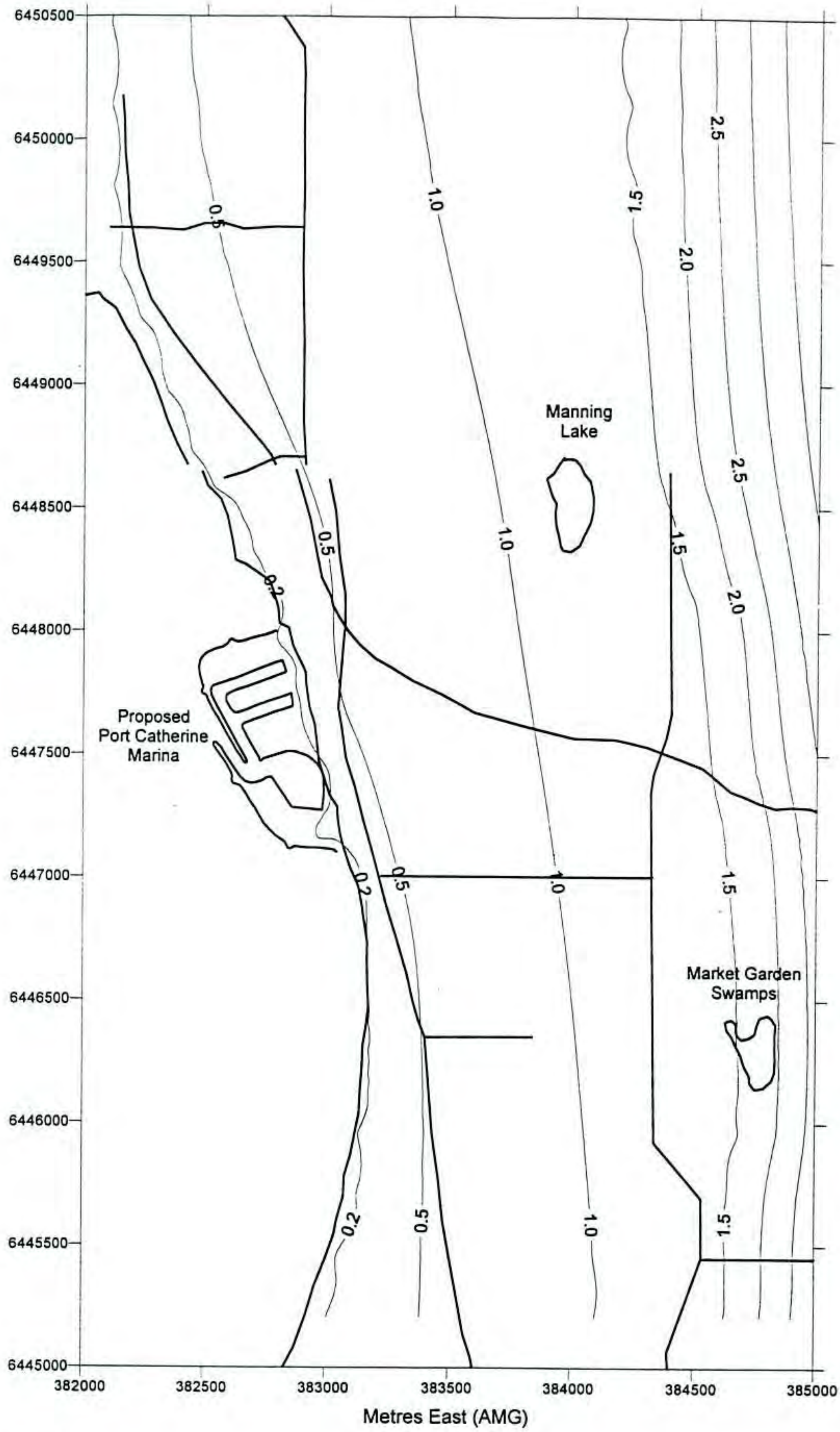
MODEL-CALCULATED END-OF-WINTER

WATER LEVELS (m AHD)

(DRAIN & INJECTION BORES NOT OPERATING)

Rockwater Pty Ltd

FIGURE 8



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CLIENT: Port Catherine PROJECT: Port Catherine Development DATE: November 2000 Dwg No: 221-2/00/1-8	MODEL-CALCULATED END OF SUMMER WATER LEVELS (m AHD), K = 100 m/d TAMALA LIMESTONE Rockwater Pty Ltd

APPENDIX IV

Marine Water Quality Assessment
(Bowman Bishaw Gorham)

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APPENDICES

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1.0 INTRODUCTION AND PURPOSE

Port Catherine Development Pty Ltd (PCD) is proposing to develop a residential and marina estate on the coast of Owen Anchorage at South Coogee, about 5 km south of Fremantle. The location and proposed design of the development are shown in Figures 1 and 2.

Due to historical industrial and urban inputs the water quality in Owen Anchorage has previously been of a poor standard. In recent years however, the closure of some industries, the improved waste management of others and the connection of adjacent urban areas to reticulated sewerage has significantly improved water quality in this area (DEP, 1996).

Despite these improvements, it is appropriate to be cautious with respect to the likely water in the proposed waterway and the possible implications of the proposed development on the future quality in the adjacent waters of Owen Anchorage. Maintenance of a high standard of water quality inside and outside of the marina and canals is crucial to both the commercial success and the environmental acceptability of the Port Catherine development proposal.

Early investigations of the environmental feasibility of the project identified elevated nutrient concentrations, principally nitrogen, in the groundwater that flows towards the proposed marina. This work identified a key issue to be addressed in the environmental planning for the project as managing the potential impact of groundwater-borne nitrogen on water quality, notably the stimulation of algal growth within the waterways.

As described in the Environmental Review, it is proposed to install a subsurface cut-off drain immediately inland of the marina, to capture most of the groundwater inflow during summer, and possibly in winter (if necessary). Water pumped from the drain will be used to irrigate nearby areas of public open space with the surplus reinjected back into the aquifer north of the project. It is anticipated that the groundwater interception scheme will be required to operate for up to twelve years, by which time the nutrient concentrations in the groundwater flowing to the development will have reduced to background levels.

To assist the environmental planning, Bowman Bishaw Gorham on behalf of PCD engaged M P Rogers & Associates Pty Ltd (in conjunction with Lawson & Treloar) to undertake three-dimensional hydrodynamic and transport-dispersion modelling for the proposed waterway. Comparative three-dimensional hydrodynamic and transport-dispersion modelling for three operating marina developments elsewhere in Metropolitan Perth was undertaken to assist interpretation of the results. The modelling results have been used to optimise the waterway design and to enable confident prediction of the marina water quality for environmental assessment of the proposal.

Additional investigations conducted to support and interpret the modelling work have included the following:

- Water quality was monitored in Owen Anchorage at the location of the proposed Port Catherine marina, and inside and outside each of the other marinas that were modelled, to derive water quality input and calibration values for the modelling.

- Historical data and other information describing the water quality at each marina were reviewed, to enable interpretation of the modelling results in light of the water quality achieved elsewhere.

- The modelled water quality at Port Catherine was interpreted and assessed based on the foregoing, to confirm that the proposal satisfies the EPA's objectives for water quality.

This report describes and interprets the results of the water quality modelling in light of the associated investigations.

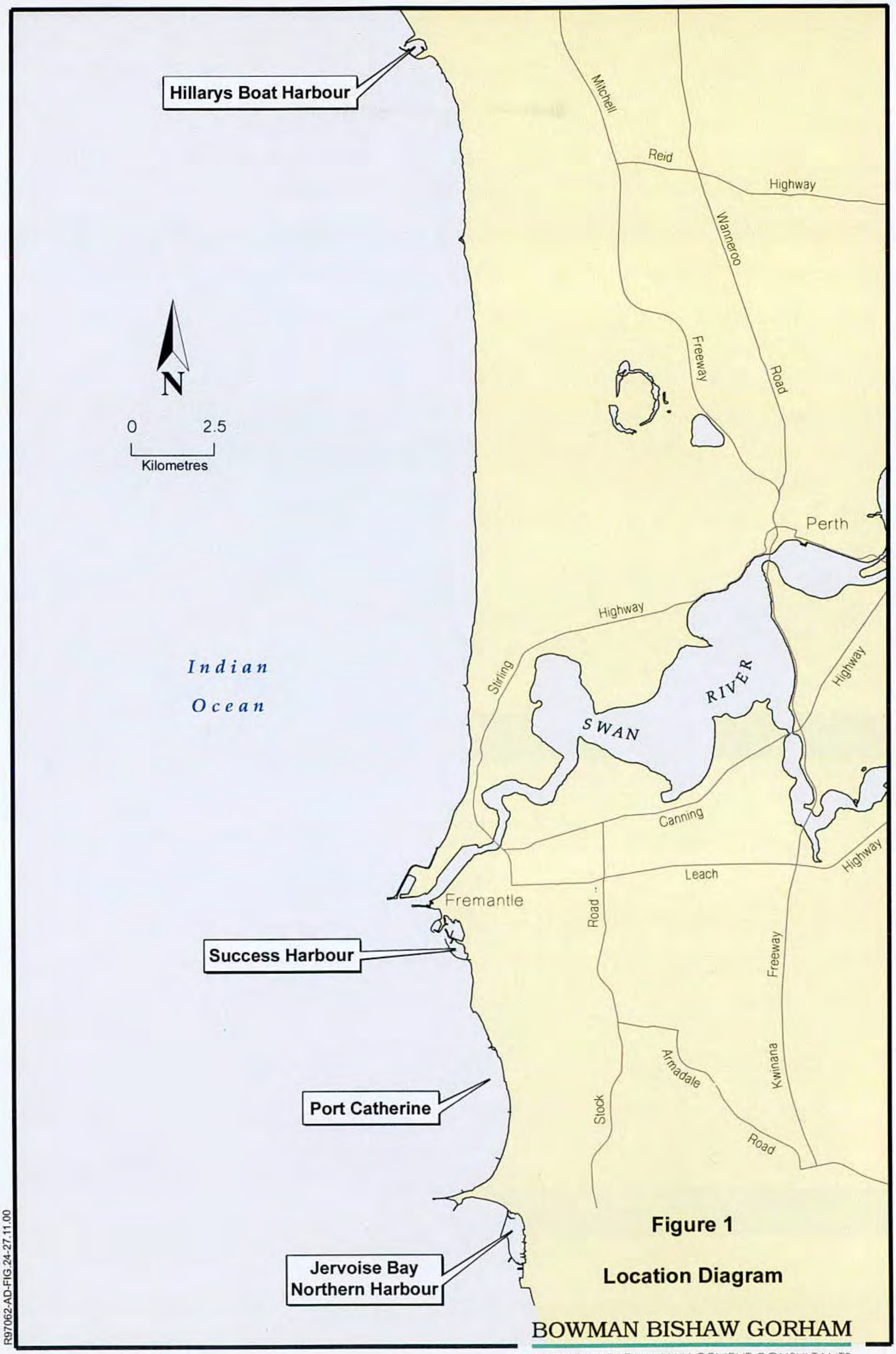

Figure 1

Location Diagram

BOWMAN BISHAW GORHAM

ENVIRONMENTAL MANAGEMENT CONSULTANTS

R97062-AD-FIG.24-27.11.00

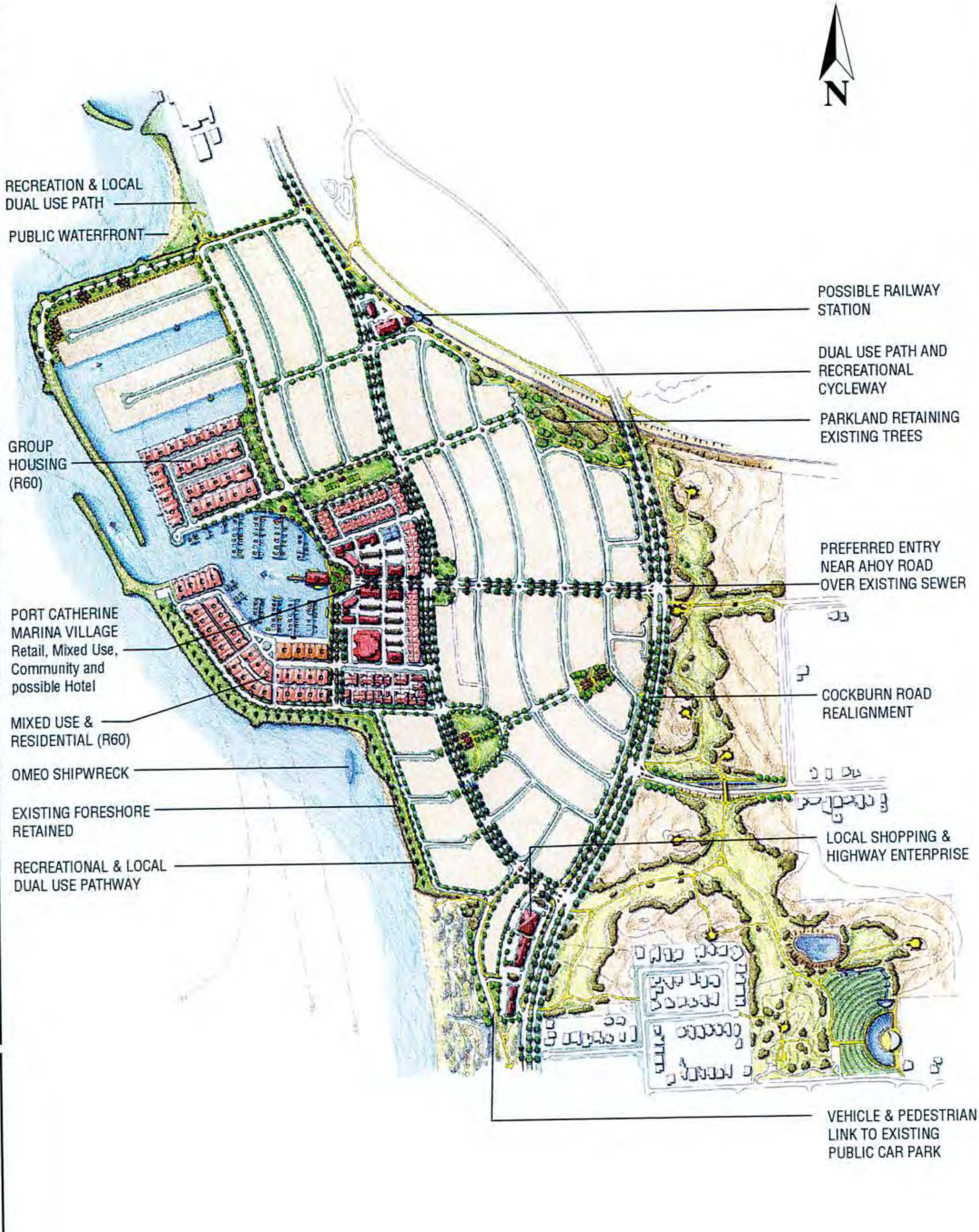

Figure 2

Project Design

Source : Taylor Burrell

BOWMAN BISHAW GORHAM
ENVIRONMENTAL MANAGEMENT CONSULTANTS

2.0 BACKGROUND

2.1 EPA Water Quality Objectives

The EPA's overall objective for marine ecosystems of Western Australia is to maintain the ecosystem integrity and biodiversity whilst recognising current and projected future uses (EPA, 2000).

In Perth's coastal waters, the EPA is implementing a management framework that is consistent with the National Water Quality Management Strategy (ANZECC and ARMCANZ, 1994) and is supported by two key scientific studies, the Southern Metropolitan Coastal Waters Study by the Department of Environmental Protection (DEP 1996) and the Perth Coastal Waters Study by the Water Authority of Western Australia (Lord and Hillman, 1995). This framework, described in EPA (2000), proposes "Environmental Values" that are important for a healthy ecosystem and social benefit, together with "Environmental Quality Objectives" (EQOs) that apply to designated areas and define specific management goals within them. The EQOs are either ecologically-based and describe the desired level of ecosystem health (eg. in terms of limits on acceptable change from natural conditions), or they are socially-based and describe the specific human uses to be protected (eg. swimming or boating).

The management framework described in EPA (2000) proposes the following environmental values and associated objectives for other marinas in Perth's coastal waters:

- Maintenance of Ecosystem Integrity (EQO 1), Moderate Protection (E3);
- Maintenance of Aquatic Life for Human Consumption (EQO 2);
- Maintenance of Primary Contact Recreational Values (EQO 3);
- Maintenance of Secondary Contact Recreational Values (EQO 4);
- Maintenance of Aesthetic Values (EQO 5); and
- Maintenance of Industrial Water Supply Values (EQO 6).

The foregoing objectives are proposed to apply to the internal waters of the Port Catherine marina. The environmental values and associated objectives that apply to Owen Anchorage waters outside the proposed marina are the same, except High Protection (E2) is prescribed for EQO 1. Accordingly, the specified limits of acceptable change for waters outside the marina (EQO 1 (E2)) are "some small changes from natural variation." The specified limits of acceptable change for waters inside the marina (EQO 1 (E3)) are "moderate changes from natural variation."

2.2 Water Quality Criteria for Nutrients

Nitrogen is the principal limiting nutrient for algal growth in Western Australian coastal waters. Excess nitrogen and the resulting growth of light-inhibiting algae has been largely blamed for the substantial decline in seagrasses in Cockburn Sound since the 1960s. Nitrogen in groundwater inflows appears to have caused significant phytoplankton blooms in the northern harbour of Jervoise Bay, 4km south of Port Catherine, during the summer of 1997-98 and subsequent years.

The soluble inorganic forms of nitrogen, collectively known as Dissolved Inorganic Nitrogen (DIN) and being nitrate, nitrite and ammonia, are immediately available to algae as nutrients so are the primary determinants of the potential for algal growth. The results of water quality monitoring programs conducted in Cockburn Sound during the 1970s and 1980s showed a significant linear relationship between externally derived DIN loads to Cockburn Sound during summer and mean phytoplankton concentrations, measured as the concentration of the photosynthetic pigment, chlorophyll-*a* (Cary et al. 1995). Although this relationship has not held up in more recent years, a number of bioassays have confirmed that DIN is generally the nutrient limiting phytoplankton growth in local coastal waters in summer (Chiffings, 1979; Thompson, 1997).

In extreme and rare circumstances, phosphorus may also become a critical nutrient in coastal waters. However phosphorus is not a significant concern at Port Catherine because its concentrations in the groundwater are low, approximately 0.05 mg/L (Environmental Review, Section 3.1.2). Phosphorus would only control the potential for nuisance algal growth in the nearshore marine environment in circumstances of extremely high DIN inflow. Non-estuarine coastal waterways that receive such high nitrogen (DIN) loading that algal production becomes phosphorus limited are considered, by definition, to have unacceptable water quality.

The relationship between DIN concentration and algal productivity is complex and is affected by other factors including temperature, light intensity, other nutrients and the species of algae. As a result of this complexity, it is not possible to specify a simple DIN criterion above which nuisance algal growth would be expected to occur.

The draft Western Australian Water Quality Guidelines for Fresh and Marine Waters (EPA, 1993) did not propose a concentration-based approach to nutrient management. The draft Guidelines specified a range of concentrations, as an indication of levels at or above which excessive algal growth had been known to occur. The ranges were 0.01mg/L to 0.1mg/L for nitrate-nitrogen and <0.005mg/L for ammonia-nitrogen.

The draft Environmental Quality Criteria that were more recently proposed by the DEP following the Southern Metropolitan Coastal Waters Study concluded that it was inappropriate to impose a concentration-based approach to nutrient management in local waters and instead proposed a criterion for primary production, as follows:

- In any water body, net primary production should not vary from levels encountered in similar, local unimpacted habitats under similar light, temperature and nutrient loading regimes (DEP, 1996).

2.3 Water Quality Objectives for Port Catherine Marina

With respect to nutrients and algal production, it is proposed that the environmental values and associated water quality objectives that would apply to the Port Catherine Marina will be as follow:

- The internal waterways will need to be attractive and visibly healthy. Algae should not be present in excessive amounts in terms of aesthetic appearance.

- The environmental quality of Owen Anchorage, outside the marina, should not be reduced in terms of its ecologically-based or socially-based values. Net primary production should not vary from levels encountered in similar, local unimpacted habitats under similar light, temperature and nutrient loading regimes.

- Recreational values, particularly for direct contact recreation, will be important both within and outside the marina. Algae should not be present in excessive amounts in terms of aesthetic appearance or water clarity. Phytoplankton blooms should not occur that may cause skin irritation.

- Fish, crabs and mussels will be taken from the marina waterway for human consumption. Phytoplankton blooms should not occur that may produce toxins in resident biota and may result in risk to human health.

2.4 Strategy for Assessing Water Quality at Port Catherine Marina

The strategy for assessing the likely water quality within the proposed Port Catherine marina was defined in consultation with the DEP and the EPA and has involved the following:

- Three dimensional hydrodynamic modelling has been used to simulate the physical processes (eg. stratification, tides, baroclinic and wind induced currents) and the resulting flushing regime within the proposed Port Catherine marina.

- DIN inputs from groundwater and seawater inflows have been included into the hydrodynamic model, to simulate the dilution and flushing of the groundwater with ocean water and thereby estimate the usual DIN concentrations that will occur within and outside the proposed marina.

- The biological response to the usual DIN concentrations has been predicted in terms of likely growth of algae and the potential for unacceptable phytoplankton blooms.

The complex and variable conditions that result in nuisance algal growth in the coastal environment have confounded the development of accurate and reliable models to simulate the biological response to elevated nutrient concentrations. Therefore, the biological response to the modelled DIN concentrations at Port Catherine has been predicted through comparisons with modelled and measured DIN concentrations at existing marinas elsewhere in metropolitan Perth. For this purpose, measurement and comparative modelling of water quality in the following marinas have been undertaken:

- Success Harbour, located at South Fremantle less than 4km north from Port Catherine.

- Hillarys Boat Harbour, located at Sorrento Beach approximately 25 km north from Port Catherine.

- Jervoise Bay Northern Harbour, located in northern Cockburn Sound approximately 5km south from Port Catherine.

Success Harbour was compared because of its proximity and its similar location in terms of exposure and source water quality. Hillarys Boat Harbour is relatively remote and is located in the more pristine conditions of Marmion Marine Park, but was compared because previous hydrodynamic and water quality monitoring studies had been undertaken to enable a more quantitative comparison. Jervoise Bay Northern Harbour was compared because it suffered a significant phytoplankton bloom in summer 1998/99 and has since been closely monitored.

It is recognised that DIN concentrations are not always the sole determinate for the propensity for semi-enclosed waterways to develop algal blooms. However the concentrations of DIN at the proposed Port Catherine marina, compared with that at Success Harbour, Jervoise Bay

Northern Harbour and Hillarys Boat Harbour, are considered to provide a confident indicator of the <u>relative</u> risk for unacceptable bloom conditions, due to the following factors:

1. Water temperature and light intensity (water clarity) within the source water at each of the compared marinas is similar, particularly during summer when the risk of algal blooms is highest and the river flow is negligible. The main cause of differences in water clarity in the source water during summer (eg. Jervoise Bay has slightly lower water clarity than near Hillarys) is phytoplankton growth itself.

2. Although there are periods when extremely high groundwater DIN inflow results in the algal growth in Jervoise Bay Northern Harbour being limited by phosphorous rather than DIN, this is an extreme phenomenon. For the present purposes, non-estuarine coastal waterways that receive such a high DIN loading that algal production becomes phosphorus limited are considered, by definition, to have unacceptable water quality.

The flushing time of a marina is an important secondary determinate of water quality. As well as affecting the dilution of groundwater nutrients, efficient flushing with clear ocean water increases the water clarity and reduces the rate at which phytoplankton settle out to enrich the sediments.

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3.0 WATER QUALITY IN HILLARYS BOAT HARBOUR, SUCCESS HARBOUR AND JERVOISE BAY NORTHERN HARBOUR

3.1 Introduction

This section describes water quality in Hillarys Boat Harbour, Success Harbour and Jervoise Bay Northern Harbour, based on previous monitoring studies, advice from the individual harbour managers and water quality monitoring at each harbour over the summer of 1998/99. The purpose of the comparisons is to derive water quality criteria for nutrients and algal growth that should ensure that the water quality objectives proposed for the Port Catherine marina are maintained.

3.2 Previous Information

3.2.1 Hillarys Boat Harbour

Previous investigations and monitoring of water quality in Hillarys Boat Harbour have included the following.

- Schwartz and Imberger (1988) investigated the flushing characteristics of Hillarys Boat Harbour, including physico-chemical measurements to define barotrophic motions and baroclinic processes and dye tracer studies to provide an estimate of harbour flushing. This study highlighted the importance of baroclinic processes (i.e. hydrodynamic processes due to differences in water density) to flush coastal marinas that receive a significant inflow of fresh groundwater. The flushing rate, defined as the e-folding time (i.e. the time taken for the concentration of the conservative tracer to reduce to 1/e (37%) of its original concentration), was measured to be around five days.

- The Department of Marine and Harbours (1990) (now Department of Transport) monitored water quality at Hillarys Boat Harbour at six-monthly intervals from 1985 to 1990. Samples were collected at five sites within the harbour, one site at the harbour entrance and four sites outside of the harbour, with analyses of the following parameters:

Water samples:

- Biochemical oxygen demand
- Dissolved oxygen
- Total nitrogen
- Total phosphorous
- Chlorophyll-*a*
- Phaeophyton
- Suspended solids
- pH

Sediment samples:

- Total nitrogen
- Total phosphorus
- Copper
- Zinc
- Lead
- Tin
- Chromium
- Organics

Aesthetic observations included:

- Odour
- Floating material
- Oil and grease
- Surfactants
- Water clarity
- Settleable matter

Unfortunately, the water quality monitoring did not include measurement of DIN so does not provide useful data for the present purposes. The observations of aesthetic conditions reflected high water quality in the marina.

Additional perspective on the environmental quality at Hillarys Boat Harbour was obtained from discussions with the Marina Commercial Manager, the Harbour Manager and the General Manager of Hillarys Underwater World.

The marina is regularly inspected by the Harbour Manager. The observed water quality has been generally attractive and visibly healthy. Algae have never been present in excessive amounts in terms of aesthetic appearance. Phytoplankton blooms have never been a problem. Rubbish tends to accumulate in small quantities in the southwest corner under Sorrento Quay, however this is readily managed.

The healthy ecology of the marina is evidenced by large schools of baitfish and marine fish (eg. sea mullet) that regularly occur in the marina, together with significant numbers of crayfish (rock lobster) that inhabit the inside of the marina breakwater. Blue manna crabs are regularly caught and mussels occur on the jetty piles throughout the marina.

The swimming beach within Hillarys Boat Harbour is very popularly used and has never suffered high phytoplankton levels that might cause aesthetic, safety or health concerns.

3.2.2 Success Harbour

Previous environmental monitoring in Success Harbour has included water quality measurements by the Department of Marine and Harbours (1989) at Success Harbour, Fremantle Fishing Boat Harbour and Challenger Harbour at approximately three-monthly intervals from 1985 to early 1998. Surface water samples were collected at two sites within each harbour, one site at the harbour entrance and two sites outside of the harbours, with analyses of the following parameters:

- Biochemical oxygen demand
- Dissolved oxygen
- Total nitrogen
- Total phosphorous
- Chlorophyll-*a*
- Phaeophyton
- Suspended solids
- pH

The monitoring did not include measurement of DIN so does not provide useful comparative data for the present purposes. The measurements of Chloropyll *a* and Phaeophytin reflected high water quality in each of the marinas.

Additional perspective on the environmental quality at Success Harbour was obtained from discussions with the Harbour Master for the Fremantle Sailing Club.

The marina is regularly inspected by the Harbour Manager. The observed water quality has always appeared healthy and algae have never been present in excessive amounts in terms of aesthetic appearance or as a cause for complaint. The Harbour Master advised that there have been two or three occasions when the water clarity was noticeably reduced, but never to the extent that it caused nuisance in terms of odour, surface scum or reduced aesthetics.

Reduced water quality at Success Harbour tends to occur following the break of season in autumn, apparently associated with the incursion of Swan River outflow into the harbour waterway. The harbour also receives direct inflow of substantial quantities of stormwater drainage from the South Fremantle urban area, to the east.

The Harbour Master advised that the worst incident of reduced water clarity that he had observed in Success Harbour had occurred following the extreme rain (>100mm, which is twelve-times the monthly average) in late January 2000 and the consequent high water discharge and toxic blue-green algal bloom in the Swan River. The water clarity observed in Success Harbour at that time reduced to less than one metre and the water was discoloured brown. It was noted that there was no associated nuisance in terms of odour or surface scum nor were any fish mortalities observed.

Bowman Bishaw Gorham monitored the water quality at Success Harbour and Port Catherine on 1 February 2000, coincident with the high Swan River discharge and consequent reduced water quality at Success Harbour. Table 1 provides summary data describing the DIN, total nitrogen and chlorophyll-*a* concentrations that were measured immediately outside Success Harbour, inside Success Harbour and nearshore at Port Catherine (300m of the shore) before, during and after this event.

Table 1 Water quality measured during reduced water clarity incident at Success Harbour, 1 February 2000.

Location	Date	DIN (mg/L)	Total nitrogen (mg/L)	Chlorophyll-*a* (µg/L)
Outside Success Harbour	20 January	0.02	0.31	1.30
	1 February	**0.42**	**0.89**	**7.62**
	8 February	0.04	0.21	0.92
	15 February	0.02	0.23	1.04
Within Success Harbour	20 January	0.01	0.33	1.63
	1 February	**0.15**	**0.49**	**6.13**
	8 February	0.02	0.30	2.79
	15 February	0.01	0.27	2.31
Nearshore Port Catherine	20 January	0.03	0.29	1.10
	1 February	0.03	0.25	1.03
	8 February	0.04	0.24	1.13
	15 February	0.02	0.24	0.90

These data collaborate the Harbour Master's observations at Success Harbour and provide additional perspective as follows:

- The high river outflow in late January, following the record rainfall on 22 January, resulted in very high concentrations of DIN and total nitrogen (DIN plus organic nitrogen) outside Success Harbour on 1 February. Phytoplankton pigment (chlorophyll-*a)* concentrations are correspondingly high, indicating high phytoplankton growth.

- There was significant entrainment of the nutrient rich river water and high phytoplankton growth within Success Harbour. It appears that the high stormwater inflow to and through Success Harbour may have reduced or diluted the internal DIN and total nitrogen concentrations.

- The DIN concentration of 0.15mg/L and the chlorophyll-*a* concentration of 6μg/L corresponded to the worst water quality that has ever been observed by the Harbour Master at Success Harbour, albeit that this did not cause nuisance in terms of odour or surface scum nor were any fish mortalities observed.

- The elevated nutrient and phytoplankton concentrations associated with the high river outflow did not extend down to Port Catherine, 4km to the south. This is likely to be due not merely to the distance, but also to the obstruction to southerly flow that would be caused by Success Bank.

The Harbour Master advised that the only environmental concerns experienced at Success Harbour were externally derived, due to incursions of materials from outside the harbour. He cited occasional rubbish and seaweed that is blown into the harbour from the sealane to Rottnest, together with an incursion of a large number of stingers (jellyfish) on one occasion last summer.

As with Hillarys Boat Harbour, the healthy ecology of Success Harbour is evidenced by large schools of baitfish and marine fish (eg. sea mullet) that frequent the marina, together with the significant numbers of crayfish (rock lobster) that inhabit the inside of the breakwater. Blue manna crabs are regularly caught.

3.2.3 Jervoise Bay Northern Harbour

Previous investigations and monitoring of water quality in Jervoise Bay Northern Harbour have included the following.

- The Department of Commerce and Trade (1998a; 1998b; 1999) has undertaken routine water and sediment quality monitoring within and near the Jervoise Bay Harbours. This monitoring program has involved quarterly water quality and annual sediment quality monitoring since March 1997. Samples are collected at three sites within the Northern Harbour, one site in the Middle Harbour, one site near the entrance to the Middle Harbour, three sites within the Southern Harbour and seven sites outside the harbours. The following parameters are measured:

  Water column profiles:

  - Temperature
  - Salinity
  - Dissolved oxygen
  - Secchi disk depth

Water samples (from the surface, mid-depth and near bottom:

- Ammonia nitrogen
- Total kjeldhal nitrogen
- Total phosphorous
- Chlorophyll-*a,b* and *c*
- Nitrate-nitrite nitroge
- Suspended solids
- Orthophosphorus

Sediment samples:

- Total nitrogen
- Polycyclic aromatic hydrocarbons
- Tributyltin
- Metals (As, Cd, Cr, Co, Cu, Pb, Hg, Ni, Sn, and Zn)
- Total phosphorus
- Organic content
- Particle size

Groundwater monitoring surveys and surveys of faecal bacteria are also undertaken.

- The Department of Commerce and Trade (1998c) also investigated a large algal bloom in the Jervoise Bay Northern Harbour during the summer of 1997-1998. This work involved weekly nutrient and physico-chemical water quality measurements, phytoplankton cell counts and phytoplankton speciation. Additional groundwater investigations were also undertaken.

The Jervoise Bay Northern Harbour was constructed in 1997. In late December 1997 and January 1998, the harbour experienced a large bloom of a non-toxic marine diatom, *Cerataulina,* which peaked at mean integrated phytoplankton counts inside the harbour of 24 million cells/litre (the chlorophyll-*a* concentration was coincidentally measured as 18 μg/L). The collapse of this bloom was replaced by a dinoflagellate bloom (*Cachonina*), a species that can form highly visible red surface scum in calm conditions. This bloom was in turn replaced by another diatom bloom and the populations peaked and collapsed over time scales of several weeks through to the end of February. The mean chlorophyll-*a* concentration measured in the harbour during late-December and January was 15 μg/L.

The contributing factors to these bloom conditions were considered to be the following (Department of Commerce and Trade, 1998c):

- Very high DIN loads enter the harbour in the groundwater flow downstream of the Weston Bioproducts factory and the WaterCorp's Woodman Point Waste Water Treatment Plant (WWTP) sludge drying beds. The mean DIN concentrations measured in groundwater bores located downstream from these sources in 1998/1999 was 55 mg/L and 22 mg/L respectively (Department of Commerce and Trade, unpublished data, 2000). The mean DIN concentration in the groundwater flowing to

Jervoise Bay Northern Harbour is 13.6 mg/L (Department of Commerce and Trade, unpublished data, 2000).

- Groundwater flows (and hence groundwater nutrient loads) to the marine environment in the region were high during December 1997 and January 1998, due to the exceptionally low sea levels, associated with the Southern Oscillation (El Nino) effects.

- The construction of the second breakwater to Northern Harbour in 1997 would have increased the mean residence time of the waterway.

- Dredging in the Northern Harbour during early-December 1997 would have resuspended the sediment, possibly releasing nutrients and algal cysts to the water column.

Ongoing monitoring of phytoplankton densities within Jervoise Bay Northern Harbour (Department of Commerce and Trade, 1999) has identified subsequent additional blooms as follow:

- During spring (October to December inclusive) of 1998, there were moderately high bloom conditions (10 to 15 million cells/litre), predominantly of the diatoms *Chaetoceros* and *Nitzschia*.

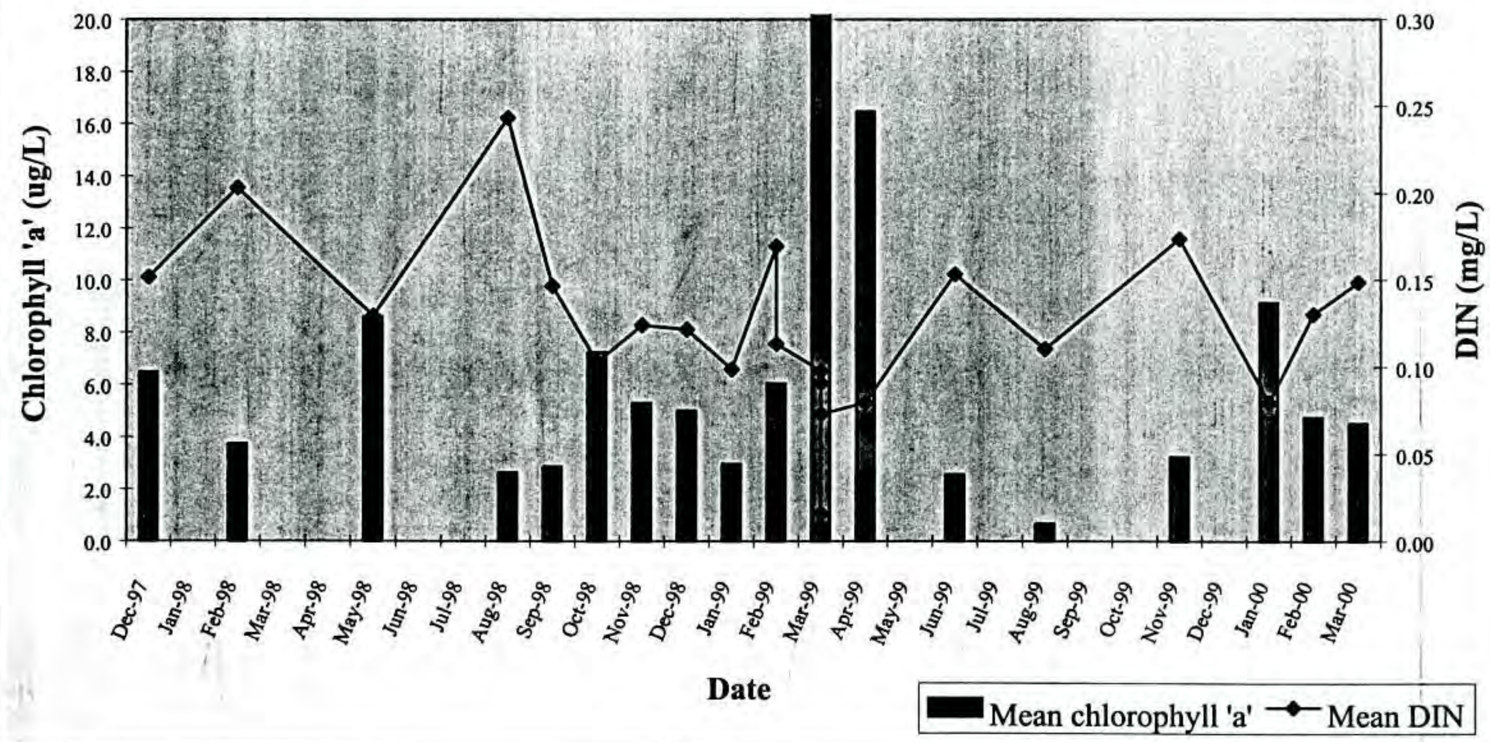
- In March and early April 1999, there were high bloom conditions (16.5 million cells/litre, maximum chlorophyll-*a* concentration of 30 μg/L) predominantly of the larger marine diatom *Ceratualina*.

- For one week only during November 1999, the harbour experienced a bloom of toxic diatoms.

- Bowman Bishaw Gorham observed bloom conditions and measured high chlorophyll-*a* concentrations (maximum value = 23.5 μg/L, mean = 12 μg/L) in the harbour through most of December 1999 and January 2000.

Figure 3 shows the average DIN and chlorophyll-*a* concentrations measured in Jervoise Bay Northern Harbour during regular monitoring surveys from December 1997 to March 2000 (DA Lord and Associates, unpublished data, 2000). The average DIN concentrations have

Figure 3. Mean DIN and chlorophyll 'a' measured in Jervoise Bay Northern Harbour, 1997 - 2000



Source: D A Lord and Associates, unpublished data, 2000.

ranged from 0.02 mg/L up to 0.24 mg/L, with a mean of 0.125 mg/L. This is more than five-times the usual background concentrations measured in the adjacent nearshore waters of Jervoise Bay.

The average chlorophyll-*a* concentrations ranged from 0.7μg/L to 32.4μg/L, with a mean value of 5.0μg/L.

For perspective, the mean DIN and chlorophyll-*a* concentrations over the entire two years at Jervoise Bay Northern Harbour were essentially the same as occurred at Success Harbour on 1 February, when extreme river discharge resulted in the worst water quality that is remembered at this waterway. The water quality in Jervoise Bay Northern Harbour has been worse than this singular extreme in Success Harbour for more than four months each year. The chlorophyll-*a* concentration during the peak bloom condition in Jervoise Bay Northern Harbour was more than five times greater than the extreme event in Success Harbour.

3.3 Marina Water Quality Measurements, 1999-2000

Bowman Bishaw Gorham monitored water quality within and outside Hillarys Boat Harbour, Success Harbour and Jervoise Bay Northern Harbour, and in the nearshore environment at Port Catherine, on a weekly basis over ten weeks during the summer of 1999/2000. Sampling occurred at three internal sites and from one site outside the breakwater at each marina. Sampling at Port Catherine occurred 150m, 300m and 1200m offshore at the location of the proposed marina. The sampling site locations are shown in Figure 4.

Water samples were collected at each site from 0.5m below the surface and from 0.5m above the seabed, using a Niskin water sampler. The samples were immediately stored on ice and transferred within 6 hours for processing and analysis at the Marine and Freshwater Research Laboratory, Murdoch University. The samples were analysed for total nitrogen (TN), ammonia nitrogen (NH_3), nitrate-nitrite nitrogen (NO_x); and chlorophyll-*a, b* and *c*.

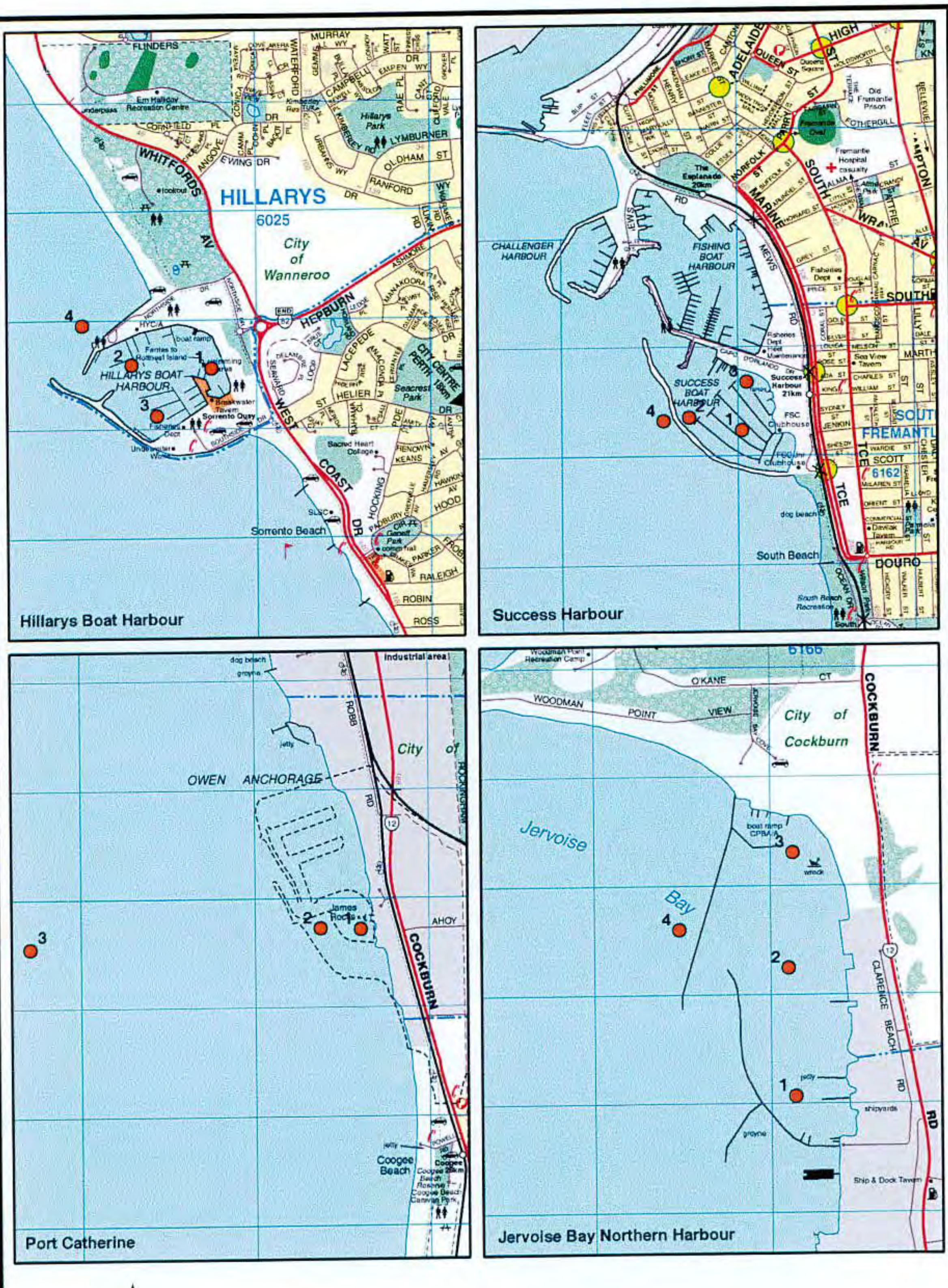
The detailed results of these investigations are appended. Table 2 provides summary results for TN, DIN and chlorophyll-*a*.

The monitoring results reflect the clear distinction between the environmental quality of Hillarys Boat Harbour and Success Harbour on the one hand, and Jervoise Bay Northern Harbour on the other. All three marinas show elevated chlorophyll-*a* concentrations in the internal waterways relative to the external source water, a reflection of increased phytoplankton productivity in response to the entrainment of nutrients from the groundwater inflow. However, the quantum and frequency of elevated chlorophyll-*a* concentrations at Jervoise Bay Northern Harbour is significantly higher than at the other two marinas.

The productivity of each marina was compared using the ratio of chlorophyll-*a* concentrations in the internal verses external waters at each marina on each sampling occasion during the 1999-2000 summer. Table 3 describes the mean and range of the productivity ratios for each marina.

The data highlight the differences in productivity between the marinas. At Hillarys and Success Harbours, the productivity ratios had a relatively low mean and never exceeded seven. At Jervoise Bay Northern Harbour the mean productivity ratio was eight. The individual ratios at Jervoise Bay Northern Harbour were greater than seven (the maximum for the other marinas) during 40% of the surveys and the maximum ratio was more than thirty.

The consistently low DIN concentrations measured inside Success Harbour during the summer monitoring period (lower than were measured in the external waters) are believed to reflect biological uptake and efficient flushing. As shown in Table 2, the concentrations of TN and chlorophyll-*a* were higher inside this marina than outside. A detailed understanding of this circumstance is confounded by the complicating influences of the nearby Swan River and the two marinas that are contiguous to Success Harbour, in addition to the overriding complexity of biological response to nutrients that initially prompted this comparative assessment.



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● Monitoring Location

Figure 4

Monitoring Sampling Locations

BOWMAN BISHAW GORHAM

ENVIRONMENTAL MANAGEMENT CONSULTANTS

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Table 2 Water quality measured at Hillarys Boat Harbour, Success Harbour, Jervoise Bay Northern Harbour and Port Catherine during 1999-2000 summer.

Location		TN (mg.N/L)	DIN (mg.N/L)	Chlorophyll-*a* (µg/L)
Hillarys Boat Harbour				
Internal	Mean	0.258	0.022	3.13
	Range	0.222 - 0.300	0.006 - 0.064	0.55 - 5.32
External	Mean	0.204	0.014	0.95
	Range	0.158 - 0.245	0.004 - 0.032	0.45 - 2.54
Success Harbour (Note: Data from 1 February during abnormal river outflow are excluded)				
Internal	Mean	0.270	0.011	2.34
	Range	0.218 - 0.323	0.006 - 0.019	1.34 - 3.52
External	Mean	0.223	0.026	1.19
	Range	0.190 - 0.307	0.006 - 0.042	0.72 - 2.66
Jervoise Bay Northern Harbour				
Internal	Mean	0.391	0.138	6.66
	Range	0.311 - 0.497	0.081 - 0.216	1.98 - 12.94
External	Mean	0.217	0.024	1.02
	Range	0.173 - 0.282	0.010 - 0.044	0.57 - 1.71
Port Catherine				
150m offshore	Mean	0.263	0.033	1.27
	Range	0.204 - 0.334	0.005 - 0.055	0.73 - 2.69
300m offshore	Mean	0.229	0.026	1.15
	Range	0.175 - 0.269	0.010 - 0.064	0.68 - 2.28
1200m offshore	Mean	0.204	0.009	0.85
	Range	0.174 - 0.241	0.004 - 0.017	0.40 - 1.52

Table 3 Productivity, measured as the ratio of internal external chlorophyll-*a* concentrations, at Hillarys Boat Harbour, Success Harbour, Jervoise Bay Northern Harbour and Port Catherine during 1999-2000 summer.

Productivity ratio	Success Harbour	Hillarys Boat Harbour	Jervoise Bay Northern Harbour
Mean	2.13	3.36	8.00
Range	0.64 – 4.89	0.96 – 6.90	1.98 – 33.47

3.4 Comparison of Marinas

The monitoring data and historical records provide strong support to the generally held perception that Success Harbour and Hillarys Boat Harbour meet ecological and social objectives for acceptability of water quality with respect to nutrients and algal productivity. With reference to the water quality criteria for algal growth that are proposed for Port Catherine in Section 2.3, Success and Hillarys Harbours are considered to satisfy the following criteria:

- The internal waterways are attractive and visibly healthy. Algae are not present in excessive amounts in terms of aesthetic appearance.

- The ecological and social values of the adjacent marine environment are not adversely affected by the marina. Net primary production in adjacent waters does not vary from levels encountered in similar, unimpacted habitats under similar light, temperature and nutrient loading regimes.

- Recreational values both within and outside the marina, particularly for direct contact recreation, are not compromised. Algae is not present in excessive amounts in terms of aesthetic appearance or water clarity. Phytoplankton blooms do not occur that may cause skin irritation.

- Fish, crabs and mussels may be taken from the marina waterway for human consumption. Phytoplankton blooms do not occur that may produce toxins in resident biota and may result in risk to human health.

In contrast, Jervoise Bay Northern Harbour does not currently meet at least three of these criteria.

Based on the foregoing evidence, it is proposed that adequate water quality will be maintained in the Port Catherine marina provided the internal mean summer chlorophyll-*a* concentration remains less than approximately 3.1 μg/L (equal to Hillarys and less than half of the summer mean at Jervoise Bay) and the upper 90 percentile chlorophyll-*a* concentration remains less than approximately 5.3 μg/L (equal to Hillarys and less than was measured during the singular event of reduced water quality at Success Harbour during early February, 1999).

For predictive purposes, the water quality data presented herein support high confidence that the foregoing criteria will be met provided that DIN, as the limiting nutrient to phytoplankton growth, does not persist within the Port Catherine marina waterway to a significantly greater extent than occurs at Hillarys or Success Harbours. Based on the monitoring data for Hillarys and Success Harbours, a conservative predictive criterion for Port Catherine marina would be that the maximum DIN concentration should remain less than 0.05mg/L. This is only two-times the background concentration in the nearshore Owen Anchorage and was exceeded by the upper 10% of measurements at Hillarys Boat Harbour. It is only 40% of the mean DIN concentration, measured over two years, in Jervoise Bay Northern Harbour.

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4.0 WATER QUALITY MODELLING

Bowman Bishaw Gorham on behalf of PCD engaged M P Rogers & Associates Pty Ltd (in conjunction with Lawson & Treloar) to undertake three-dimensional hydrodynamic and transport-dispersion modelling for the proposed Port Catherine marina. Modelling was initially undertaken to simulate design variations to the Port Catherine marina to optimise the flushing efficiency and environmental performance. The optimal marina design was subsequently modelled with and without the groundwater intercept drain, applying groundwater inputs both with the current nitrogen concentration and with the predicted nitrogen concentrations in groundwater in approximately twelve years, once the elevated nitrogen concentrations reduce (Appendix III).

Comparative modelling was undertaken for Hillarys Boat Harbour, Success Harbour and Jervoise Bay Northern Harbour to validate the model and to assist interpretation of the results.

This section describes the model set-up and summarises and assesses the results. A detailed description of the modelling is provided as Appendix V.

4.1 Model Description and Set-up

The model used was Delft3D, a 3-dimensional numerical hydrodynamic and transport model package developed by WL/Delft Hydraulics of the Netherlands that simulates non-steady flow and transport phenomena. The model takes into account bathymetry and water density variations, as well as external forcings such as tides, winds and discharges.

The modelling incorporated groundwater inputs and used DIN as a measure of the potential for nuisance plant growth in the respective waterways.

4.1.1 Model Grid and Domain

The model was established with a horizontal resolution (grid spacing) of 10m in both directions at Port Catherine, 15m at Hillarys Boat Harbour and 25m at Success Harbour and Jervoise Bay Northern Harbour. In the vertical direction, the model grid had five equally spaced layers regardless of the water depth i.e. the thickness of each layer at any point was one-fifth of the depth.

The modelled domain extended 1km to the north and south of each marina, to include simulation of regional groundwater inflows and their impact on adjacent nearshore water quality.

The bathymetry at each marina was digitised from the most recent detailed hydrographic survey. At Port Catherine, the minimum depth of the marina waterway was set at the proposed dredged depth of –3m AHD.

4.1.2 Wind and Tide Input

The time period for all modelling was for the model to "warm-up" during December 1997 and then run during 1 to 14 January 1998. This period was chosen because it coincided with the initial significant algal bloom in Jervoise Bay Northern Harbour.

The inputs of wind and tide data to the models were 10 minute wind records from Swanbourne and 15 minute tide readings from Fremantle Fishing Boat Harbour, measured during the period.

Hydrodynamic modelling results documented in Department of Environmental Protection (1996) and Lord & Hillman (1995) suggest that the current regime in the nearshore waters of the Perth metropolitan area are predominantly shore parallel. To simulate the alongshore transport process, the northern and southern boundaries were specified by the tide levels measurement at Fremantle and the western boundary was made a no-flow boundary. The tide levels were checked to ensure that the water level throughout the model grid was essentially the same as the tide level applied at the model boundaries. The applied tide levels at the boundaries produced nearshore currents that were typically less than 0.1m/s and were in general agreement with observations and measurements.

4.1.3 Marine Water Quality

The background marine water DIN concentration outside each marina was set at 0.025mg/L for Port Catherine, Success Harbour and Jervoise Bay, and at 0.015mg/L for Hillarys. These values corresponded to the mean DIN concentrations measured outside each marina during the weekly monitoring by Bowman Bishaw Gorham during the summer of 1999-2000 (Section 3.3).

4.1.4 Groundwater Inputs

The groundwater inflow rates and DIN concentrations that were used for the modelling of each marina are described in Table 4.

Groundwater inflow rates to the Port Catherine marina were determined from site-specific investigations and groundwater modelling by consultant hydrologists Rockwater Pty Ltd (Appendix II). The groundwater flows used in the modelling were slightly higher than the most likely, to be conservative.

The groundwater inflow rates for the modelling of the other marinas were derived from flows calculated by Davidson (1995) between the 1m groundwater contour and the coast at the respective locations.

The groundwater DIN concentrations used in the modelling were derived from location-specific monitoring. Two scenarios were modelled for the Port Catherine marina, based on existing and future DIN concentrations in groundwater flowing to the development, as discussed in Appendix III and summarised below.

The first scenario incorporated a groundwater DIN concentration of 4.4mg/L, which is the 95% upper confidence limit on the mean DIN concentration measured in 91 groundwater samples collected within 2.5km inland of the proposed marina location (Appendix III). This scenario represents the groundwater DIN inflow towards the marina during the twelve years until the plume of nutrient enriched groundwater caused by previous market gardening activity has passed through.

The second scenario had a groundwater DIN concentration of 1.0mg/L, which is the 95% upper confidence limit on the mean DIN concentration measured in 20 bores further than 2.5km inland of the proposed marina location (Appendix III). This scenario represents the groundwater DIN inflow towards the marina after the next seven to twelve years once the plume of nutrient enriched groundwater caused by previous market gardening activity has passed through and groundwater DIN concentrations are expected to reduce to this concentration typical of urban development.

Table 4 Groundwater flow and DIN inputs to the water quality models

Model	Input Location	Groundwater Inflow (m^3/d)	Groundwater [DIN] (mg/L)
Port Catherine: current	Marina (850m)	310	4.4
	1 km north	2,360	4.4
	1 km south	2,315	4.4
Port Catherine: post-2012	Marina (850m)	1,370	1.0
	1 km north	3,444	1.0
	1 km south	4,026	1.0
Hillarys Boat Harbour	Marina (450m)	1,150	3.0
	1 km north	2,500	3.0
	1 km south	2,500	3.0
Success Harbour	Marina (500m)	1,300	5.0
	1 km north	2,600	5.0
	1 km south	2,600	5.0
Jervoise Bay Northern Harbour	Marina (1600m)	4,800	13.6
	500m north	1,500	3.0
	1 km south	3,000	3.0

Notes:

Port Catherine current:
- Intercept drain operating
- An additional $128m^3/d$ of groundwater with 1.0mg/L DIN was added to the waterway from urban inputs to the west of the intercept drain.
- Flows from Rockwater (2000)
- [DIN] from 95% upper confidence limit on mean [DIN] in groundwater <2.5km inland from marina.

Port Catherine post-2012:
- Intercept drain not operating
- An additional $128m^3/d$ of groundwater with 1.0mg/L DIN was added to the waterway from urban inputs to the west of the intercept drain.
- Flows from Rockwater (2000)
- [DIN] from 95% upper confidence limit on mean [DIN] in groundwater >2.5km inland from marina.

Hillarys Boat Harbour:
- Inflows derived from flows calculated by Davidson (1995) between 1m contour and coast for Gnangara Mound south flowlines 2 and 3.
- [DIN] from average of Bowman Bishaw Gorham seepage monitoring at marina and five Water Corporation bores <2km inland of marina.

Success Harbour:
- Inflows derived from flows calculated by Davidson (1995) between 1m contour and coast for Jandakot Mound south flowline 2.
- [DIN] from average of ten Council and private bores <2.5km inland of marina, sampled by Bowman Bishaw Gorham on 10 March 2000.

Jervoise Bay Northern Harbour Harbour:
- Inflows derived from flows calculated by Davidson (1995) between 1m contour and coast for Jandakot Mound south flowline 2, checked by calculation of preliminary gradients and transmissivities provided by PPK, unpublished data, 2000..
- [DIN] in groundwater to harbour from average of 44 measurements over 11 bores by PPK, unpublished data, 2000.
- [DIN] in groundwater to 1km north and south from average of 12 measurements over 3 bores by PPK, unpublished data, 2000.

The first Port Catherine scenario (DIN concentration = 4.4mg/L) incorporated the proposed groundwater extraction and reuse/recharge system, whereby the residual groundwater flow to the marina was reduced to $310m^3/d$, approximately 10% of the natural inflow to the development. The second scenario (DIN concentration = 1.0mg/L) was modelled without any groundwater interception, to simulate conditions post-2012 if the groundwater extraction system is turned off following groundwater DIN concentrations reducing to normal.

Both of the modelled scenarios for Port Catherine included an input of water and DIN from urban gardens and public gardens within the development area that is down-gradient of the proposed intercept drain. The DIN concentration in the recharge from this source was estimated as 1.0mg/L, being equal to the DIN concentration in groundwater below other urban areas to the east. The groundwater recharge was calculated assuming an average irrigation rate of 10mm/d throughout the 3.8ha that is the maximum likely garden and irrigable areas to the west of the intercept drain. An average irrigation rate of 10mm/d is three-times the average irrigation rate by non-bore users in Perth (Metropolitan Water Authority, 1985).

For Hillarys Boat Harbour, Success Harbour and Jervoise Bay Northern Harbour, the groundwater DIN concentrations used in the modelling were the mean values measured as follows:

Hillarys Boat Harbour:

- Average of Bowman Bishaw Gorham seepage monitoring at marina and five Water Corporation bores <2km inland of marina.

Success Harbour:

- Average of ten Council and private bores <2.5km inland of marina, sampled by Bowman Bishaw Gorham on 10 March 2000.

Jervoise Bay Northern Harbour Harbour:

- DIN concentration in groundwater to harbour is the average of 44 measurements over eleven bores by PPK, unpublished data, 2000.
- DIN concentration in groundwater to the north and south of the harbour is the average of twelve measurements over three bores by PPK, unpublished data, 2000.

The inputs of groundwater to each marina were distributed evenly along the shoreline as shown in Figures 5 to 9, at approximately mid-depth (-1.5m AHD).

4.1.5 Calibration of Modelled DIN

The model was calibrated by adjusting the horizontal diffusion co-efficient until the concentration of DIN at the end of the warm-up period within the Jervoise Bay Nothern Harbour was slightly higher than the field measurements. The calibrated horizontal diffusion co-efficient was $1m^2/s$, which is within the range of usual values.

4.2 Model Results

A detailed description of the results of the modelling is provided in Appendix V. Table 5 describes the mean and range of modelled DIN concentrations within each marina and compares them with the measured DIN concentrations during the summer 1999-2000.

The comparisons in Table 5 show relatively close agreement between modelled and measured average and range DIN concentrations for Jervoise Bay Northern Harbour and Hillarys Boat Harbour, with the modelled values mostly being slightly higher than the measured values. It is noted that the model was run over December 1998 to January 1999, whereas the measurements were made during summer 1999-2000. The mean DIN concentrations measured in Jervoise Bay Northern Harbour during summer 1998-1999 were slightly higher (0.151 – 0.203 mg/L) than during summer 1999-2000.

The modelled DIN concentrations at Success Harbour were significantly higher than the measured concentrations (Table 5). However as discussed in Section 3.3, consistently low DIN concentrations were measured in Success Harbour during the summer of 1999-2000 (lower than the source ocean water). It is believed that this reflected higher biological uptake inside Success Harbour. Other possible confounding influences included high stormwater drainage inputs and riverine discharge.

Other aspects of the model output that support confidence in the modelling results include the following:

1. The modelled flushing time for Hillarys Boat Harbour (*e-folding* time of approximately 4 days) was similar to the Schwartz and Imberger (1988) measured *e-folding* time of approximately 5 days.

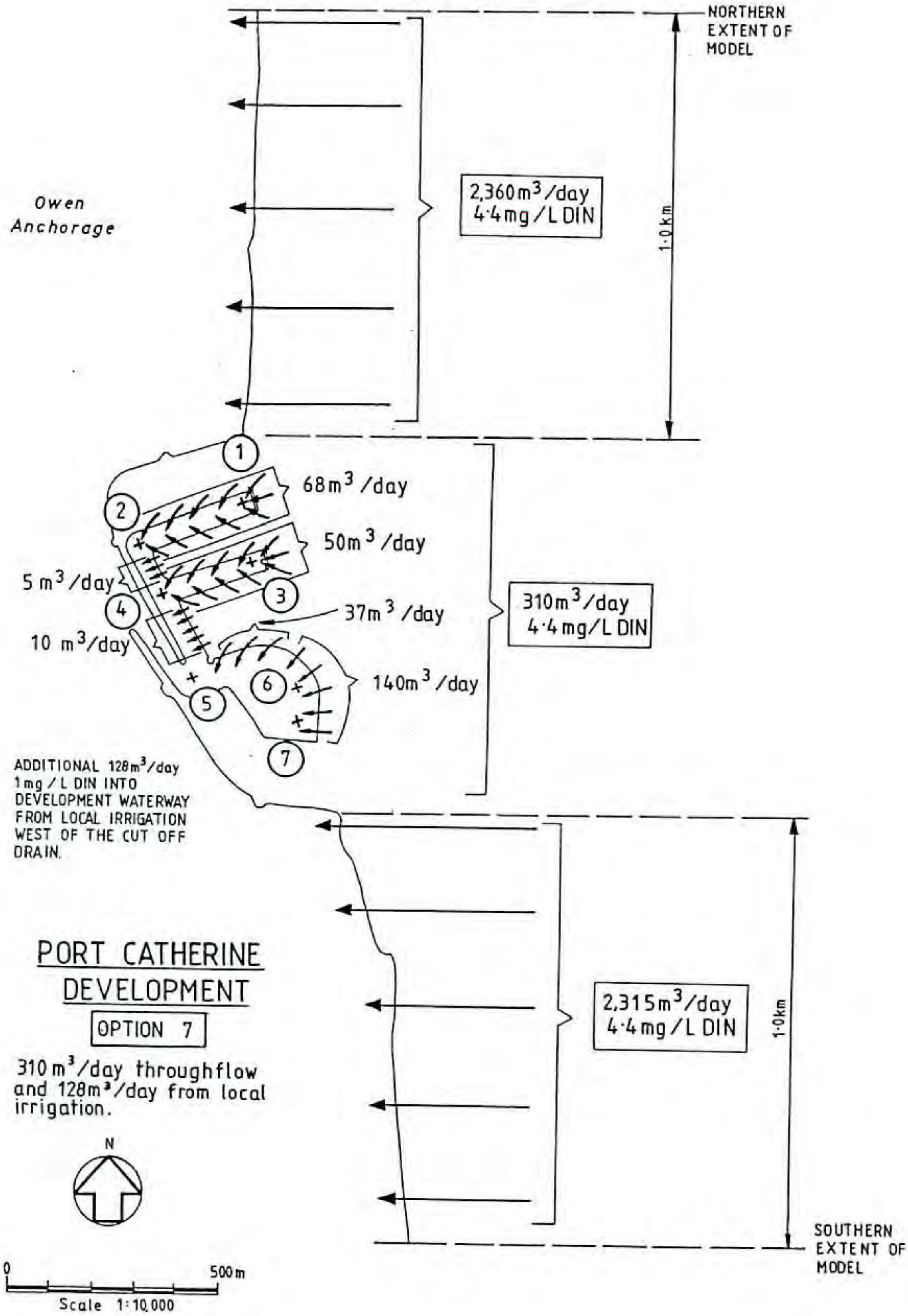

Figure 5

PORT CATHERINE (CURRENT SCENARIO) INFLOWS AND LOCATION OF MONITORING POINTS

Source: M P Rogers & Associates

BOWMAN BISHAW GORHAM

ENVIRONMENTAL MANAGEMENT CONSULTANTS

Pinpoint Cartographics 0417 904 798 d:\drafting\BBG\R97062\D2\R97062-D2F6.dgn 24-9-00

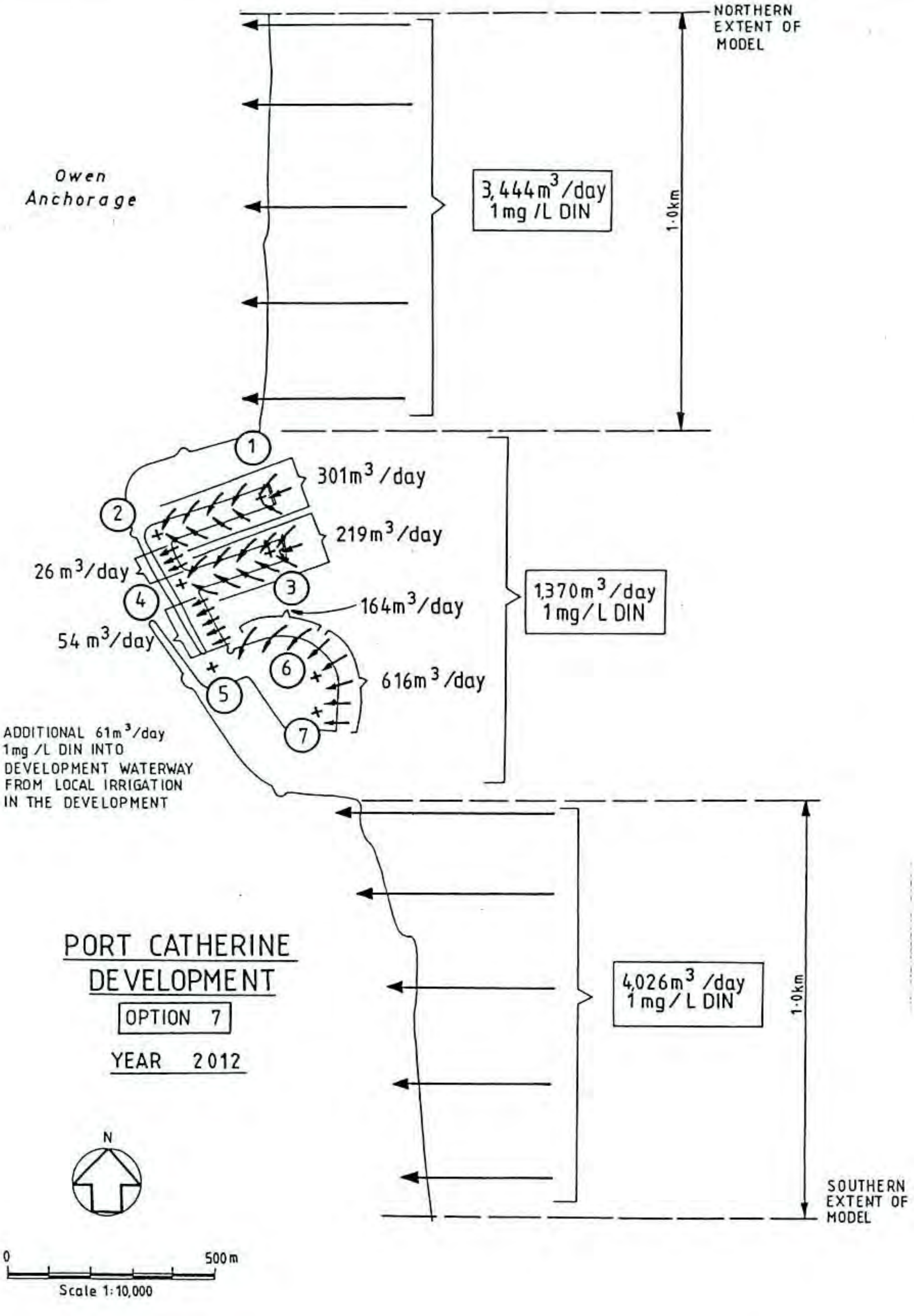

Figure 6

PORT CATHERINE (POST-2012 SCENARIO)
INFLOWS AND LOCATION OF
MONITORING POINTS

Source: M P Rogers & Associates

BOWMAN BISHAW GORHAM
ENVIRONMENTAL MANAGEMENT CONSULTANTS

Pinpoint Cartographics 0417 904 798 d:\drafting\BBG\R97062\D2\R97062-D2F7.dgn 24-9-00

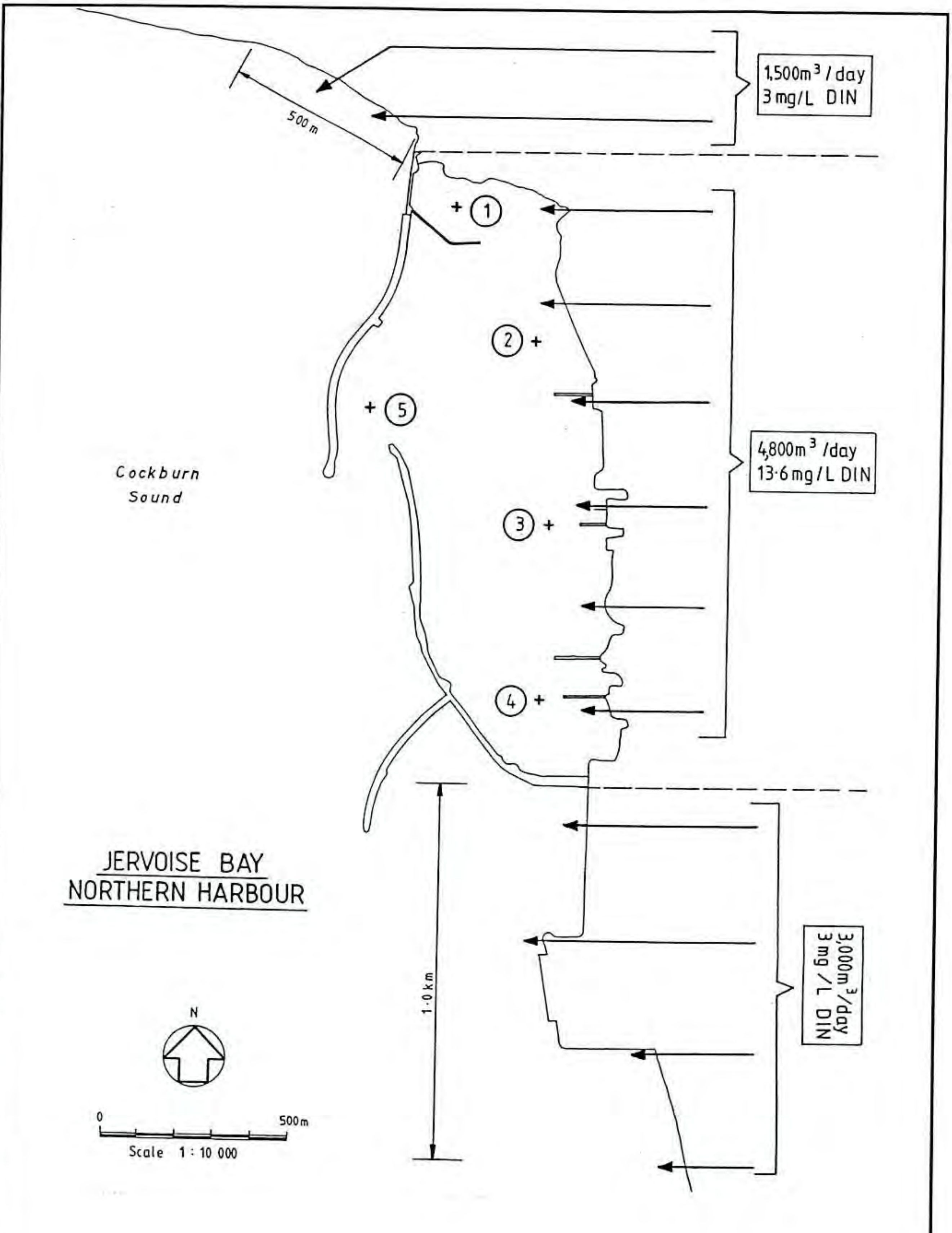

Figure 7

JERVOISE BAY NORTHERN HARBOUR
INFLOWS AND LOCATION OF
MONITORING POINTS

Source: M P Rogers & Associates

BOWMAN BISHAW GORHAM
ENVIRONMENTAL MANAGEMENT CONSULTANTS

Pinpoint Cartographics 0417 904 798 d:\drafting\BBG\R97062\D2\R97062-D2F8.dgn 24-9-00

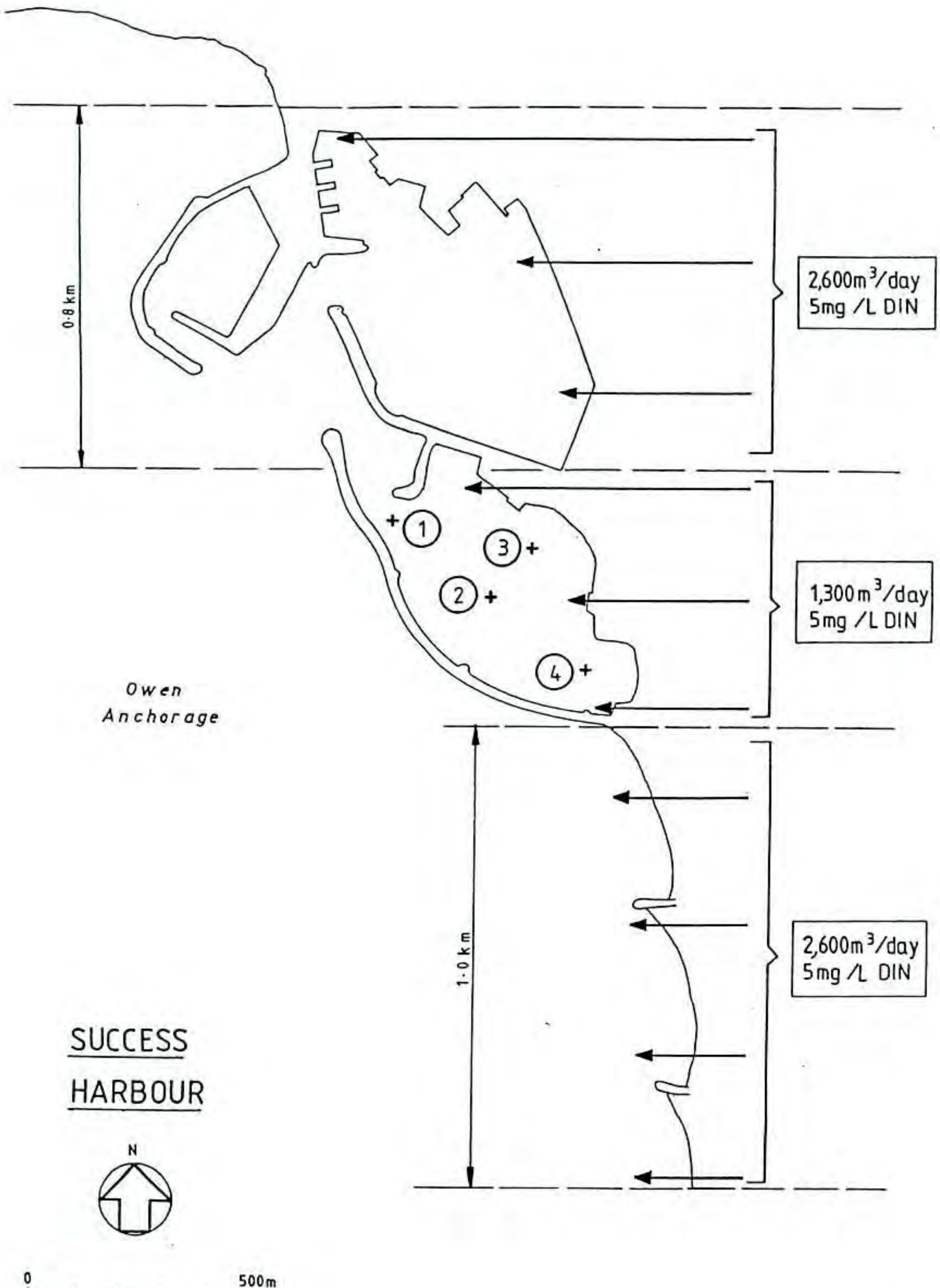

Figure 8

SUCCESS HARBOUR
INFLOWS AND LOCATION OF
MONITORING POINTS

Source: M P Rogers & Associates

Pinpoint Cartographics 0417 904 798 d:\drafting\BBG\R97062\D2\R97062-D2F9.dgn 24-9-00

BOWMAN BISHAW GORHAM

ENVIRONMENTAL MANAGEMENT CONSULTANTS

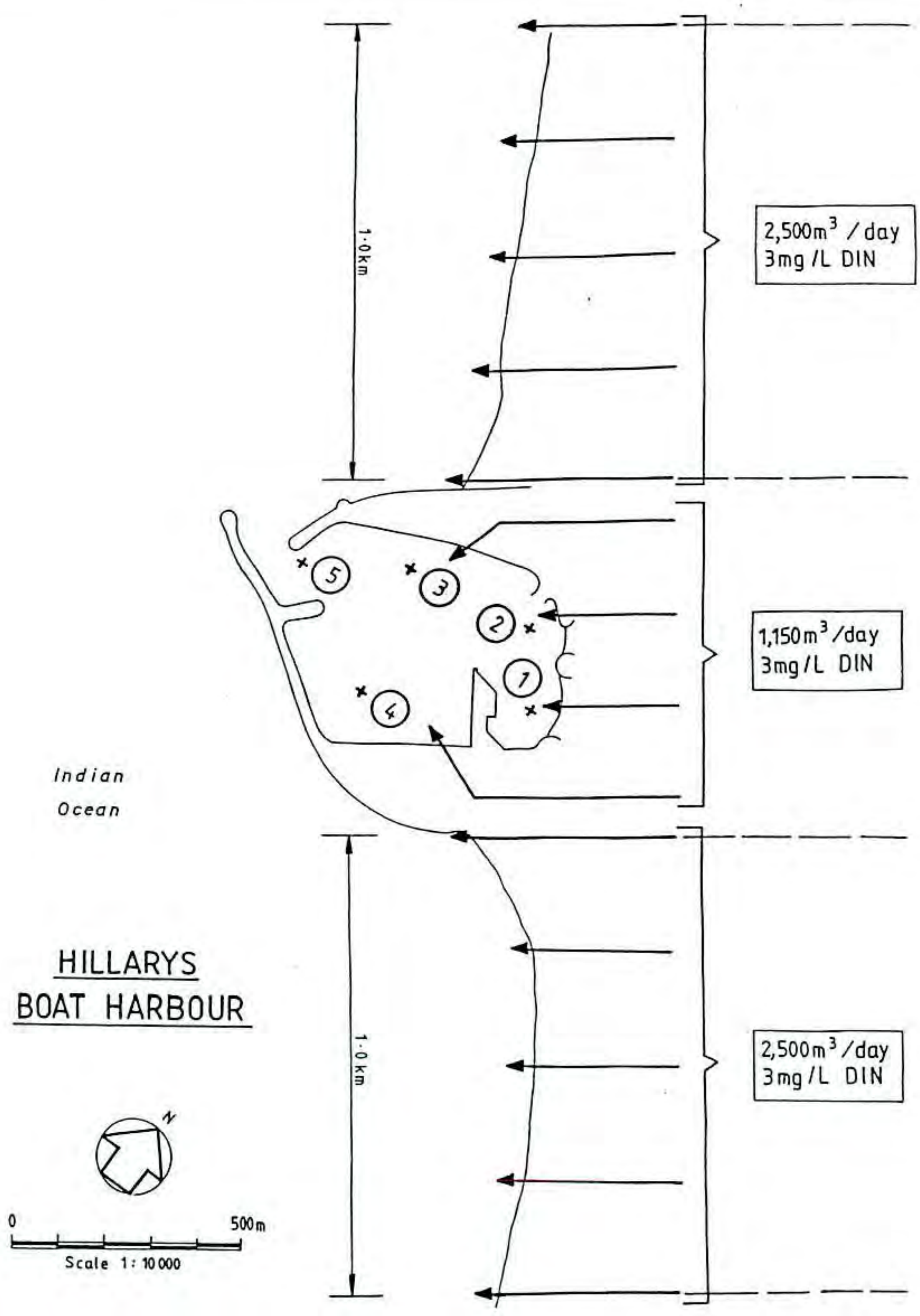

Figure 9

HILLARYS BOAT HARBOUR
INFLOWS AND LOCATION OF
MONITORING POINTS

Source: M P Rogers & Associates

BOWMAN BISHAW GORHAM

ENVIRONMENTAL MANAGEMENT CONSULTANTS

Table 5 Average and range of modelled DIN concentrations within each marina, compared with measured DIN concentrations during summer 1999-2000

Waterway	Modelled [DIN] (mg/L)	Measured [DIN] (mg/L)
Jervoise Bay Northern Harbour		
- **Mean**	0.161	0.138
- **Range**	0.072 – 0.239	0.081 – 0.216
Hillarys Boat Harbour		
- **Mean**	0.029	0.022
- **Range**	0.019 – 0.034	0.006 – 0.064
Success Harbour		
- **Mean**	0.041	0.011
- **Range**	0.035 – 0.048	0.006 – 0.019
Port Catherine: current scenario		
- **Mean**	0.041	n.a.
- **Range**	0.036 – 0.045	
Port Catherine: 2012 scenario		
- **Mean**	0.038	n.a.
- **Range**	0.033 – 0.041	

2. The model results for Hillarys Boat Harbour and Jervoise Bay Northern Harbour show temporary water column stratification during low tides and calm winds, as has been observed in field studies at each location (Schwartz and Imberger, 1988; Department of Commerce and Trade, 1998c).

3. The modelled horizontal and vertical salinity structure within Jervoise Bay Northern Harbour was essentially similar to that measurement during detailed water quality measurements (Department of Commerce and Trade, 1998c).

4. The nearshore currents produced by the modelling were typically lessthan 0.1m/s and were in general agreement with observations and measurements, including those

documented by Department of Environmental Protection (1996) and Lord and Hillman (1995).

On the basis of the foregoing, it is believed that the Delft3D model provided a reasonable simulation of the water quality in each harbour.

4.2.1 Model Results at Port Catherine with Proposed Groundwater Interception System

The Port Catherine marina (current scenario) model assumed that the intercept drain would allow a residual groundwater flow to the marina of $310m^3$/day containing 4.4mg/L DIN.

Figure 10 compares representative spatial plots of the modelled DIN concentrations in the surface layer within the Port Catherine marina, Hillarys Boat Harbour, Success Harbour and Jervoise Bay Northern Harbour during the model runs. The different marinas are shown at equal scales. It is noted that these plots only represent a snapshot in time and that the model was run for fourteen days after warm-up. A full series of time plots of DIN concentrations at designated sites in each marina are presented in Appendix V.

From Figure 10, the modelled DIN concentrations in the Port Catherine marina were comparable to the modelled DIN concentrations in both Hillarys and Success Harbours and significantly lower than the modelled DIN in the Jervoise Bay Northern Harbour.

Figure 11 shows a spatial plot of the modelled DIN concentrations in the surface layer during ebb tide for the Port Catherine marina, again with $310m^3$/day inflow of groundwater containing 4.4mg/L DIN. The figure shows that the mean modelled concentration of DIN in the marina waterway is less than 0.05mg/L and that there is very little variation in the concentration of DIN throughout the development.

The model output data was monitored at seven representative sites within the proposed Port Catherine marina, shown in Figure 4. Plots showing the variation in time of DIN at the surface, mid-depth, and at the bottom at each of these sites are presented in Appendix V. Decay curves at the surface, mid-depth, and bottom at these locations are also presented.

The time history plots show that the modelled DIN concentration in the waterway of the proposed Port Catherine development is generally within the range 0.035mg/L to 0.045mg/L and that there is very little variation in DIN over time and over the water column at each of the monitored locations.

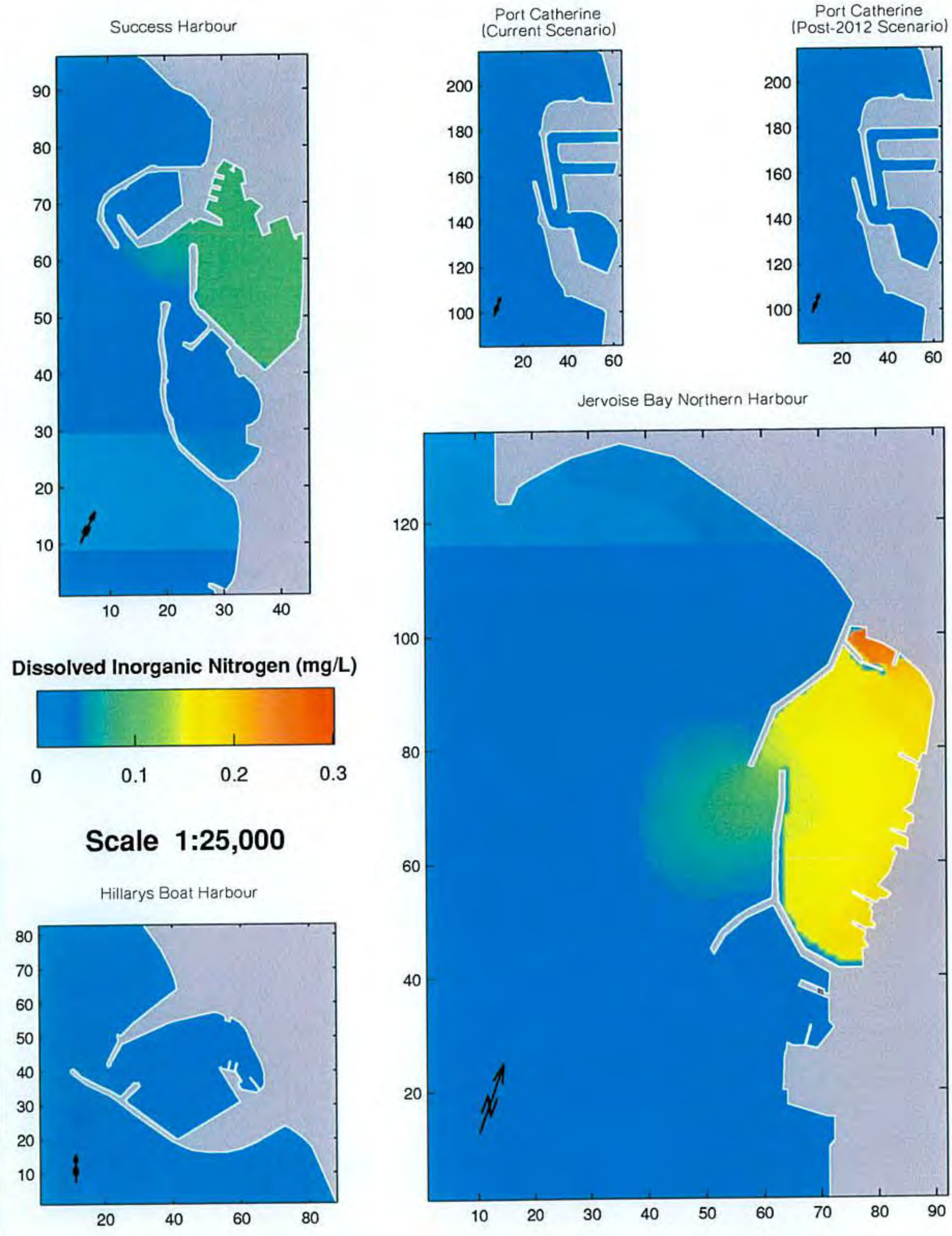

Figure 10

Spatial Plots of the Modelled DIN Concentrations in each of the Modelled Marinas

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R97062-AD-FIG.25-29.11.00

TIME: **Peak Ebb Tide** LAYER: **Surface**

SCALE: **1:25000** GRID RESOLUTION: **10 m by 10 m**

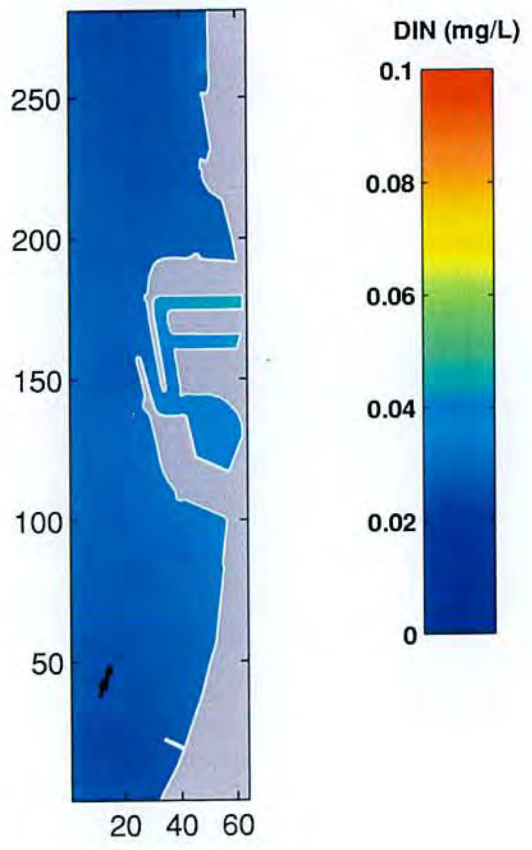

Figure 11

Spatial Plot of the Modelled DIN in the Surface Layer for Port Catherine Marina During Ebb Tide (Current Senario)

Source : MP Rogers and Associates

R97062-AD-FIG-28-29.11.00

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4.2.2 Model Results at Port Catherine Post-2012 Without Groundwater Interception

The post-2012 scenario for the Port Catherine marina model anticipated that the groundwater interception may be discontinued once the nutrient plume has passed through, by 2012 at the latest. Under this scenario, the groundwater flow to the marina will be 1,370m^3/day containing 1.0mg/L DIN, with a local recharge of 61m^3/day containing 1.0mg/L.

Figure 10 shows that the modelled DIN concentration in the Port Catherine waterway under this scenario will remain comparable with the modelled DIN concentration in both Hillarys and Success Harbours, and much lower than the modelled DIN in the Jervoise Bay Northern Harbour.

Figure 12 shows a spatial plot of the modelled DIN concentration in the surface layer during ebb tide for the Port Catherine marina (post-2012) scenario. The figure shows that the concentration of DIN in the development waterway is less than 0.05mg/L and that there is very little variation in the concentration of DIN throughout the development.

Plots showing the variation in time of DIN at the surface, mid-depth and at the bottom of seven locations in the marina are provided in Appendix V. These plots indicate that the modelled DIN concentration in the waterway is generally within the range of 0.030mg/L to 0.045mg/L and that there is very little variation in DIN over time and over the water column at each of the monitored locations. These plots also show that the DIN concentration at the eastern end of the two residential canals will remain only marginally higher than in the main marina area.

4.2.3 Comparative Harbour Flushing Times

- The water quality modelling results for the proposed Port Catherine marina estimate that the eastern end of the northern-most canal has a flushing time (defined as the e-folding time, or the time taken for the concentration of the conservative tracer to reduce to 1/e (37%) of its original concentration) of around 4 to 5 days. The main marina area has an estimated e-folding time in the order of 2 to 3 days.

This compares with the modelled flushing times of approximately 1 day at Success Harbour and approximately 4 days at Hillarys Boat Harbour. Schwartz and Imberger (1988) measured the flushing time at Hillarys Boat Harbour at approximately 5 days.

In contrast, the modelled flushing time at Jervoise Bay Northern Harbour was 10 – 11 days.

TIME: Peak Ebb Tide **LAYER:** Surface
SCALE: 1:25000 **GRID RESOLUTION:** 10 m by 10 m

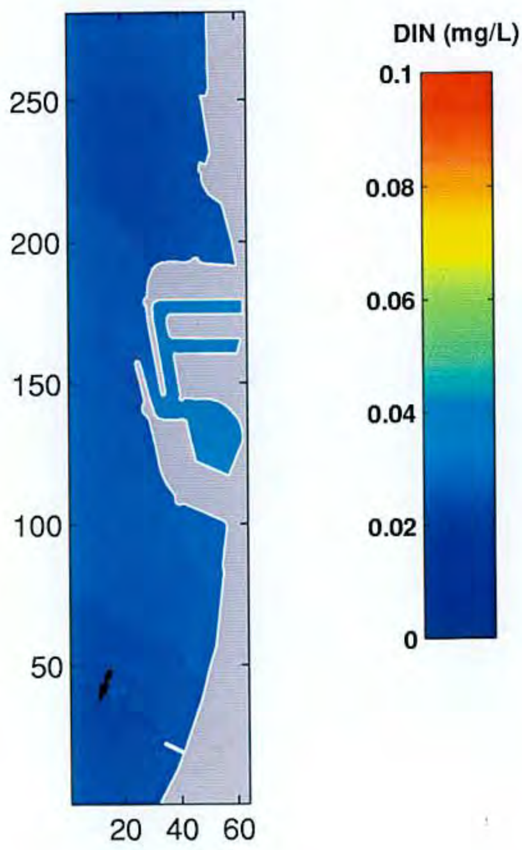

Figure 12

Spatial Plot of the Modelled DIN in the Surface Layer for Port Catherine Marina During an Ebb Tide (Post - 2012 Senario)

R97062-AD-FIG.27-29.11.00

Source : MP Rogers and Associates

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5.0 CONCLUSIONS

The results of the water quality modelling demonstrate that, with the proposed management techniques to intercept and divert nutrient rich groundwater over the first few years of the project, the water quality in the Port Catherine marina will be comparable to both Hillarys and Success Harbours.

The modelling simulated water quality during a period when severe water quality problems were experienced at the Jervoise Bay Northern Harbour, yet the mean and maximum concentrations of DIN within the proposed Port Catherine marina remained low: the mean DIN concentration was 0.041 mg/L and the maximum concentration was 0.045 mg/L. This mean value is only 65% higher than the background concentration in the nearshore Owen Anchorage. The maximum value was exceeded by 10% of measured DIN concentrations recorded at Hillarys Boat Harbour and is only one-third of the mean DIN concentration, measured over two years, in Jervoise Bay Northern Harbour.

The modelled DIN concentrations were within the conservative predictive criterion for Port Catherine marina that was derived from monitoring data for Hillarys and Success Harbours, that the DIN concentration should remain less than 0.050 mg/L.

Monitoring data and historical records provide strong support to the generally held perception that Success Harbour and Hillarys Boat Harbour meet ecological and social objectives for acceptability of water quality with respect to nutrients and algal productivity. Using DIN concentration as an indicator of the propensity of a waterway to support nuisance algal growth, the predicted water quality at Port Catherine marina will remain well within the range experienced at Success and Hillarys.

The modelled flushing times for Port Catherine marina were also between those of Success Harbour and Hillarys Boat Harbour and less than half of the flushing time for Jervoise Bay Northern Harbour.

With reference to the criteria that are proposed in Section 2.3, it is concluded that the Port Catherine marina will satisfy the following environmental criteria for algal productivity:

- The internal waterway should remain attractive and visibly healthy. Algae should not occur in excessive amounts in terms of aesthetic appearance.

- The ecological and social values of the adjacent marine environment should not be adversely affected by the marina. Net primary production in adjacent waters should not vary from levels encountered in similar, non-impacted habitats under similar light, temperature and nutrient loading regimes.

- Recreational values both within and outside the marina, particularly for direct contact recreation, should not be compromised. Algae will not occur in excessive amounts in terms of aesthetic appearance or water clarity. Phytoplankton blooms should not occur that may cause skin irritation.

- Fish, crabs and mussels may be taken from the marina waterway for human consumption. Phytoplankton blooms should not occur that may produce toxins in resident biota and may result in risk to human health.

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APPENDIX A

Water Quality Monitoring Results

Marine and Freshwater Research Laboratory Environmental Science

Accreditation No: 10603
NATA endorsed test report

MURDOCH UNIVERSITY
PERTH, WESTERN AUSTRALIA

Telephone: (08) 9360 2907 Facsimile: (08) 9360 6613

WATER QUALITY DATA

Client: Mike Forde
Our Reference: BBG 99-2

Date of Issue: 13/1/00
Your Reference:

METHOD SAMPLE CODE	DATE	2000A AMMONIA µg.N/L	4100A ORTHO-P µg.P/L	2100A NO3+NO2 µg.N/L	4700A TOTAL-P µg.P/L	2700A TOTAL-N µg.N/L	3020B CHLORO 'a' µg/L	3020B CHLORO 'b' µg/L	3020B CHLORO 'c' µg/L
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RECEIVED
17 JAN 2000

Signatory: Xiaoh[illegible]
Date: 13/1/00

Marine and Freshwater Research Laboratory Environmental Science

Accreditation No: 10603
NATA endorsed test report

MURDOCH UNIVERSITY
PERTH, WESTERN AUSTRALIA

Telephone: (08) 9360 2907 Facsimile: (08) 9360 6613

WATER QUALITY DATA

Client: Mike Forde
Our Reference: BBG 99-3

Date of Issue: 20/1/00
Your Reference:

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PC 1	21/12/99	19		13		334	1.9	<0.1	0.4
2	21/12/99	6		22		239	1.9	0.1	0.3
3	21/12/99	5		3		209	1.2	<0.1	0.2
SH 1	21/12/99	6		3		326	2.0	0.2	0.2
2	21/12/99	4		3		298	2.3	0.2	0.3
3	21/12/99	18		2		335	2.1	0.2	0.4
4	21/12/99	23		14		199	0.8	<0.1	0.1

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Marine and Freshwater Research Laboratory
Environmental Science

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NATA endorsed test report

MURDOCH UNIVERSITY
PERTH, WESTERN AUSTRALIA

WATER QUALITY DATA

Client: Mike Forde
Our Reference: BBG 00-1

Date of Issue: 24/1/00
Your Reference:

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METHOD SAMPLE CODE	DATE	2000A AMMONIA µg.N/L	4100A ORTHO-P µg.P/L	2100A NO3+NO2 µg.N/L	4700A TOTAL-P µg.P/L	2700A TOTAL-N µg.N/L	3020B CHLORO 'a' µg/L	3020B CHLORO 'b' µg/L	3020B CHLORO 'c' µg/L
Reporting Limit		<3	<2	<2	<5	<50	<0.1	<0.1	<0.1
File			00011703			00012403		00011901	
HBH 1	13/1/00	5		2		215	6.8	<0.1	1.0
2	13/1/00	<3		2		218	3.2	<0.1	0.5
3	13/1/00	3		3		234	6.0	<0.1	1.0
4	13/1/00	<3		2		175	2.5	<0.1	0.4
JB 1	13/1/00	59		62		453	13.1	<0.1	3.1
2	13/1/00	17		48		405	14.6	<0.1	3.4
3	13/1/00	9		50		360	11.1	<0.1	2.5
4	13/1/00	3		7		224	1.3	<0.1	0.3
PC 1	13/1/00	<3		3		205	2.7	<0.1	0.6
2	13/1/00	7		3		175	2.3	<0.1	0.5
3	13/1/00	<3		2		182	0.8	<0.1	0.2
SH 1	13/1/00	9		3		211	2.1	0.2	0.4
2	13/1/00	<3		2		257	1.5	0.1	0.2
3	13/1/00	<3		3		186	1.5	0.1	0.3
4	13/1/00	5		9		215	2.7	<0.1	0.5

Signatory: Xiaolong
Date: 24/1/00

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WATER QUALITY DATA

Client: Mike Forde
Our Reference: BBG 00-2

Date of Issue:31/1/00
Your Reference:

METHOD		2000A	4100A	2100A	4700A	2700A	3020B	3020B	3020B
SAMPLE CODE	DATE	AMMONIA	ORTHO-P	NO3+NO2	TOTAL-P	TOTAL-N	CHLORO 'a'	CHLORO 'b'	CHLORO 'c'
		µg.N/L	µg.P/L	µg.N/L	µg.P/L	µg.N/L	µg/L	µg/L	µg/L
Reporting Limit		<3	<2	<2	<5	<50	<0.1	<0.1	<0.1
File			00012503			00013103		00012802	
HBH 1	20/1/00	17		4		320	3.7	0.1	0.6
2	20/1/00	4		3		285	3.2	<0.1	0.5
3	20/1/00	3		3		292	3.4	0.1	0.5
4	20/1/00	5		11		234	0.5	<0.1	0.1
JB 1	20/1/00	52		67		532	20.1	<0.1	3.3
2	20/1/00	14		59		480	27.8	<0.1	4.9
3	20/1/00	12		59		481	22.4	<0.1	3.8
4	20/1/00	17		27		252	0.7	<0.1	0.1
PC 1	20/1/00	6		32		308	1.0	<0.1	0.2
2	20/1/00	3		14		269	1.2	<0.1	0.2
3	20/1/00	4		3		212	0.4	<0.1	0.1
SH 1	20/1/00	3		3		356	1.7	0.2	0.3
2	20/1/00	<3		3		322	1.5	0.2	0.3
3	20/1/00	3		26		299	1.7	0.2	0.3
4	20/1/00	8		12		307	1.3	0.1	0.2

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te: 31/1/00

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08 FEB 2000

WATER QUALITY DATA

Client: Mike Forde
Our Reference: BBG 00-3

Date of Issue:4/2/00
Your Reference:

METHOD		2000A	4100A	2100A	4700A	2700A	3020B	3020B	3020B
SAMPLE CODE	DATE	AMMONIA	ORTHO-P	NO3+NO2	TOTAL-P	TOTAL-N	CHLORO 'a'	CHLORO 'b'	CHLORO 'c'
		μg.N/L	μg.P/L	μg.N/L	μg.P/L	μg.N/L	μg/L	μg/L	μg/L
Reporting Limit		<3	<2	<2	<5	<50	<0.1	<0.1	<0.1
File			00020303			00020403		00020301	
HBH 1	1/2/00	32		41		270	0.9	<0.1	0.2
2	1/2/00	33		32		260	0.4	<0.1	0.1
3	1/2/00	31		24		274	0.4	<0.1	0.1
4	1/2/00	9		15		178	0.6	<0.1	0.1
JB 1	1/2/00	160		128		542	3.1	<0.1	0.6
2	1/2/00	42		156		431	3.3	<0.1	0.7
3	1/2/00	17		145		415	2.8	<0.1	0.5
4	1/2/00	8		33		282	1.2	<0.1	0.2
PC 1	1/2/00	9		23		262	1.1	<0.1	0.2
2	1/2/00	7		25		240	1.0	<0.1	0.2
3	1/2/00	6		3		241	0.9	<0.1	0.2
SH 1	1/2/00	7		114		472	6.2	0.4	1.1
2	1/2/00	7		168		509	6.1	0.1	1.0
3	1/2/00	6		151		502	6.1	0.2	1.0
4	1/2/00	7		416		887	7.6	0.1	1.0

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WATER QUALITY DATA

Client: Mike Forde
Our Reference: BBG 00-4

Date of Issue: 23/2/00
Your Reference:

METHOD SAMPLE CODE	DATE	2000A AMMONIA µg.N/L	4100A ORTHO-P µg.P/L	2100A NO3+NO2 µg.N/L	4700A TOTAL-P µg.P/L	2700A TOTAL-N µg.N/L	3020B CHLORO 'a' µg/L	3020B CHLORO 'b' µg/L	3020B CHLORO 'c' µg/L
Reporting Limit		<3	<2	<2	<5	<50	<0.1	<0.1	<0.1
File			00020903-2303			00022103		00021501	
HBH 1	8/2/00	17		33		281	1.3	0.1	0.3
2	8/2/00	10		22		225	1.4	<0.1	0.3
3	8/2/00	12		17		205	1.2	<0.1	0.2
4	8/2/00	13		20		233	0.6	<0.1	0.1
JB 1	8/2/00	90		78		375	2.5	<0.1	0.4
2	8/2/00	52		71		339	2.2	<0.1	0.4
3	8/2/00	21		87		329	2.1	<0.1	0.4
4	8/2/00	12		15		198	1.1	<0.1	0.2
PC 1	8/2/00	28		27		262	1.3	<0.1	0.2
2	8/2/00	10		26		223	0.9	<0.1	0.2
3	8/2/00	7		10		181	1.5	<0.1	0.3
SH 1	8/2/00	20		7		300	3.6	0.3	0.5
2	8/2/00	7		5		327	2.4	0.1	0.4
3	8/2/00	9		10		280	2.4	0.2	0.4
4	8/2/00	14		28		213	0.9	<0.1	0.1

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WATER QUALITY DATA

Client: Mike Forde
Our Reference: BBG 00-5

Date of Issue:23/2/00
Your Reference:

METHOD SAMPLE CODE	DATE	2000A AMMONIA µg.N/L	4100A ORTHO-P µg.P/L	2100A NO3+NO2 µg.N/L	4700A TOTAL-P µg.P/L	2700A TOTAL-N µg.N/L	3020B CHLORO 'a' µg/L	3020B CHLORO 'b' µg/L	3020B CHLORO 'c' µg/L
Reporting Limit		<3	<2	<2	<5	<50	<0.1	<0.1	<0.1
File			00021803			00022103		00022201	
HBH 1	15/2/00	8		5		283	4.1	0.1	0.8
2	15/2/00	3		3		230	3.6	<0.1	0.7
3	15/2/00	3		3		237	3.9	0.1	0.7
4	15/2/00	7		5		188	0.8	<0.1	0.1
JB 1	15/2/00	228		57		503	2.3	<0.1	0.5
2	15/2/00	45		71		325	2.7	<0.1	0.6
3	15/2/00	22		56		306	2.7	<0.1	0.5
4	15/2/00	5		6		212	0.7	<0.1	0.1
PC 1	15/2/00	12		11		236	1.0	<0.1	0.2
2	15/2/00	10		11		235	0.8	<0.1	0.1
3	15/2/00	7		5		225	0.6	<0.1	0.1
SH 1	15/2/00	6		3		285	2.7	0.2	0.3
2	15/2/00	5		5		270	2.0	0.1	0.3
3	15/2/00	4		3		247	2.2	0.1	0.3
4	15/2/00	7		9		226	1.0	<0.1	0.2

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Date: 23/2/00

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WATER QUALITY DATA

Client: Mike Forde
Our Reference: BBG 00-7

Date of Issue: 29/2/00
Your Reference:

METHOD		2000A	4100A	2100A	4700A	2700A	3020B	3020B	3020B
SAMPLE CODE	DATE	AMMONIA	ORTHO-P	NO3+NO2	TOTAL-P	TOTAL-N	CHLORO 'a'	CHLORO 'b'	CHLORO 'c'
		µg.N/L	µg.P/L	µg.N/L	µg.P/L	µg.N/L	µg/L	µg/L	µg/L
Reporting Limit		<3	<2	<2	<5	<50	<0.1	<0.1	<0.1
File			00022303			00022403		00022901	
HBH 1	21/2/00	11		11		246	4.2	0.1	0.8
2	21/2/00	9		10		244	4.0	0.1	0.8
3	21/2/00	18		12		268	3.9	0.1	0.8
4	21/2/00	4		4		245	0.8	<0.1	0.1
JB 1	21/2/00	48		58		364	4.2	<0.1	0.7
2	21/2/00	39		59		311	3.8	<0.1	0.7
3	21/2/00	15		37		260	3.1	<0.1	0.6
4	21/2/00	6		5		204	0.6	<0.1	0.1
PC 1	21/2/00	5		49		273	0.9	<0.1	0.2
2	21/2/00	5		59		238	0.9	<0.1	0.2
3	21/2/00	5		2		218	0.7	<0.1	0.1
SH 1	21/2/00	6		2		240	2.0	0.5	0.3
2	21/2/00	2		2		212	2.2	0.5	0.3
3	21/2/00	3		3		277	2.3	0.5	0.3
4	21/2/00	4		8		190	1.0	0.1	0.2

Signatory: Xiao
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Telephone: (08) 9360 2907 Facsimile: (08) 9360 6613

WATER QUALITY DATA

Client: Mike Forde
Our Reference: BBG 00-9

Date of Issue: 21/3/00
Your Reference:

METHOD		2000A	4100A	2100A	4700A	2700A	3020B	3020B	3020B
SAMPLE CODE	DATE	AMMONIA	ORTHO-P	NO3+NO2	TOTAL-P	TOTAL-N	CHLORO 'a'	CHLORO 'b'	CHLORO 'c'
		µg.N/L	µg.P/L	µg.N/L	µg.P/L	µg.N/L	µg/L	µg/L	µg/L
Reporting Limit		<3	<2	<2	<5	<50	<0.1	<0.1	<0.1
File			00030303			00031303		00030701	
HBH 1	2/3/00	5		3		246	5.7	<0.1	1.2
2	2/3/00	3		3		258	4.8	<0.1	1.0
3	2/3/00	3		3		238	5.5	<0.1	1.1
4	2/3/00	6		11		215	1.5	0.1	0.2
JB 1	2/3/00	65		77		342	4.3	<0.1	0.8
2	2/3/00	53		80		352	3.7	<0.1	0.7
3	2/3/00	116		163		504	3.6	<0.1	0.7
4	2/3/00	15		15		238	1.7	<0.1	0.3
PC 1	2/3/00	8		12		240	0.9	<0.1	0.1
2	2/3/00	9		10		225	0.7	<0.1	0.1
3	2/3/00	4		3		179	1.2	<0.1	0.2
SH 1	2/3/00	3		3		262	3.4	0.3	0.6
2	2/3/00	3		3		252	3.6	0.4	0.7
3	2/3/00	3		3		246	3.5	0.3	0.6
4	2/3/00	7		30		265	1.4	0.1	0.2

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WATER QUALITY DATA

Client: Mike Forde
Our Reference: BBG 00-10

Date of Issue: 29/3/00
Your Reference:

METHOD SAMPLE CODE	DATE	2000A AMMONIA µg.N/L	4100A ORTHO-P µg.P/L	2100A NO3+NO2 µg.N/L	4700A TOTAL-P µg.P/L	2700A TOTAL-N µg.N/L	3020B CHLORO 'a' µg/L	3020B CHLORO 'b' µg/L	3020B CHLORO 'c' µg/L
Reporting Limit		<3	<2	<2	<5	<50	<0.1	<0.1	<0.1
File			00031403			00032003		00030701	
HBH 1	8/3/00	15		4		316	4.2	<0.1	0.7
2	8/3/00	5		3		235	3.3	<0.1	0.5
3	8/3/00	11		3		255	4.0	<0.1	0.7
4	8/3/00	5		5		159	1.0	<0.1	0.1
JB 1	8/3/00	162		77		397	3.8	<0.1	0.8
2	8/3/00	35		68		304	3.9	<0.1	0.8
3	8/3/00	14		25		257	3.8	<0.1	0.8
4	8/3/00	9		5		180	1.0	<0.1	0.2
PC 1	8/3/00	18		11		235	1.2	0.1	0.1
2	8/3/00	9		11		243	1.1	<0.1	0.1
3	8/3/00	8		5		174	0.6	<0.1	0.1
SH 1	8/3/00	6		3		246	3.0	0.4	0.5
2	8/3/00	6		3		251	4.2	0.4	0.7
3	8/3/00	8		3		280	3.3	0.4	0.5
4	8/3/00	13		12		194	0.7	0.1	0.1

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APPENDIX V
Water Quality Modelling
(M.P. Rogers & Associates)

September 2000

Port Catherine Developments

Port Catherine Water Quality Modelling

M P ROGERS & ASSOCIATES

Coastal & Port Engineers

Job J198/5 Report R082 Rev 1

September 2000

Port Catherine Developments

Port Catherine Water Quality Modelling

Job J198/5 Report R082 Rev 1 - Record of Document Revisions

Rev	Purpose of Document	Prepared	Reviewed	Approved	Date
A	Draft for MRA internal review only	D Pang	M Rogers	M Rogers	8/8/00
0	MRA and Client review	D Pang	M Rogers	M Rogers	9/8/00
1	Issued for Client use	D Pang	M Rogers	MP Rogers	12/9/00

M P ROGERS & ASSOCIATES - Coastal & Port Engineers

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Email: rogers@tpgi.com.au

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Table of Contents

1. Introduction

1.1 Background

Port Catherine Developments Pty Ltd (PCD) is proposing to develop a large residential and marina estate in the former South Coogee industrial area about 5 km south of Fremantle. The location of the proposed development is shown in Figure 1.1.

PCD has been involved in the project over the last 3 years and over this period of time the proposed development layout has evolved to best suit planning, environmental, and financial goals. Details of water quality analysis and computer modelling completed for the previous development layouts are described in Rogers & Associates (1998) and Rogers & Associates (1999). The current development scheme is shown in Figure 1.2, and is the primary focus of this report.

Due to industrial inputs the water quality in Owen Anchorage has previously been of a poor standard. In recent years however, the water quality in this area has slowly been improving due largely to the reduction in the discharge of contaminants as various industries have been closed. These improvements have been monitored and are documented in Department of Environmental Protection (1996) and Lord & Hillman (1995).

Despite these recent improvements, the environmental authorities are still cautious of developments within Owen Anchorage that may affect the water quality in the area. As such, M P Rogers & Associates Pty Ltd (in conjunction with Lawson & Treloar) were engaged by Bowman Bishaw Gorham on behalf of PCD to undertake 3 dimensional hydrodynamic and transport-dispersion modelling to investigate the water quality within and adjacent to the proposed Port Catherine development.

The Department of Environmental Protection has suggested that Dissolved Inorganic Nitrogen (DIN) is a good measure of the potential for nuisance plant growth within enclosed waterbodies (pers comm Richard Gorham, BBG). Consequently, for the purposes of this computer modelling investigation, DIN has been used to assess the water quality in the various waterways.

This report presents the methodology and findings of these investigations.

1.2 Computer Modelling Objectives

1.2.1 Modelling of Comparison Harbours

It is generally known that the principal limiting nutrient for algal growth in the nearshore coastal waters of Perth is nitrogen. However, the relationship between the concentration of nitrogen and the production of algae is complex and is affected by many factors including temperature, light intensity, turbidity, other nutrients and the species of algae. As such, it is very difficult to define a precise level of nitrogen above which nuisance algal growth could be expected to occur.

EPA (1993) provides a rough guide to the level of nitrogen in coastal waters where nuisance algal growth has been known to occur. These guidelines however, only provide a range of values above which excessive algal growth had been known to occur. They suggest that if the nitrate-nitrogen (a component of DIN) level exceeds 0.01 to 0.1 mg/L, then there is a reasonable chance that excessive algal growth could occur.

To better define an appropriate upper limit for the concentration of DIN for the proposed Port Catherine development part of this water quality investigation included the computer modelling of other established harbours within the Perth Metropolitan area. The following harbours were chosen to be modelled:

- Success Harbour
- Hillarys Boat Harbour, and
- Jervoise Bay Northern Harbour.

The locations of these harbours are shown in Figure 1.1.

The results of the computer modelling and the known performance of the above harbours (in terms of water quality) were then used as a guide to what level of DIN should be targeted for the Port Catherine development.

1.2.2 Modelling of Port Catherine Development Scheme

Measurements of the groundwater flowing towards the coast in the vicinity of the proposed Port Catherine Development site by BBG shows elevated levels of nitrogen. Empirical calculations and computer modelling indicates that without appropriate management techniques, the level of DIN in the proposed waterway will be unacceptable and would greatly increase the probability of algal blooms. As such, groundwater extraction involving the use of a cut-off drain is proposed to reduce the amount of groundwater flow into the development waterway. More details on the methodology of the groundwater extraction can be found in Rockwater (2000).

However, results of extensive borehole monitoring by BBG suggest that the elevated levels of DIN currently in the groundwater adjacent to the proposed Port Catherine Development site is only a medium term problem. BBG has estimated that the elevated concentration of DIN in the groundwater is likely to completely pass through the system in around 7 to 12 years.

Consequently, the aims of the Port Catherine development modelling are to demonstrate that:

- with appropriate groundwater extraction for the first decade or so, the resultant DIN concentrations in the development waterway would be acceptable, and
- following the first decade or so, there would not be the need for groundwater extraction in order to achieve acceptable levels of DIN and resultant water quality in the development waterway.

2. Model Description and Set-Up

2.1 Model Description

The model used in this water quality investigation was a computer package called Delft3D. Delft3D is a general 3-dimensional numerical model package developed by WL | Delft Hydraulics of the Netherlands. This package has been successfully used on numerous major projects around the world. The flow module of the Delft3D system is a multi-dimensional (2D or 3D) hydrodynamic and transport simulation program which calculates non-steady flow and transport phenomena taking into account bathymetry and density variations, as well as external forcings such as tides, winds, and discharges.

The Delft3D model solves the full Navier-Stokes equations (with the shallow water approximation applied) using a staggered grid finite difference scheme. The main elements of the Delft3D model include:

- Density gradients due to salinity concentration and a non-uniform temperature distribution,
- Inclusion of density (pressure) gradient terms in the momentum equation (density driven flows),
- Spatially varying wind and barometric pressure,
- Turbulence model to account for the vertical turbulent viscosity and diffusivity based on the eddy viscosity concept,
- Shear stresses exerted by turbulent flow on the bottom based on a quadratic Chézy or Manning's formula,
- Wind stresses on the water surface modelled by a quadratic friction law, and
- Coriolis force.

The effect of groundwater inflow, both by bringing pollutant into the system and creating density currents (horizontally and vertically) were considered to be an important aspect of the water quality modelling. Therefore, it was necessary to undertake transport-dispersion modelling of the development using a 3-dimensional model that included the effects of both horizontal and vertical density gradients. The Delft3D modelling system can simulate these processes and is appropriate for the intended modelling. A more detailed description of the Delft3D model is provided in Appendix A.

2.2 Model Set-Up

2.2.1 Model Grids

Port Catherine Development Scheme

The grid used in the modelling of the latest Port Catherine development scheme (Option 7) is 640 metres x 2,810 metres in its 'x' and 'y' directions respectively, and has a resolution (grid spacing) of 10 metres in both directions. The fine horizontal resolution of the grid was required to properly represent the canals within the development. The bathymetry of the model grid was digitised from a detailed hydrographic survey of the region completed in 1996. The minimum depth in the development waterways was set to –3 metres AHD.

The model grid extends from about Catherine Point in the north to Coogee Beach Jetty in the south and was rotated 20 degrees anti-clockwise so that the coastline was aligned with the y-axis of the model grid. The extent of the model grid was selected to properly model the Port Catherine Development and have a dissipation zone to represent the nearshore area of Owen Anchorage.

In the vertical direction, the model grid has 5 equally spaced layers regardless of the water depth (ie sigma co-ordinate system). As such, at each horizontal location in the grid, the thickness of the vertical layers is dependent on the depth.

A plot of the Port Catherine Development bathymetry used in the modelling is shown in Figure 2.1.

Comparison Harbours

Details of the model grids used in the modelling of the comparison harbours are shown in Table 2.1 below.

Table 2.1 – Details of Model Grids

Item	Hillarys Boat Harbour	Success Boat Harbour	Jervoise Bay Northern Harbour
Grid Size	1,335 m by 1,245 m	1,150 m by 2,400 m	2,325 m by 3,400 m
Grid Spacing	15 m x 15 m	25 m x 25 m	25 m x 25 m
Grid Rotation	0°	25° anti-clockwise	20° anti-clockwise
Layers	5 sigma layers	5 sigma layers	5 sigma layers

The bathymetry for each of the comparison harbours modelled was obtained from available plans, charts and hydrographic surveys of the area. In all three cases, the bathymetry outside the harbour of interest was obtained from chart AUS 117 (produced by the Hydrographic Service, Royal Australian Navy). The bathymetry inside each of the 3 harbours was obtained from specific hydrographic surveys. Table 2.2 below lists the source of the hydrographic data used to set-up the model bathymetry for each of the harbours. The position of the model boundaries was selected so as properly model these harbours and have a sufficient dissipation zone in the ocean waters outside the respective harbours.

Table 2.2 – Sources of Hydrographic Data

Harbour	Source
Hillarys Boat Harbour	DMH Drawing No: 211-1-1
Success Boat Harbour	Halpern Glick Drawing No: 4058/C515
Jervoise Bay Northern Harbour	Egis Drawing No: RW1267-003

2.2.2 Wind and Tide Input

For all of the model simulations undertaken, wind and tide data for December 1997 were used to warm up the model. Data for the period from 1 January 1998 to 14 January 1998 were used to drive the model. This time period was chosen to be modelled because in early January 1998 Jervoise Bay Northern Harbour experienced what was perceived to be a significant algal bloom.

The 10 minutely wind data used to represent the wind field in the model was recorded by the Bureau of Meteorology's automatic wind station located at Swanbourne. The 15 minutely tidal data used in the model was obtained from water level measurements at the Fremantle Fishing Boat Harbour taken by the Department of Transport. These water level measurements include both the astronomical and meteorological effects. Plots of the tide and wind data used in the modelling are shown in Figures 2.2 and 2.3. The tide data used covers a typical 14 day spring / neap cycle with a minimum neap tidal range of around 0.3 metres and a maximum spring tidal range of around 0.8 metres (refer to Figure 2.2). The measured wind data shown in Figure 2.3 exhibits the typical summer land / sea breeze cycle. Wind speeds in the order of 8 to 10 m/s are generally reached at the peak of the daily afternoon sea breeze.

2.2.3 Groundwater and Dissolved Inorganic Nitrogen Input

Port Catherine Development Scheme

Groundwater inflow rates for the modelling of the Port Catherine development scheme were determined by specialist hydrogeologists Rockwater Pty Ltd (Rockwater) and are outlined in Rockwater (2000). The groundwater flows were taken to be slightly higher than the most likely value so as not to underestimate the flows. The concentration of DIN into the waterway of the Port Catherine development from the groundwater was supplied by BBG.

For the modelling of the Port Catherine development scheme, two scenarios were examined (refer to Section 1.2). The first scenario was the Port Catherine development scheme with groundwater extraction. An initial estimate of the amount of groundwater extraction required was determined using the concentration of DIN in the groundwater (supplied by BBG) and appropriate empirical methods. The empirical calculations suggested that a throughflow of 310 m^3/day (or extraction of 90% of the natural groundwater inflow into the development) is likely to result in acceptable water quality within the development waterway. It is proposed to use the extracted groundwater to irrigate various areas of Public Open Space. The excess groundwater will be injected into bores to the north of the development site. The effect of this disposal method of nutrient rich groundwater has been included in Rockwater's assessment of the various groundwater flows used in the modelling. Details of the methodology of the groundwater extraction and the disposal method can be found in Rockwater (2000).

The second scenario was the Port Catherine development scheme without groundwater extraction but with a lower level of DIN in the groundwater. This would be representative of the conditions after 7 to 12 years when the nutrient rich groundwater has been depleted.

The estimated daily inflow rate of groundwater and the concentration of DIN in the groundwater entering from the coast into the model domain for the two Port Catherine development cases are shown in Figures 2.4 and 2.5. Table 2.3 below shows a comparison of the groundwater inflow and DIN concentration entering the Port Catherine waterway prior to development, with groundwater extraction, and after the year 2012 with no groundwater extraction.

Table 2.3 – Groundwater and DIN Inputs

Scenario	Groundwater Flow	DIN Concentration
PCD Site Prior to Development	3,100 m^3/day	4.4 mg/L
PCD Option 7 with Groundwater Extraction	310 m^3/day	4.4 mg/L
PCD Option 7 in the year 2012 with No Groundwater Extraction	1,370 m^3/day	1 mg/L

In addition to the input of DIN from the groundwater, preliminary calculations suggested that the additional input of DIN from irrigable areas within the proposed development may be significant. As such, an estimate of the possible DIN input from these sources was included in the modelling. These estimates were based on a conservative 20% overwatering of the irrigable land and a DIN concentration of 1 mg/L (pers comm Richard Gorham, BBG).

The background concentration of DIN in Owen Anchorage used in the modelling of the Port Catherine development scheme was 0.025 mg/L (pers comm Richard Gorham, BBG). It should be noted that this value is appropriate for the nearshore waters of Owen Anchorage. The DIN concentration 1.2 km from the shore has been measured at less than half of this value.

Comparison Harbours

Groundwater inflow rates for the three comparison harbours were determined by Bowman Bishaw Gorham in conjunction with Rockwater. The input of DIN into the waterways of these harbours was estimated by Bowman Bishaw Gorham.

The estimated daily inflow rate of groundwater and the concentration of DIN in the groundwater entering from the coast into the model domain for each of the three comparison harbours are shown in Figures 2.6 to 2.8. Table 2.4 below shows a comparison of the groundwater inflow and DIN concentration entering the waterway of each harbour.

Table 2.4 – Groundwater and DIN Inputs

Harbour Site	Groundwater Flow	DIN Concentration
Hillarys Boat Harbour	1,150 m^3/day	3 mg/L
Success Boat Harbour	1,300 m^3/day	5 mg/L
Jervoise Bay Northern Harbour	4,800 m^3/day	13.6 mg/L

Table 2.4 indicates that the Jervoise Bay Northern Harbour has the highest input of groundwater and DIN, and that Hillarys Boat Harbour has the lowest input of groundwater and DIN.

The background concentration of DIN of the ocean waters used in the modelling of the comparison harbours was supplied by BBG and is shown in Table 2.5 below.

Table 2.5 – Background DIN Concentrations

Harbour Site	Background DIN
Hillarys Boat Harbour	0.015 mg/L
Success Boat Harbour	0.025 mg/L
Jervoise Bay Northern Harbour	0.025 mg/L

2.2.4 Boundary Conditions

Hydrodynamic modelling results documented in Department of Environmental Protection (1996) and Lord & Hillman (1995) suggest that the current regime in the nearshore waters of the Perth metropolitan area are predominantly shore parallel. From the limited current measurements available it was estimated that the nearshore currents would typically be less than 0.1 m/s.

In order to simulate the alongshore transport process the northern and southern boundaries were specified by real tide levels recorded in the Fremantle Fishing Boat Harbour (as described in Section 2.2.2) and the western boundary was made a no-flow boundary. The tide levels were checked to ensure that the water level throughout the model grid was essentially the same as the tide level applied at the model boundaries. The applied tide levels at the boundaries produced nearshore currents that were typically less than 0.1 m/s and were in general agreement with observations and measurements.

At the landward boundary, groundwater inflow (as per the rates described in Section 2.2.3 and Figures 2.4 to 2.8) was parameterised by a series of inflow points along the landward boundary. The vertical locations of these source points were alternated between mid-depth and the seabed along the land boundary. The inflow of groundwater was input in the lower half of the water column so as to artificially simulate the mixing which is known to occur behind the land / sea interface between the saltwater wedge and the groundwater.

2.2.5 Salinity and Temperature

Based on monitoring results documented in Department of Environmental Protection (1996), the background salinity of the ocean water used in the modelling was 35 ppt. The input groundwater inflows were assumed to be fresh and had a modelled salinity of 1 ppt.

For this modelling salinity was assumed to be the dominant descriptor of water density. In addition, it is believed that the likely variations in the temperature that would be experienced would only have a minor secondary effect on the hydrodynamics of the area modelled. Therefore, a constant temperature of 20°C for both the ocean water and the groundwater inflows was used in all of the modelled cases.

2.2.6 Other Parameters

A constant Chézy bed friction value of 50 was used in all of the model runs. The constant turbulent closure model with a constant value of 10^{-6} m^2/s in the vertical and 1 m^2/s in the horizontal was chosen. The values chosen for the bed friction and the turbulent closure model are typical of values that have been previously used in comparable model simulations.

The computational timestep for the Port Catherine Development and Hillarys Boat Harbour cases was 15 seconds. A timestep of 30 seconds was selected for the Success Boat Harbour and Jervoise Bay Northern Harbour cases.

2.3 Model Calibration and Verification

Calibration of Modelled DIN

Measurements of DIN were taken by Bowman Bishaw Gorham at Hillarys Boat Harbour, Success Harbour, and Jervoise Bay Northern Harbour on 10 occasions between January and March 2000. Using these measurements the horizontal diffusion co-efficient (which determines the rate of spreading of the DIN) in the Delft3D model was calibrated using these measurements.

The model was calibrated by adjusting the horizontal diffusion co-efficient until the concentration of DIN at the end of the warm-up period within the

Jervoise Bay Northern Harbour was slightly higher than the field measurements. The model was then run with the same horizontal diffusion co-efficient for Hillarys Boat Harbour and Success Harbour to ensure that the modelled DIN generally agreed with the field measurements. Table 2.6 below shows a comparison between the modelled DIN and the measured DIN for the three harbours for the calibrated horizontal diffusion co-efficient of 1 m^2/s.

Table 2.6 – Comparison of Modelled and Measured DIN

Harbour Site	Measured DIN	Modelled DIN
Hillarys Boat Harbour	0.02 mg/L	0.03 mg/L
Success Boat Harbour	0.01 mg/L*	0.04 mg/L
Jervoise Bay Northern Harbour	0.14 mg/L	0.16 mg/L

*NOTE: This value is less than the background DIN concentration in the ocean. It is believed that there may be some biological uptake of DIN within Success Harbour.

Verification of Modelled Salinity

Halpern Glick Maunsell (1998) conducted Conductivity Temperature Depth (CTD) measurements at the Jervoise Bay Northern Harbour. Relevant salinity transects from this report were examined and compared to the modelled salinity profiles to provide further confidence in the model results.

Figure 2.9 and 2.10 shows the measured and modelled salinity profile along a similar transect for the Jervoise Bay Northern Harbour. The transects shown in Figures 2.9 and 2.10 show that the model is capable of reproducing similar vertical and horizontal salinity structures observed in the Jervoise Bay Northern Harbour.

It should be noted that the salinity transect shown in Figure 2.9 is from a different period of time to that in Figure 2.10, and as such, the modelled transect is not expected to exactly replicate the field measurements. However, the general agreement between the measured and modelled horizontal and vertical salinity structure can be clearly seen. This suggests that the model can adequately reproduce the vertical structures observed in the field.

Discussion

These various comparisons with measured data provide confidence that the model is able to adequately represent the physical processes occurring in the various harbours and is therefore suitable for the comparison of the concentration of DIN between the harbours.

On the basis of this limited calibration and verification exercise it is believed that the Delft3D model has been correctly set-up and run for the three harbours. The modelled DIN concentrations tend to be slightly higher than the measured concentrations.

2.4 Harbour Flushing Times

A measure of the flushing time of the various waterways modelled can be determined by calculating the *e-folding* time. The *e-folding* time is the time taken for a known concentration of a conservative tracer to be reduced to $^1/_e$ of its original concentration (ie 37%).

For this modelling investigation, the e-folding time was determined by dosing the entire modelled waterway (ie excluding the ocean) with a known mass of conservative tracer. The model was then run and the concentration of the tracer recorded at the surface, mid-depth and seabed at several key locations within the modelled waterway. The concentration of tracer at each location was then plotted to determine the e-folding time for each of the modelled waterways.

It should be noted that the e-folding time is very much dependent on the prevailing conditions over the period which it is calculated. For instance, the e-folding time of a waterway would be significantly increased during periods of calm winds and low groundwater inflow. For the calculation of the e-folding time, real wind and tide conditions during December 1997 were used.

Imberger & Schwartz (1988) estimated from a dye tracer experiment at the Hillarys Boat Harbour that the e-folding time was about 5 days. The model results for the December 1997 conditions indicated that the e-folding time was about 4 days (refer to Section 3.3). This again shows that the model results are in reasonable agreement with available site measurements.

3. Model Results of Comparison Harbours

3.1 Jervoise Bay Northern Harbour

A spatial plot of the modelled DIN concentration in the surface layer for the Jervoise Bay Northern Harbour at the time 21:00, 9 January 1998 is shown in Figure 3.1. It should be noted that this plot only represents one snapshot in time, and that the model was run for 14 days in total to cover a spring / neap tidal cycle following the warm-up period. Figure 3.1 shows that there is a noticeable variation in the concentration of DIN within the harbour. The model results suggest that the highest concentration of DIN within the harbour is at the northern end (behind the skirt breakwater).

Figure 2.6 shows the location of 5 key locations within the Jervoise Bay Northern Harbour. Plots showing the variation in time of DIN at the surface, mid-depth, and at the bottom have been produced at these 5 locations. Decay curves at the surface, mid-depth, and bottom at these 5 locations have also been produced. For convenience, the percentage concentration equivalent to $^1/_e$ of the original concentration (ie 37%) is shown on the plots.

Figures 3.2 to 3.4 show the time history plots of DIN for locations 1, 4 and 5. Plots at the other locations can be found in Appendix B. Figures 3.2 and 3.3 show that the concentration at the northern end of the harbour (Location 1) is around 0.23 mg/L, and is around 0.16 to 0.17 mg/L near the southern end of the harbour (Location 4). Near the entrance (Location 5), the concentration of DIN is typically around 0.1 mg/L, but varies significantly with the tide (refer to Figure 3.4). With the exception of the entrance, the time history plots show that there is generally little variation in the concentration of DIN over the water column.

Decay curves at locations 1 and 4 are shown in Figures 3.5 to 3.6. Decay curves for the other locations are included in Appendix C. These decay curves suggest that the Jervoise Bay Northern Harbour has an e-folding time of around 10 to 11 days under the modelled conditions.

3.2 Success Harbour

Figure 3.1 shows a spatial plot of the modelled DIN concentration in the surface layer for Success Boat Harbour at the time 21:00, 9 January 1998. It should be noted that this plot only represents one snapshot in time, and that the model was run for 14 days after the warm-up period. Figure 3.1 shows that there is very little variation in the concentration of DIN throughout the harbour. An interesting point to note is that the model results suggest that the DIN concentration in the Fremantle Fishing Boat Harbour (located immediately north of Success Harbour) is around 0.1 mg/L throughout the harbour.

Figure 2.7 shows the location of 4 key locations within Success Harbour. Plots showing the variation in time of DIN at the surface, mid-depth, and at the bottom have been produced at these 4 locations. Decay curves at the surface, mid-depth, and bottom at these 4 locations have also been produced. For convenience, the percentage concentration equivalent to 1/e of the original concentration is shown on the plots.

Figures 3.7 and 3.8 show the time history plots of DIN for locations 1 and 4 inside Success Harbour. Plots at the other locations have been included in Appendix B. Figures 3.7 and 3.8 show that the modelled concentration of DIN at the southern end of Success Harbour (Location 4) is generally marginally higher than at the entrance (Location 1). The time history plots typically indicate that the modelled DIN concentration in Success Harbour is around 0.04 to 0.05 mg/L and that there is very little variation in DIN over time and over the water column at all of the key locations.

A decay curve of the southern end of Success Harbour (Location 4) is shown in Figure 3.9. Decay curves for the other locations are included in Appendix C. These decay curves suggest that Success Harbour has an e-folding time in the order of 1 day under the modelled conditions. Intuitively, this e-folding time seems to be too small. However, closer examination shows that the orientation of the harbour entrance and the geometry of the harbour favours water exchange under the land / sea breeze conditions experienced in the period that the e-folding time was calculated. Empirical calculations also suggest that the e-folding time could be in the order of 1 day under the wind conditions modelled.

3.3 Hillarys Boat Harbour

Figure 3.1 shows a spatial plot of the modelled DIN concentration in the surface layer for Hillarys Boat Harbour at the time 21:00, 9 January 1998. It should be noted that this plot only represents one snapshot in time, and that the model was run for 14 days after the warm-up period. Figure 3.1 shows that the modelled DIN in the harbour is around 0.02 to 0.03 mg/L and that there is very little variation in the concentration of DIN throughout the harbour. It should be noted that the background DIN concentration used in the Hillarys Boat Harbour modelling is 0.01 mg/L (ie 0.015 mg/L instead of 0.025 mg/L) less than at the other harbour sites.

Figure 2.8 shows the location of 5 key locations within Hillarys Boat Harbour. Plots showing the variation in time of DIN at the surface, mid-depth, and at the bottom have been produced at these 5 locations. Decay curves at the surface, mid-depth, and bottom at these 5 locations have also been produced. For convenience, the percentage concentration equivalent to $^1/_e$ of the original concentration (ie 37%) is shown on the plots.

Figure 3.10 shows the time history plot of DIN at location 2 inside Hillarys Boat Harbour. Plots at the other locations have been included in Appendix B. In general, these time history plots indicate that the modelled DIN concentration in Hillarys Boat Harbour is around 0.03 mg/L and that there is very little variation in DIN over time and over the water column at each of the 5 locations.

A plot of the decay curve at location 2 is shown in Figure 3.11. Decay curves at the other locations can be found in Appendix C. These decay curves suggest that Hillarys Boat Harbour generally has an e-folding time of around 4 days under the modelled conditions. These plots also suggest that there is very little variation in the e-folding time at different locations within Hillarys Boat Harbour, except near the entrance (Location 5). As discussed in Section 2.4, the modelled e-folding time agrees well with the field measurements at Hillarys Boat Harbour reported in Schwartz & Imberger (1988).

3.4 Discussion

The range of modelled DIN concentrations within the three comparison harbours is shown below in Table 3.1.

Table 3.1 – Range of Modelled DIN Concentrations

Waterway	Min DIN	Max DIN
Hillarys Boat Harbour	0.019 mg/L	0.034 mg/L
Success Harbour	0.035 mg/L	0.048 mg/L
Jervoise Bay Northern Harbour	0.072 mg/L	0.239 mg/L

There has been significant concern about the water quality in Jervoise Bay Northern Harbour and general acceptance of the water quality in Hillarys and Success Harbours. Based on this and the results in Table 3.1 it is suggested that the limiting concentration of DIN be set between 0.05 and 0.07 mg/L. However, the limit for DIN in the proposed Port Catherine development will be taken to be 0.05 mg/L to provide additional security that excessive algal growth does not occur.

4. Model Results of Port Catherine Development Scheme

4.1 PCD Option 7 - 310 m^3/day Throughflow

A spatial plot of the modelled DIN concentration in the surface layer for the Port Catherine development Option 7 scheme (with 310 m^3/day throughflow of groundwater after extraction) during ebb tide is shown in Figure 4.1. It should be noted that this plot only represents one snapshot in time, and that the model was run for 14 days in total to cover a spring/neap tidal cycle following the warm-up period. Figure 4.1 shows that the concentration of DIN in the development waterway is less than 0.05 mg/L and that there is very little variation in the concentration of DIN throughout the development.

A comparison of the proposed Port Catherine development with the three comparison harbours at the time 21:00, 9 January 1998 is shown in Figure 3.1. Figure 3.1 shows that the concentration of DIN in the Port Catherine development allowing 310 m^3/day throughflow of groundwater is comparable to the concentration of DIN in both Hillarys and Success Harbours, and significantly lower than the modelled DIN in the Jervoise Bay Northern Harbour.

Figure 2.4 shows the location of 7 key locations within the proposed Port Catherine development scheme. Plots showing the variation in time of DIN at the surface, mid-depth, and at the bottom have been produced at these 7 locations. Decay curves at the surface, mid-depth, and bottom at these 7 locations has also been produced. For convenience, the percentage concentration equivalent to 1/e of the original concentration is shown on the plots.

Figures 4.1 to 4.2 show the time history plots of DIN at the eastern end of the northern most residential canal (Location 1) and at the southern end of the marina (Location 7). Plots at the other key locations are included in Appendix B. These plots show that the DIN concentration is marginally higher at the eastern end of the two residential canals than in the main marina area. These time history plots also show that in general, the modelled DIN concentration in the waterway of the proposed Port Catherine development is between 0.035 and 0.045 mg/L and that there is very little variation in DIN over time and over the water column at each of the 7 locations.

Decay curves at locations 1 and 7 are shown in Figures 4.3 and 4.4. These decay curves suggest that the eastern end of the northern most canal (Location 1) has an estimated e-folding time of around 4 to 5 days under the modelled conditions. The main marina area, which is expected to have better water exchange, is estimated to have an e-folding time in the order of 2 to 3 days under the modelled conditions.

4.2 PCD Option 7 – 2012 Case

A spatial plot of the modelled DIN concentration in the surface layer for the Port Catherine development Option 7 scheme (in 12 years time) during ebb tide is shown in Figure 4.2. It should be noted that this plot only represents one snapshot in time, and that the model was run for 14 days after the warm-up period. Figure 4.2 shows that the concentration of DIN in the development waterway is less than 0.05 mg/L and that there is very little variation in the concentration of DIN throughout the development.

A comparison of the proposed Port Catherine development with the three comparison harbours at the time 21:00, 9 January 1998 is shown in Figure 3.1. Figure 3.1 shows that the concentration of DIN in the Port Catherine development in about 12 years time is comparable to the concentration of DIN in both Hillarys and Success Harbours, and much lower than the modelled DIN in the Jervoise Bay Northern Harbour.

Figure 2.5 shows the location of 7 key locations within the proposed Port Catherine development scheme. Plots showing the variation in time of DIN at the surface, mid-depth, and at the bottom have been produced at these 7 locations. The decay curves for this case is the same as for the groundwater extraction case (refer to Figures 4.1 and 4.2, and Appendix C).

Figures 4.5 to 4.6 show the time history plots of DIN at locations 1 and 7 inside the proposed Port Catherine development waterway. Plots of DIN at the other locations can be found in Appendix B. In general, these time history plots indicate that the modelled DIN concentration in the waterway of the proposed Port Catherine development is between 0.03 and 0.045 mg/L and that there is very little variation in DIN over time and over the water column at each of the 7 locations. These plots also show that the DIN concentration is only marginally higher at the eastern end of the two residential canals than in the main marina area.

5. Conclusions & Recommendations

A detailed water quality modelling study of the proposed Port Catherine Option 7 scheme has been completed. This study involved the set-up, calibration and verification of the Delft3D hydrodynamic and transport model to simulate the proposed development waterway allowing a throughflow of 310 m^3/day of nitrogen rich groundwater, and the proposed development waterway without groundwater extraction in about 12 years time. Because of the difficulty in defining a precise level of Dissolved Inorganic Nitrogen (DIN) which excessive algal growth could be expected to occur, modelling of several established harbours within the Perth Metropolitan area was also undertaken as part of this study in order to better define an acceptable level of DIN.

The results of this modelling study indicates that the proposed Port Catherine Development Option 7 scheme can achieve acceptable water quality similar to the harbours already established in the Perth Metropolitan area which have good water quality. A summary of how the proposed Port Catherine Development Option 7 scheme performs (in terms of concentration of DIN) against the other modelled harbours is shown in Table 5.1 below.

Table 5.1 – Comparison of Model Results

Waterway	Ave DIN (mg/L)	Min DIN (mg/L)	Max DIN (mg/L)
Hillarys Boat Harbour[1]	0.029	0.019	0.034
PCD Option 7 – 2012 Case	0.038	0.033	0.041
PCD Option 7 – With Extraction	0.041	0.036	0.045
Success Harbour	0.041	0.035	0.048
Jervoise Bay Northern Harbour	0.161	0.072	0.239

NOTES: 1. The background DIN concentration at Hillarys is 0.015 mg/L. The background DIN concentration used at the other harbours was 0.025 mg/L.

The results of the modelling demonstrates that, with the proposed management techniques, the water quality in the waterway of the proposed Port Catherine Development will be comparable to both Hillarys and Success Harbours (which are generally regarded as having good water quality). The proposed management techniques will involve extracting nitrogen rich groundwater (allowing only 310 m^3/day throughflow) for the next 7 to 12 years. The groundwater extraction can be ceased in about 7 to

12 years when the elevated levels of nitrogen in the groundwater have completely passed through the system.

In addition to the proposed groundwater extraction scheme to actively manage the inflow of nutrient rich groundwater, it is proposed to develop practical and detailed contingency plans. These could include:

- Increased groundwater extraction rates,
- Enhanced water exchange with the ocean using pipes and pumps, and
- Enhanced mixing using pumps or propeller wash.

It is recommended that these contingency plans be sufficiently developed and implemented to allow a rapid response should they be required.

6. References

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Figures

Figure 1.1 – Location Diagram

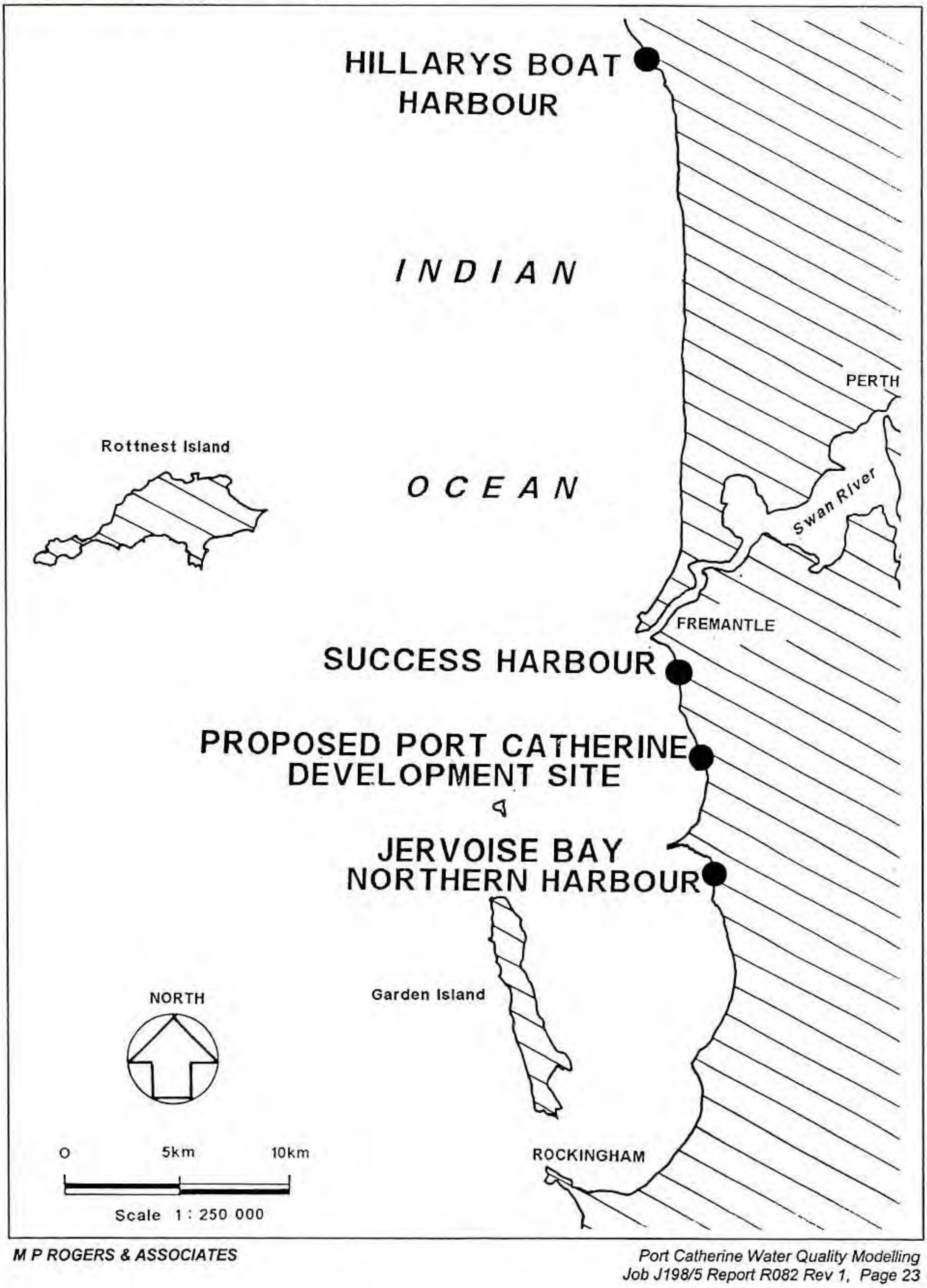
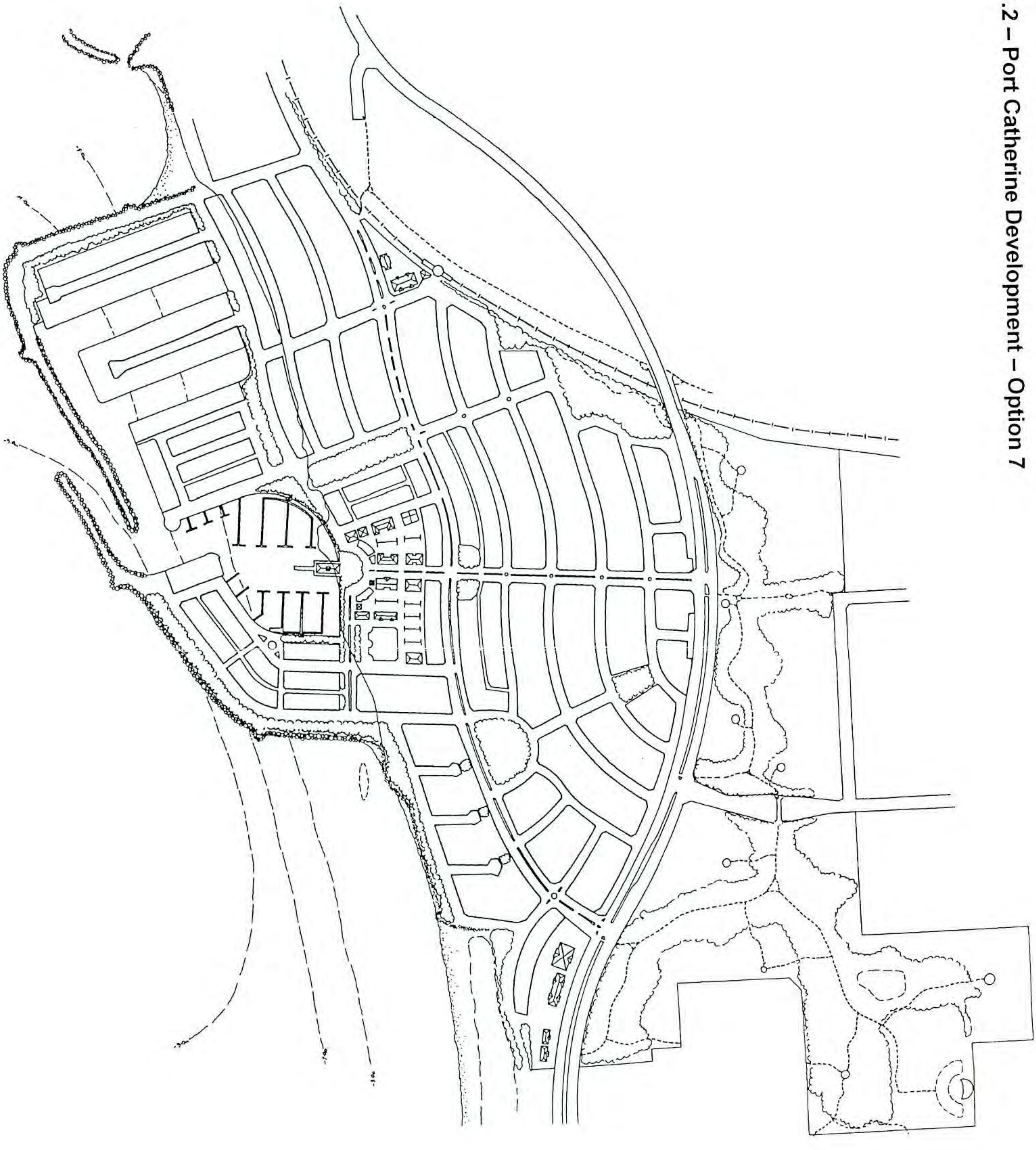


Figure 1.2 – Port Catherine Development – Option 7



Client	Date	Plan No.	North
Australand	July, 2000	90/57/52	

Scale 0 50 100 150 200m

PORT CATHERINE
OUTLINE DEVELOPMENT PLAN

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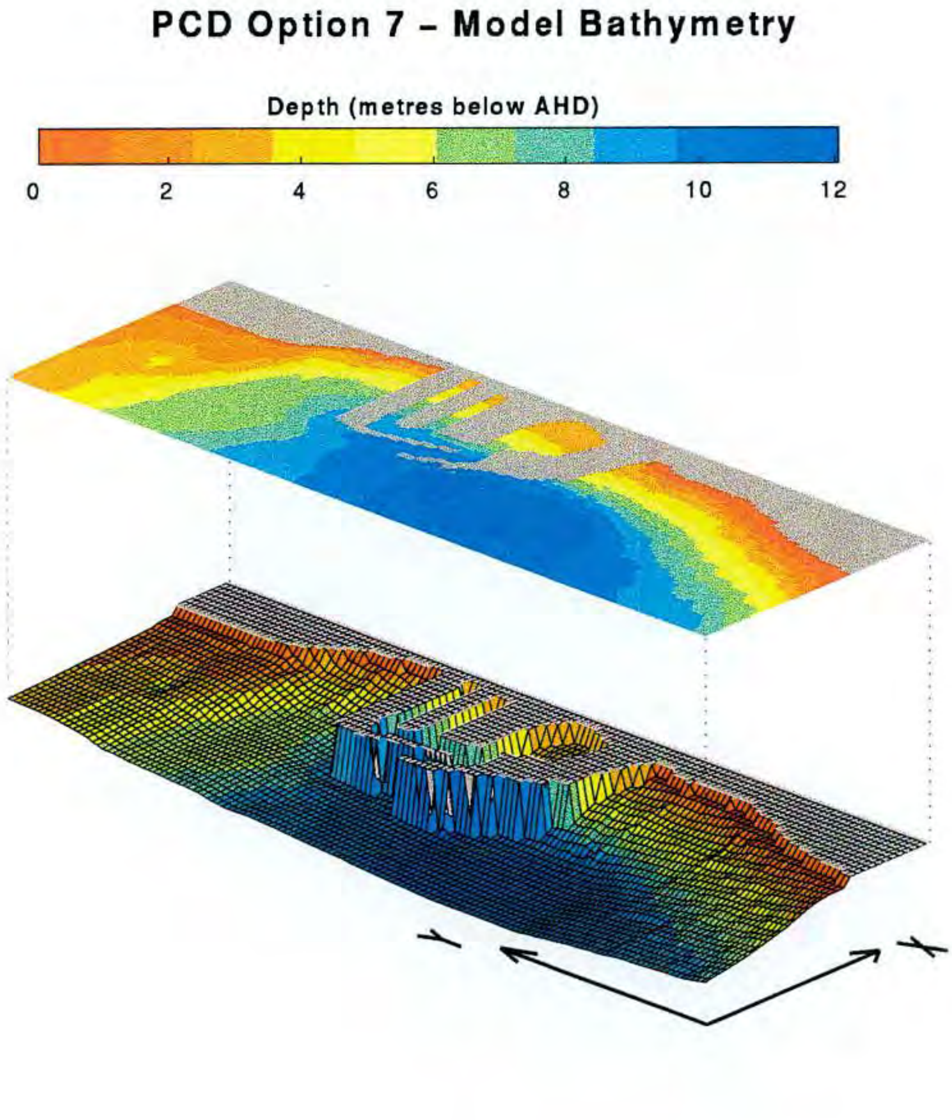
Figure 2.1 – Port Catherine Development Option 7 Model Bathymetry



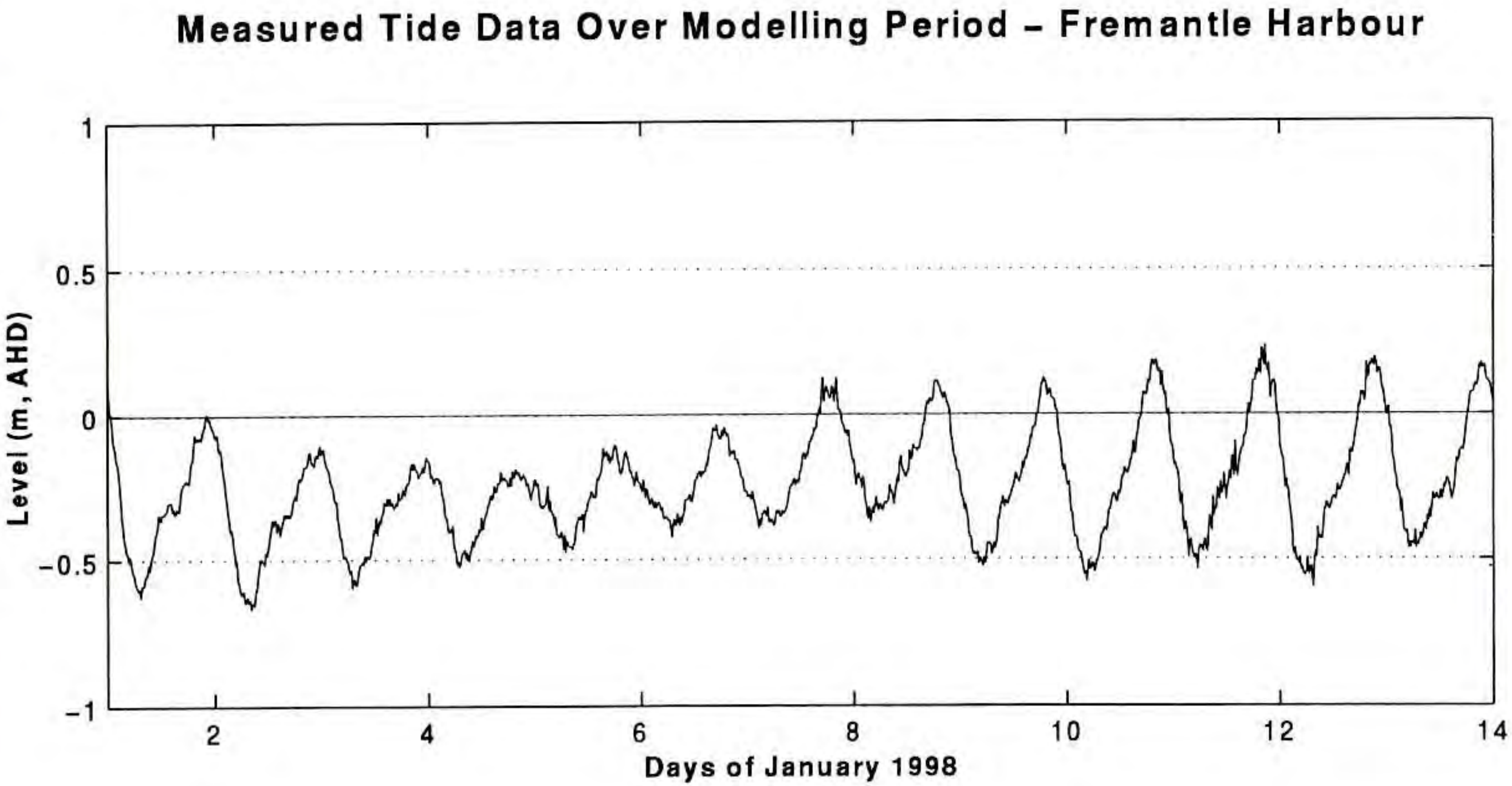
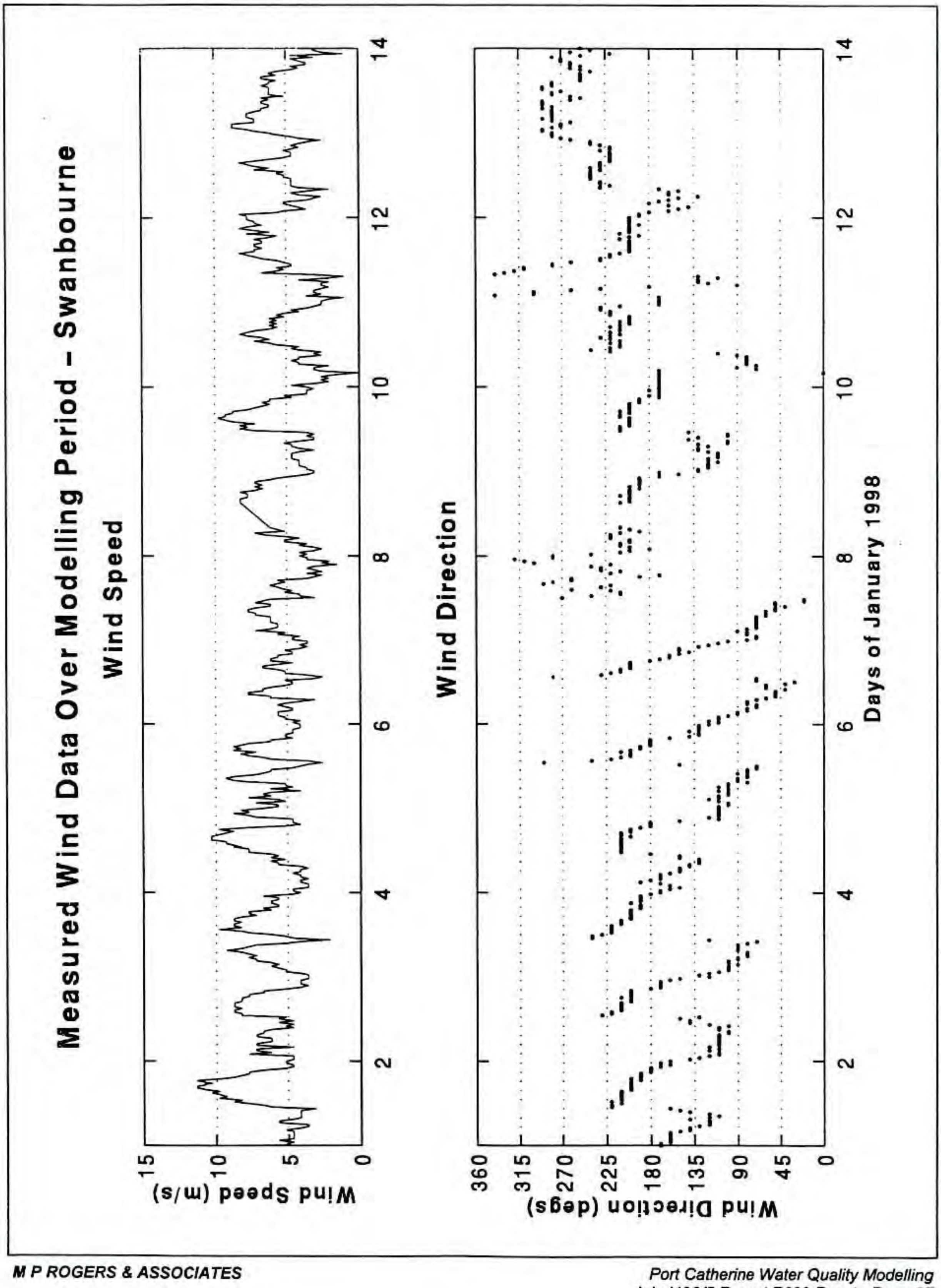


Figure 2.2 – Input Tide Data for Model Runs

Figure 2.3 – Input Wind Data for Model Runs



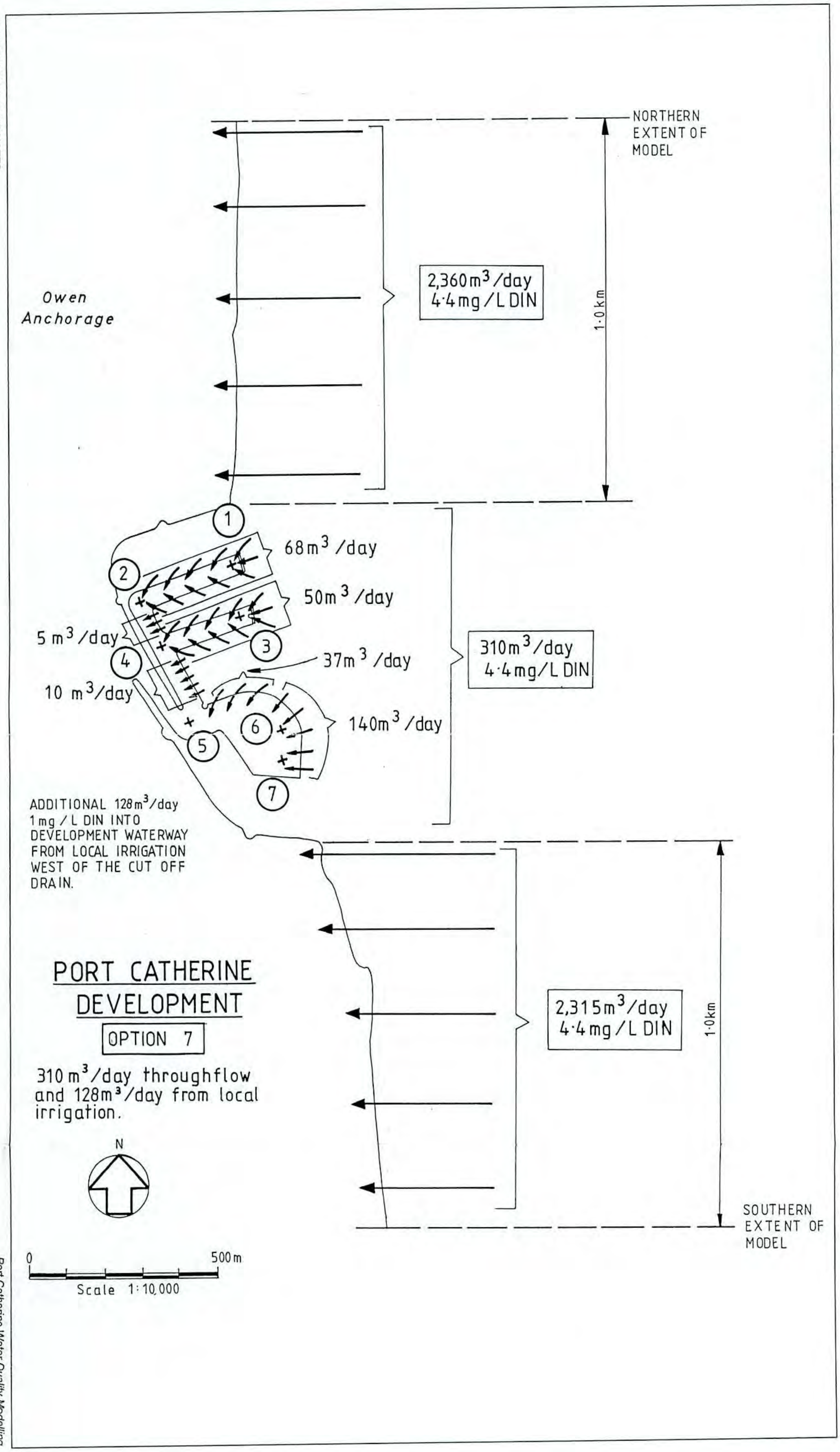


Figure 2.4 – Port Catherine Development Option 7 (310 m³/day Throughflow) Inflows and Location of Key Points

Figure 2.5 – Port Catherine Development Option 7 (2012 Case) Inflows and Location of Key Points

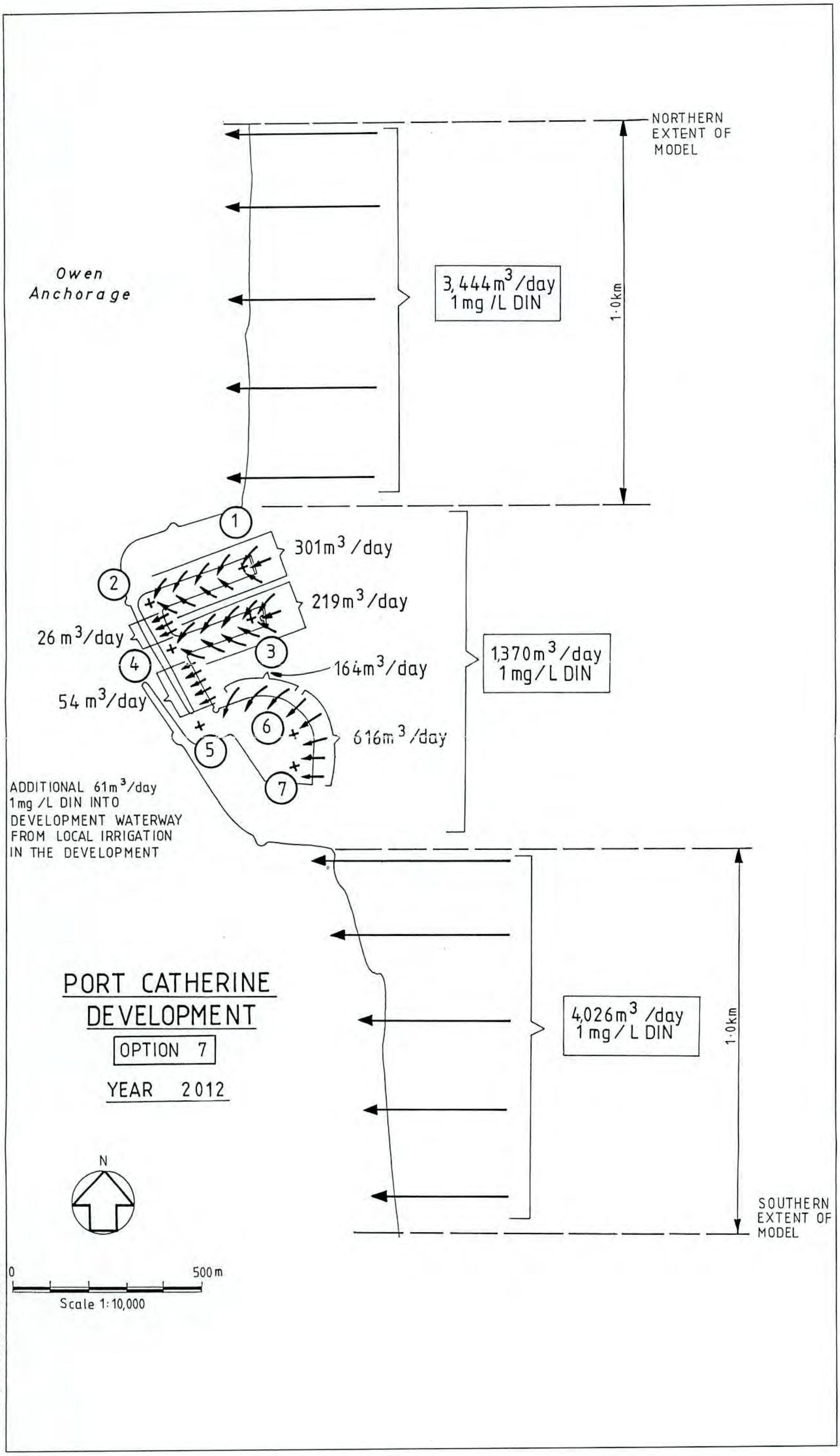


Figure 2.6 – Jervoise Bay Northern Harbour Inflows and Location of Key Points

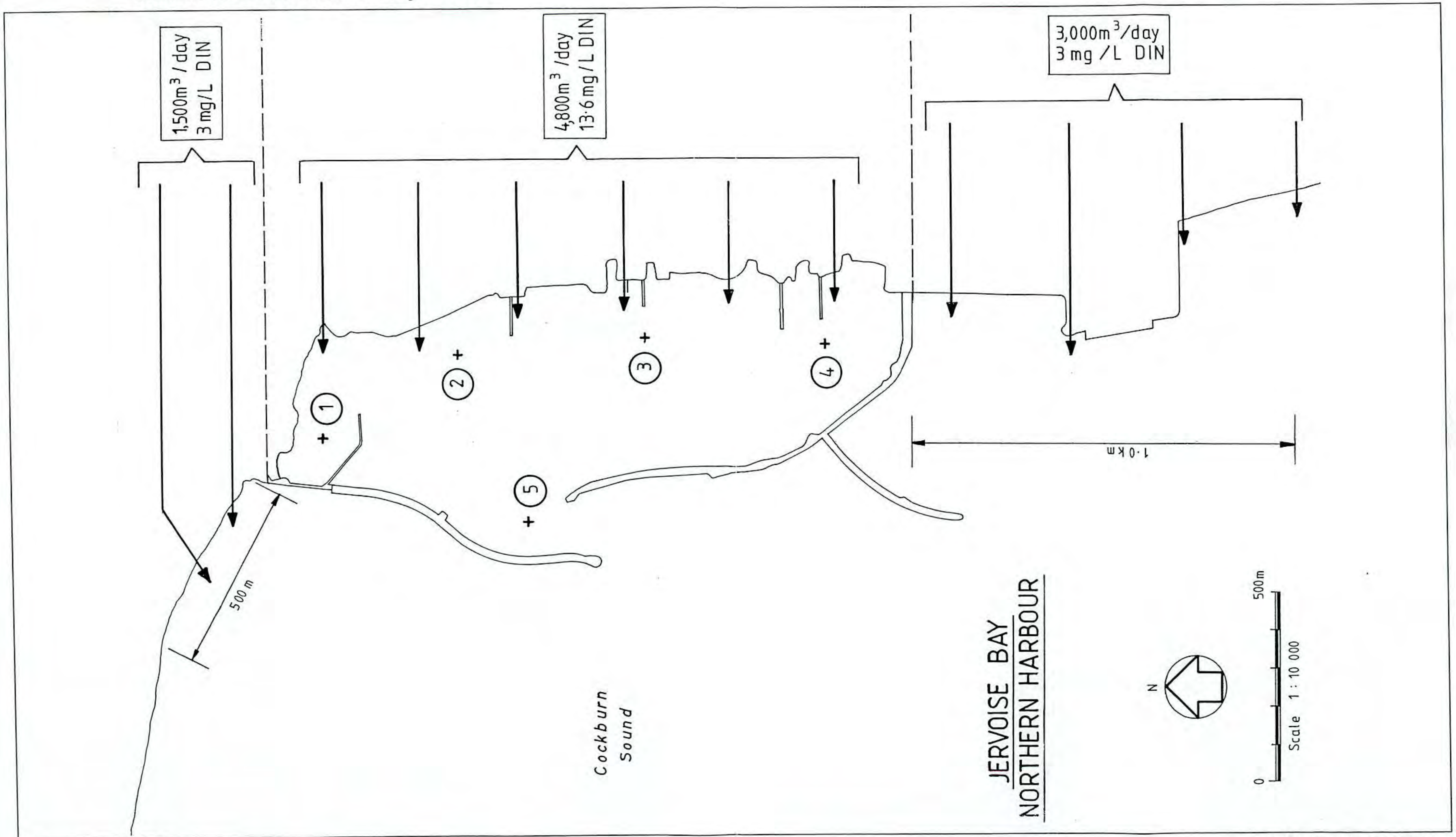


**Figure 2.7 – Success Harbour
Inflows and Location of Key Points**

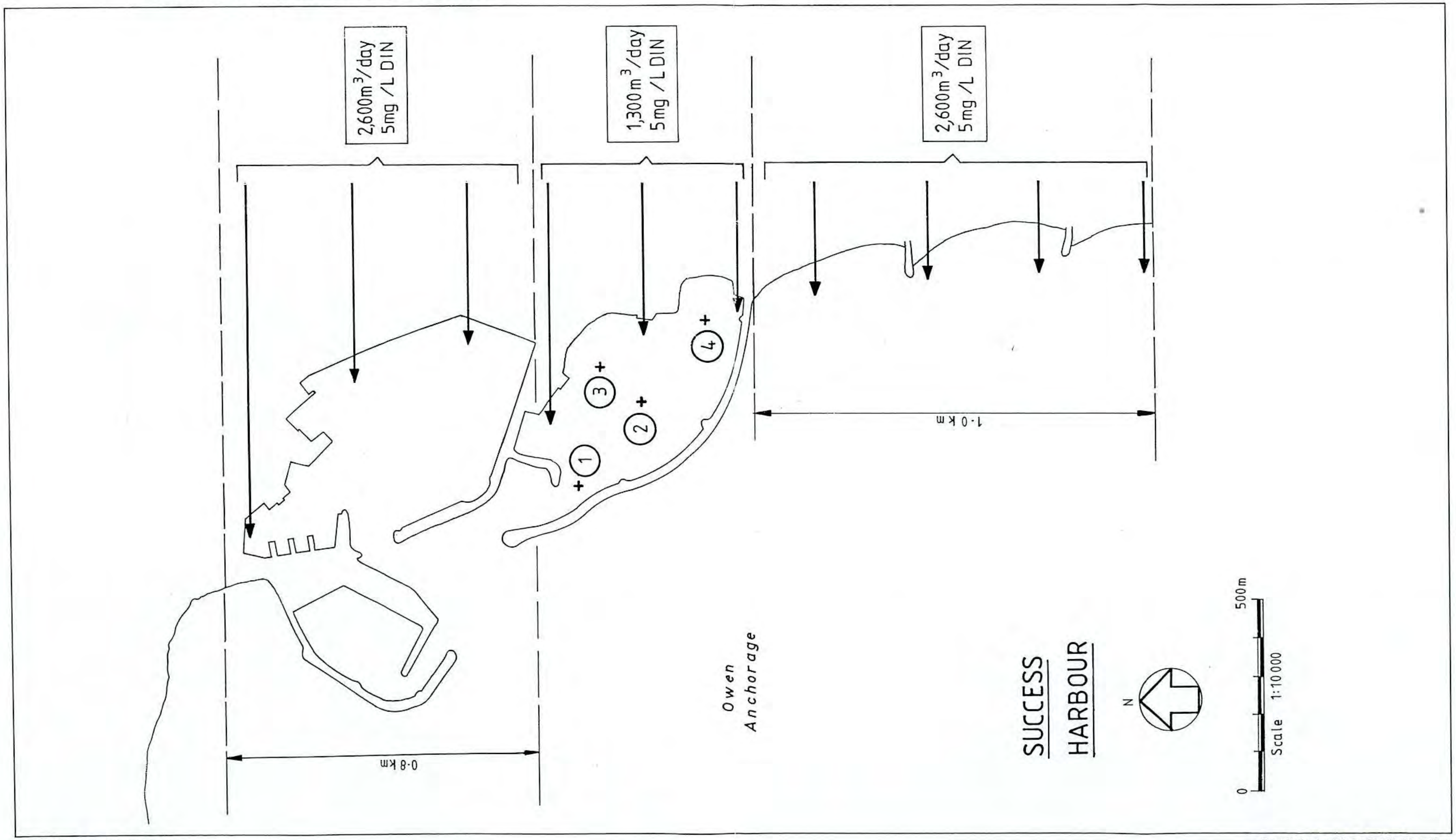


**Figure 2.8 – Hillarys Boat Harbour
Inflows and Location of Key Points**

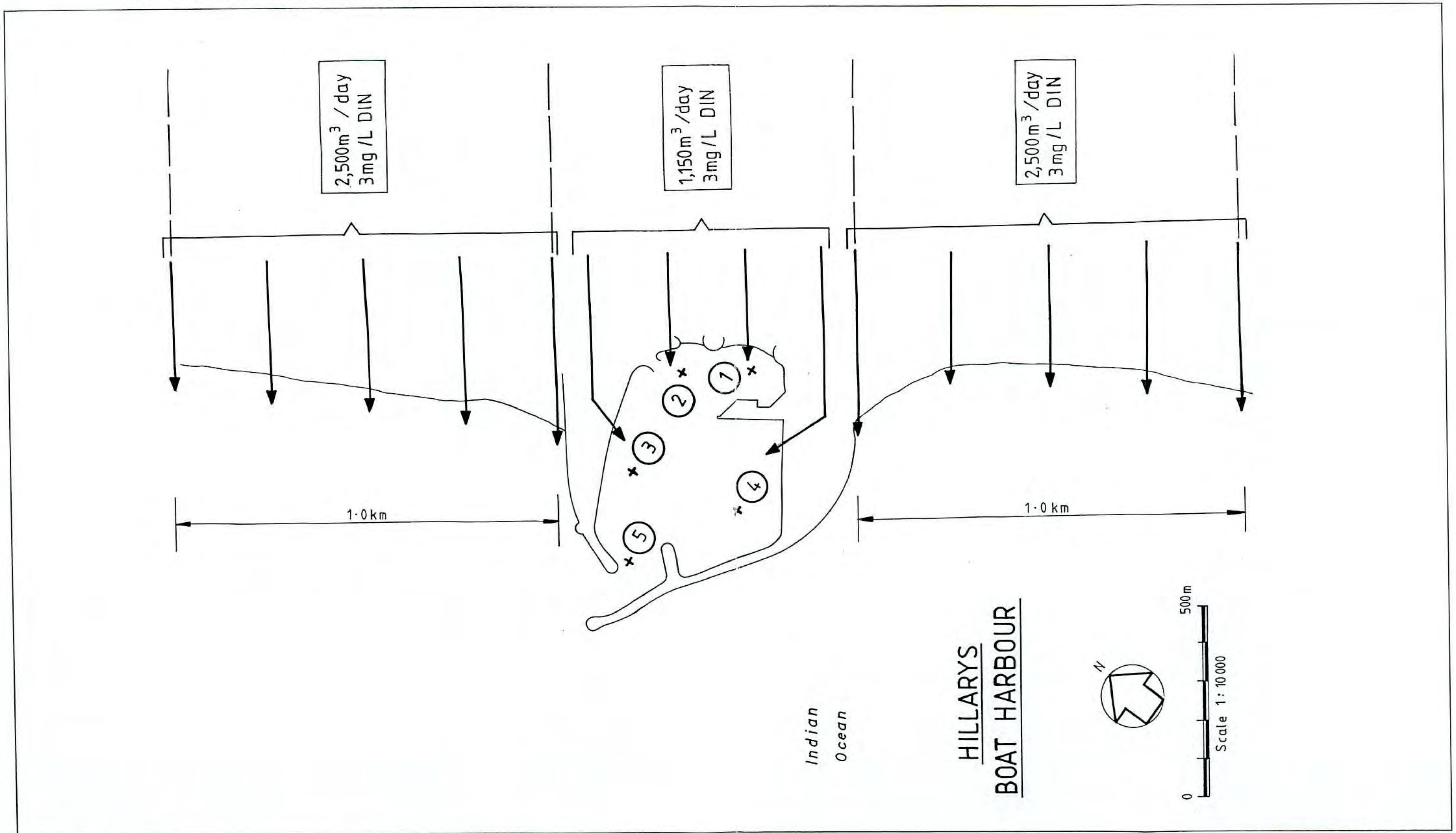
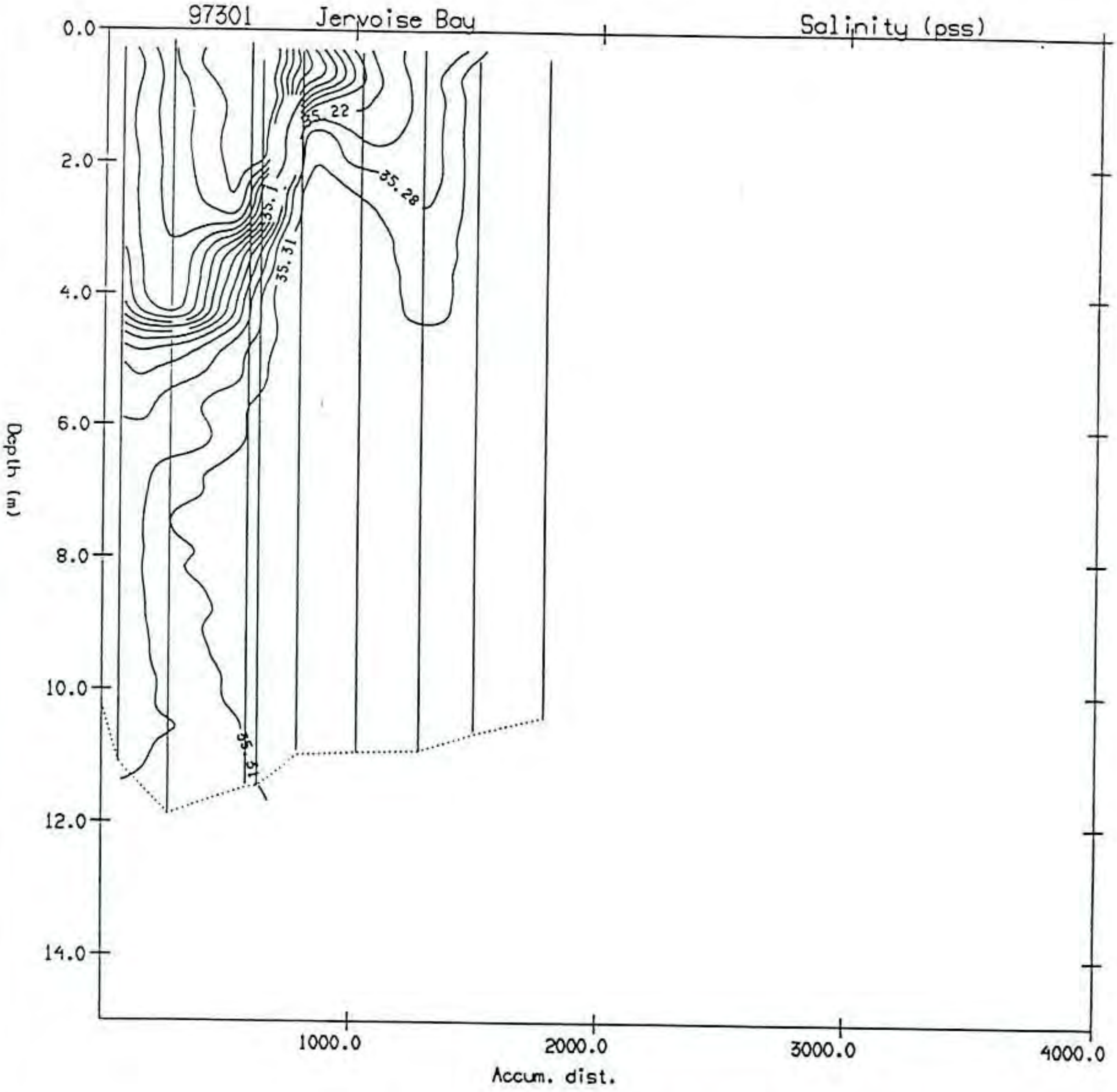


Figure 2.9 – Jervoise Bay Northern Harbour Measured Salinity Transect



CTD Transect #2 - westward from Northern Harbour shoreline through harbour entrance - 28 October 1997

Source: Halpern Glick Mausell (1997)

Figure 2.10 – Jervoise Bay Northern Harbour Modelled Salinity Transect

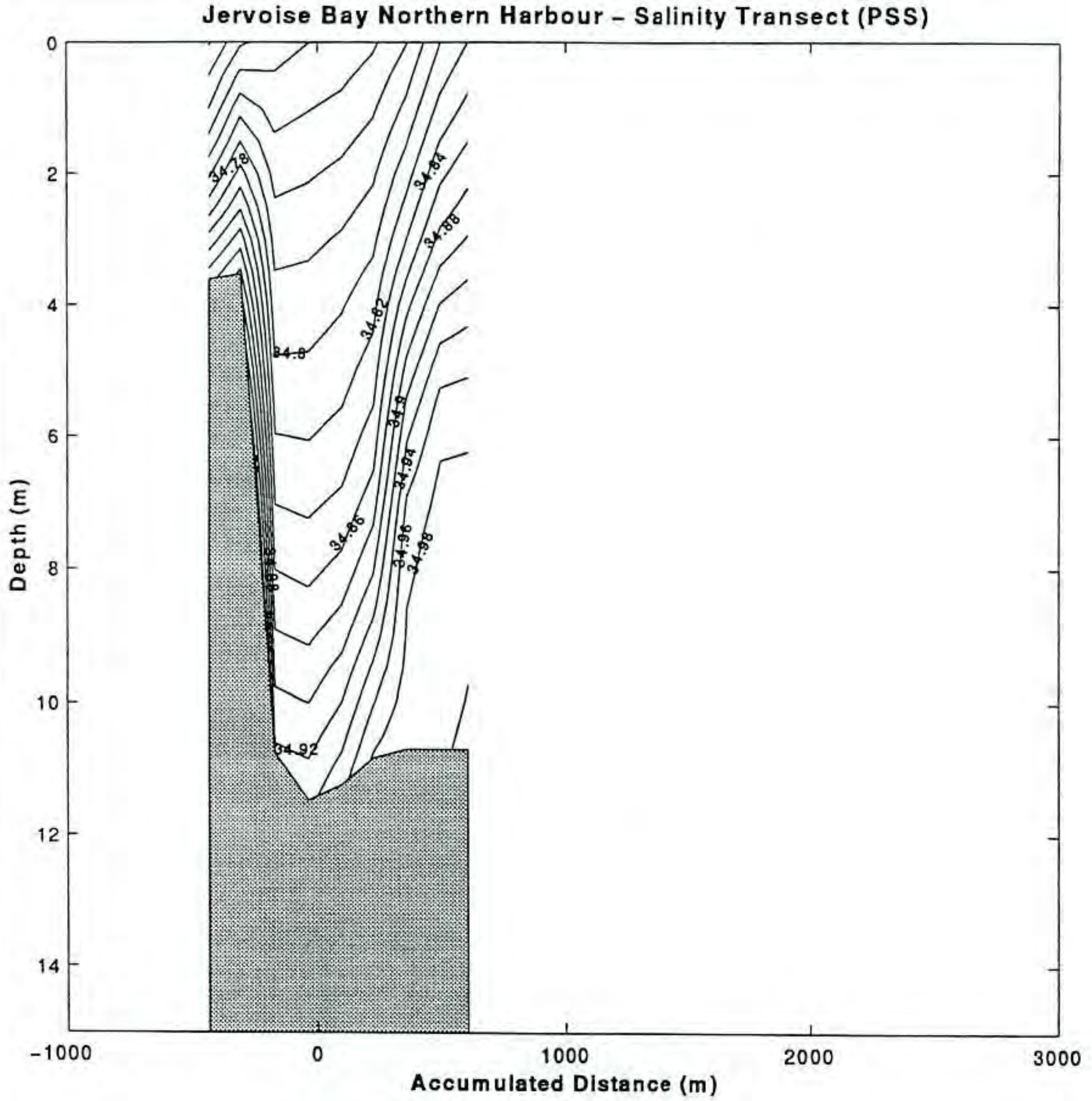


Figure 3.1 – Comparison of Modelled Waterways
Spatial Concentration of DIN – 21:00 9/01/98

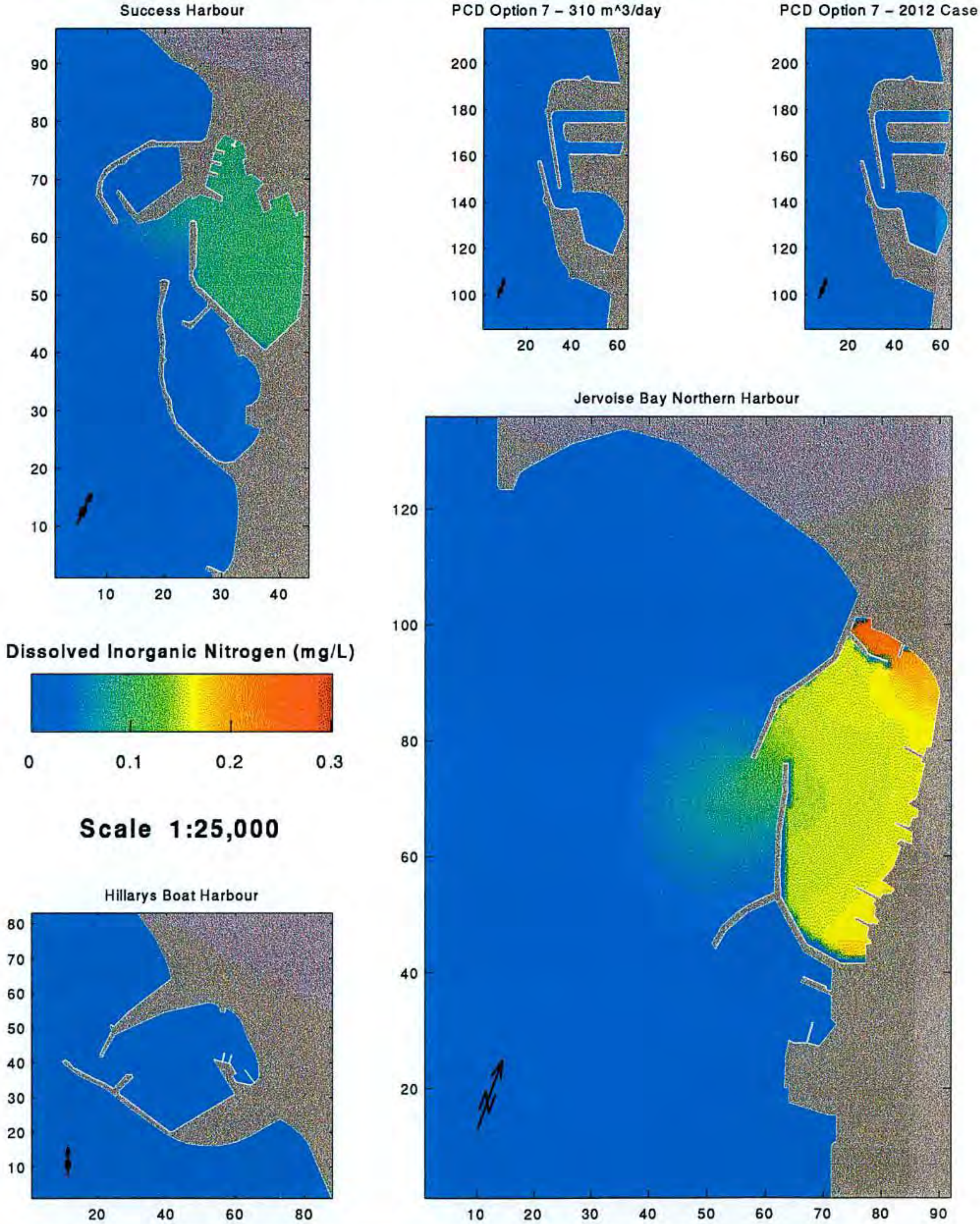


Figure 3.2 – Jervoise Bay Northern Harbour
Time History of DIN – Location 1

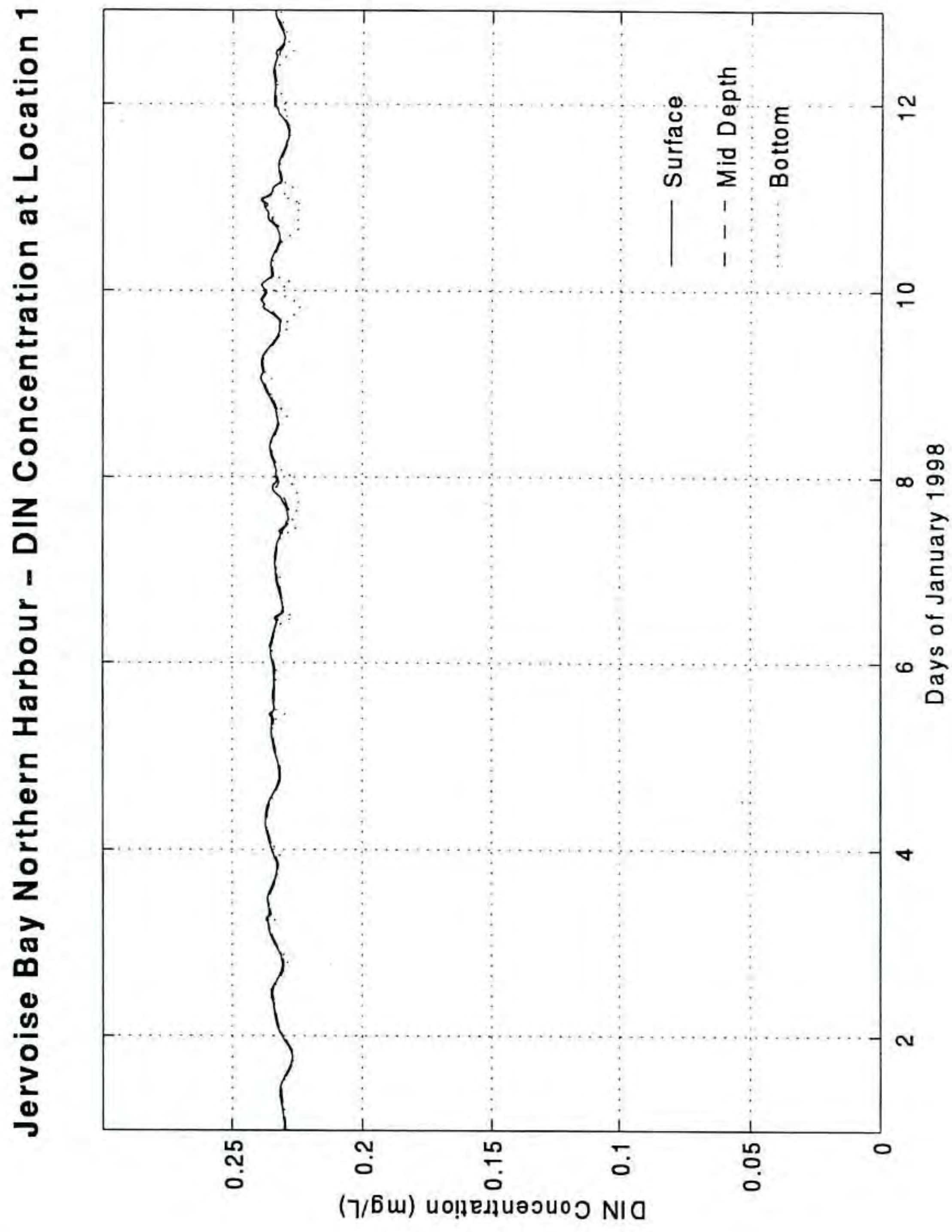
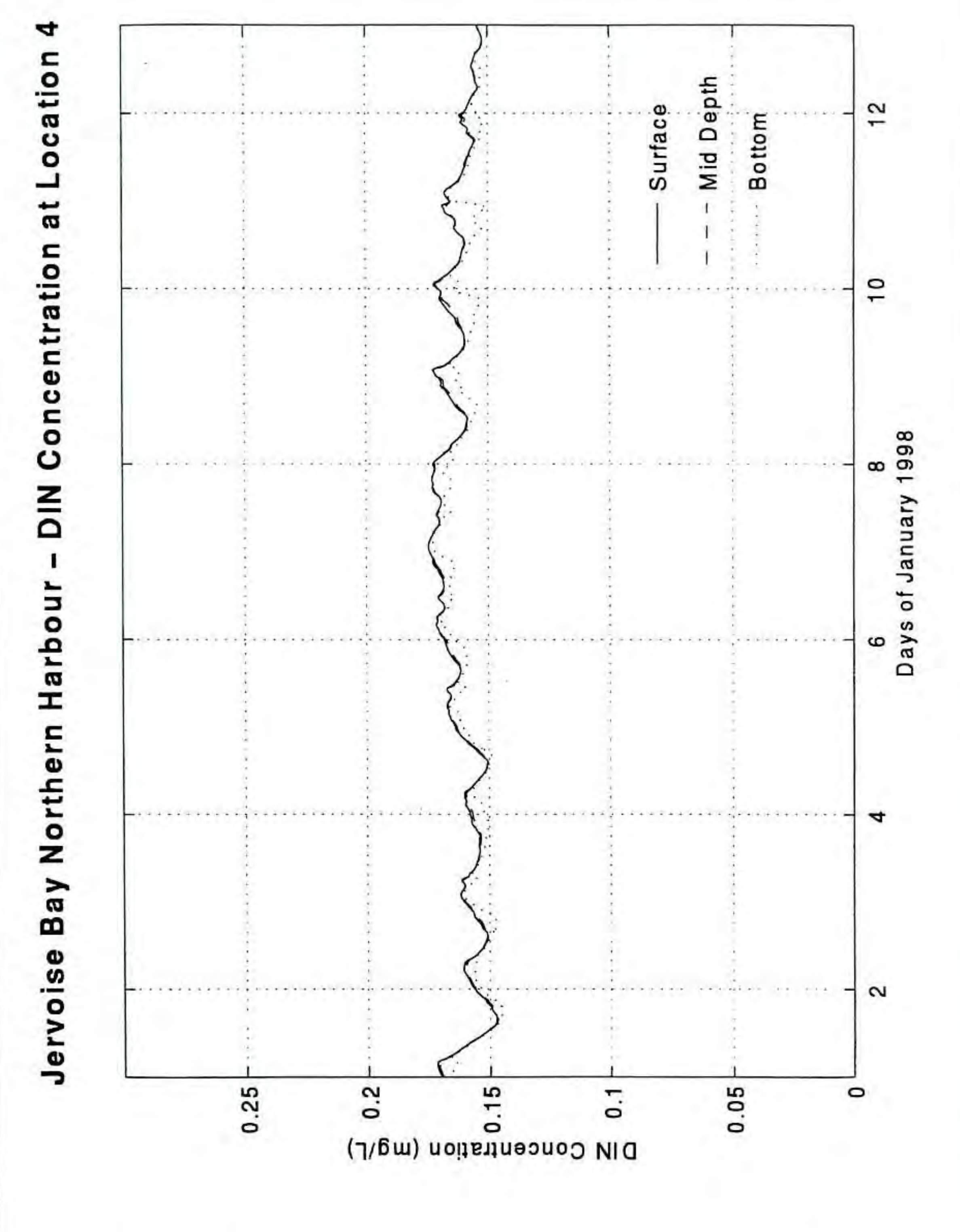


Figure 3.3 – Jervoise Bay Northern Harbour
Time History of DIN – Location 4



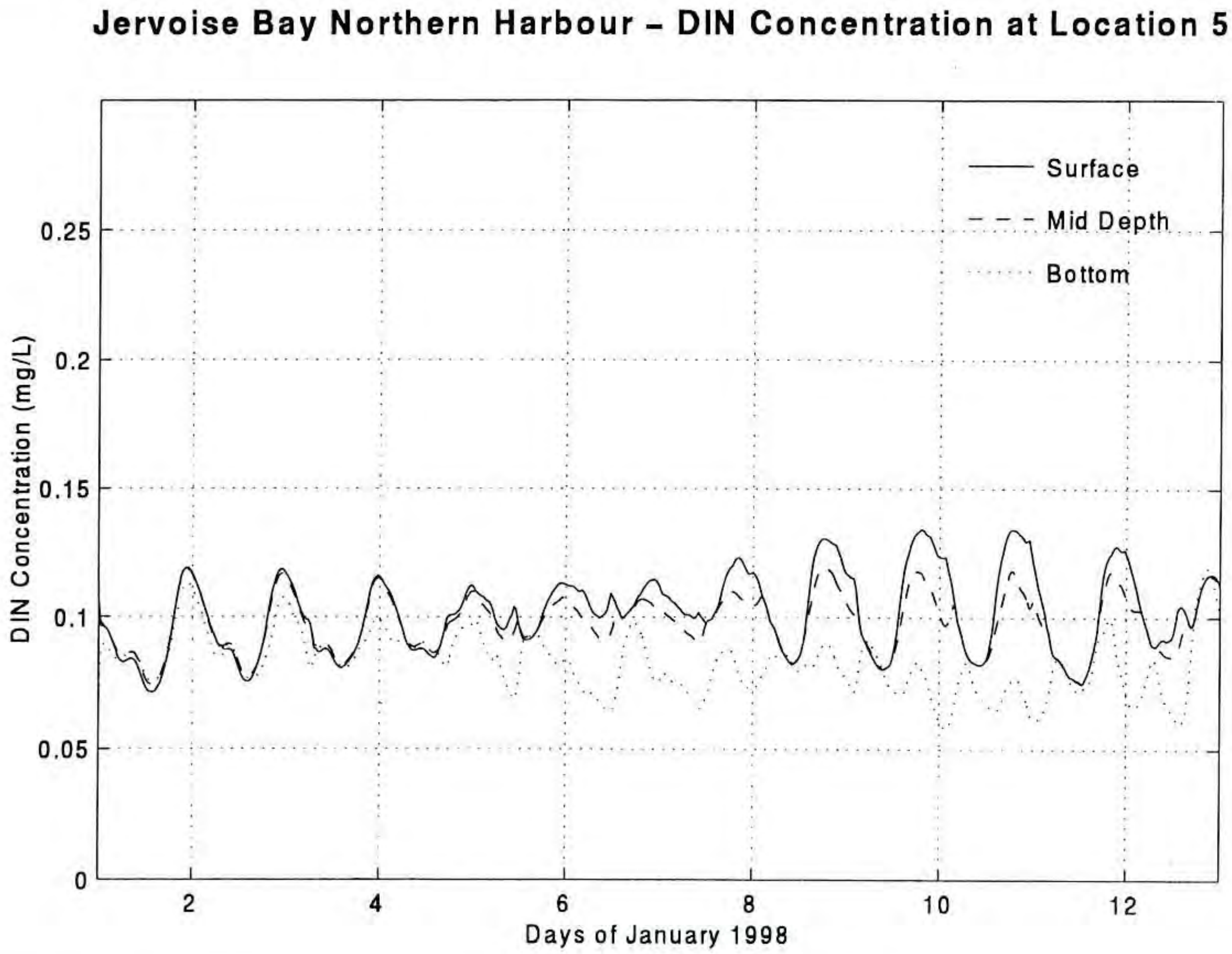


Figure 3.4 – Jervoise Bay Northern Harbour
Time History of DIN – Location 5

Figure 3.5 – Jervoise Bay Northern Harbour
Decay Curves – Location 1

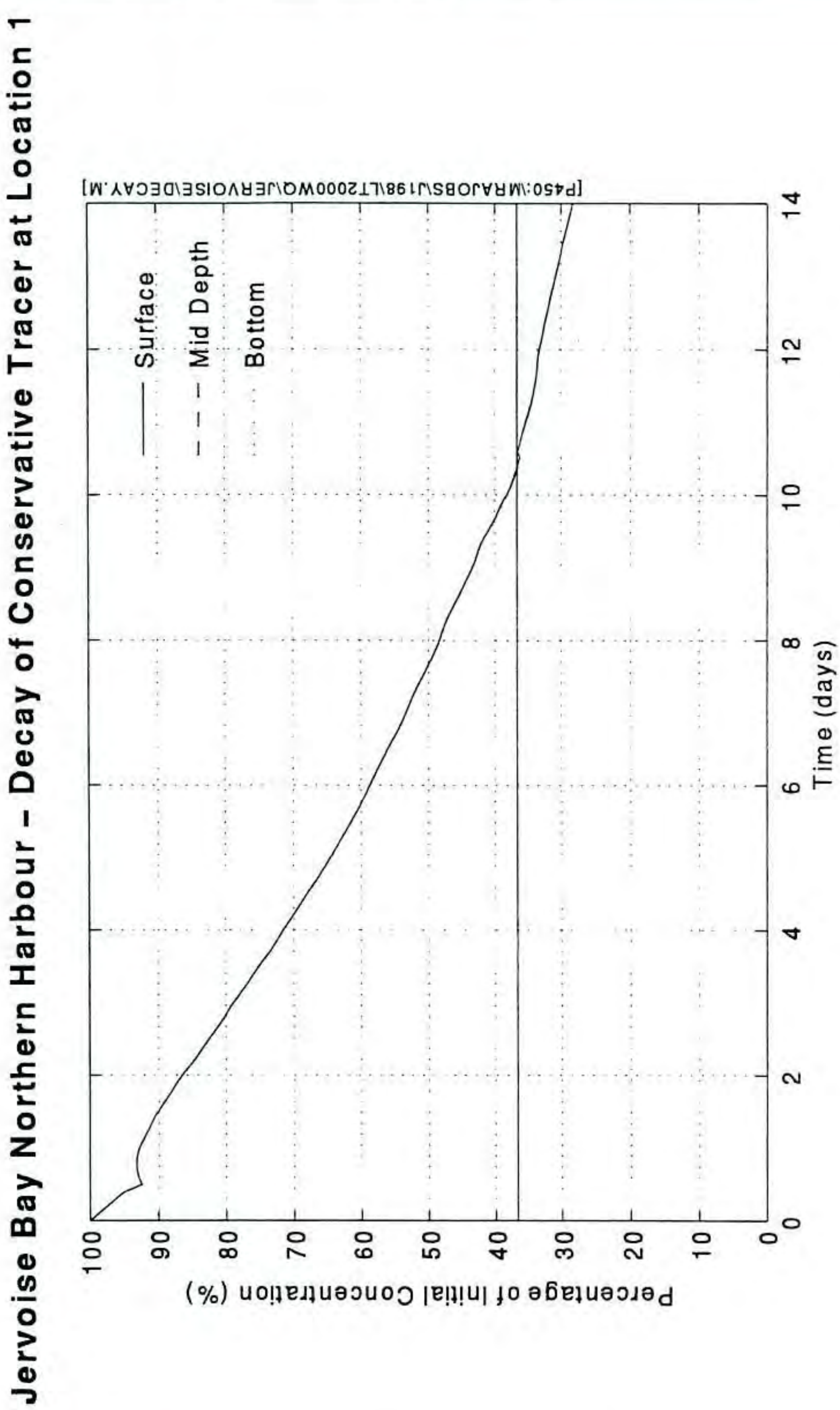


Figure 3.6 – Jervoise Bay Northern Harbour Decay Curves – Location 4

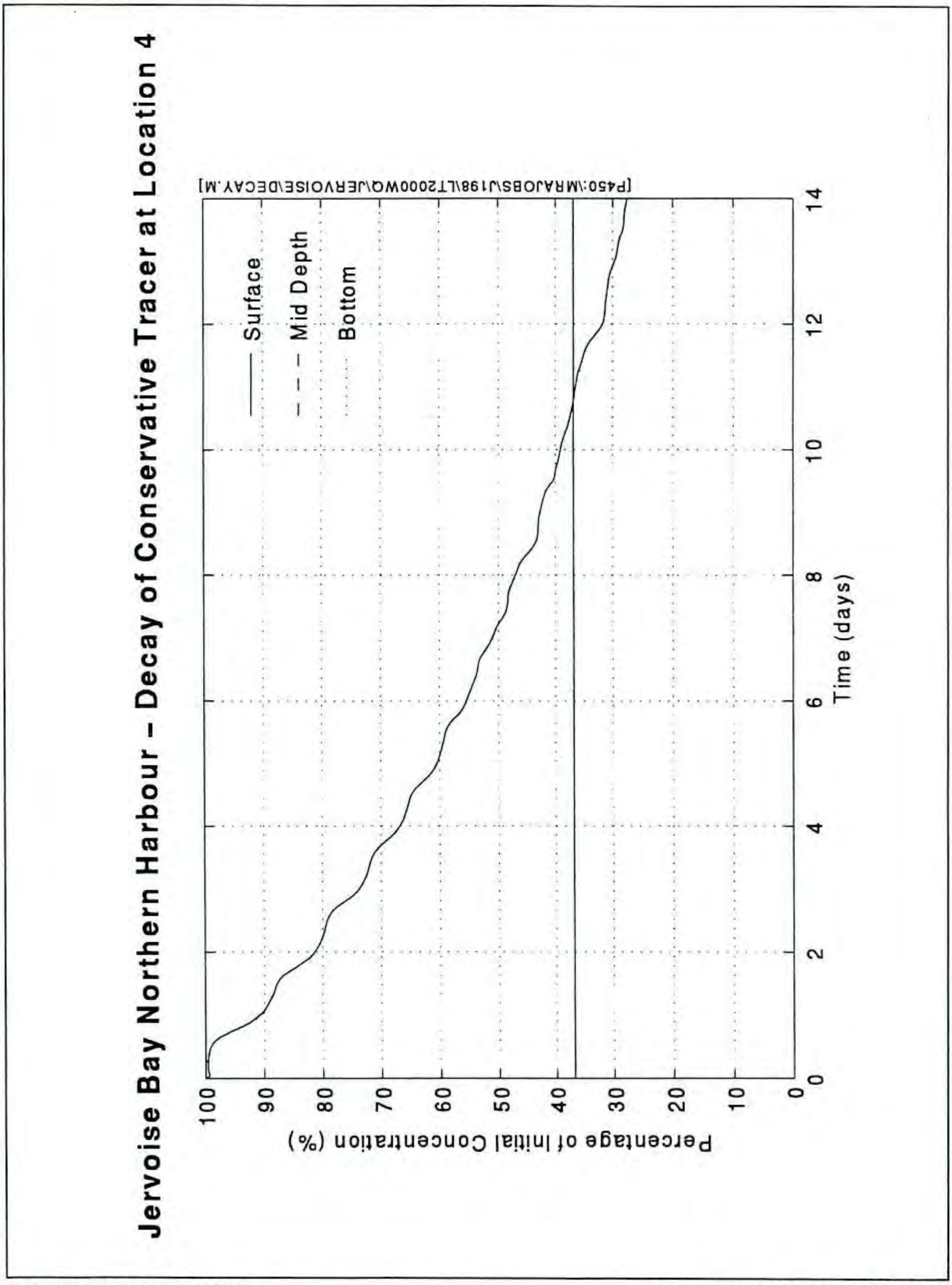


Figure 3.7 – Success Harbour
Time History of DIN – Location 1

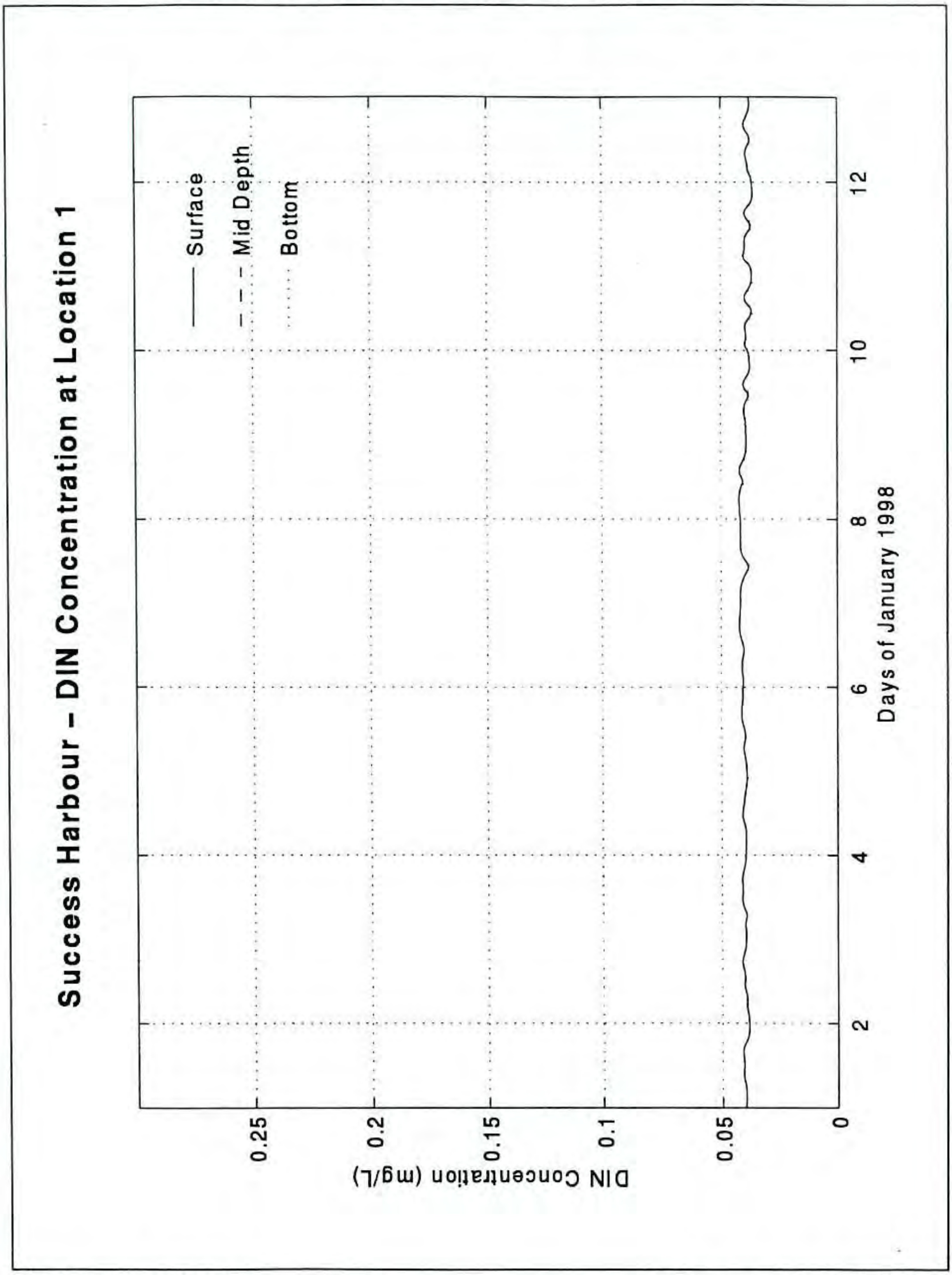


Figure 3.8 – Success Harbour
Time History of DIN – Location 4

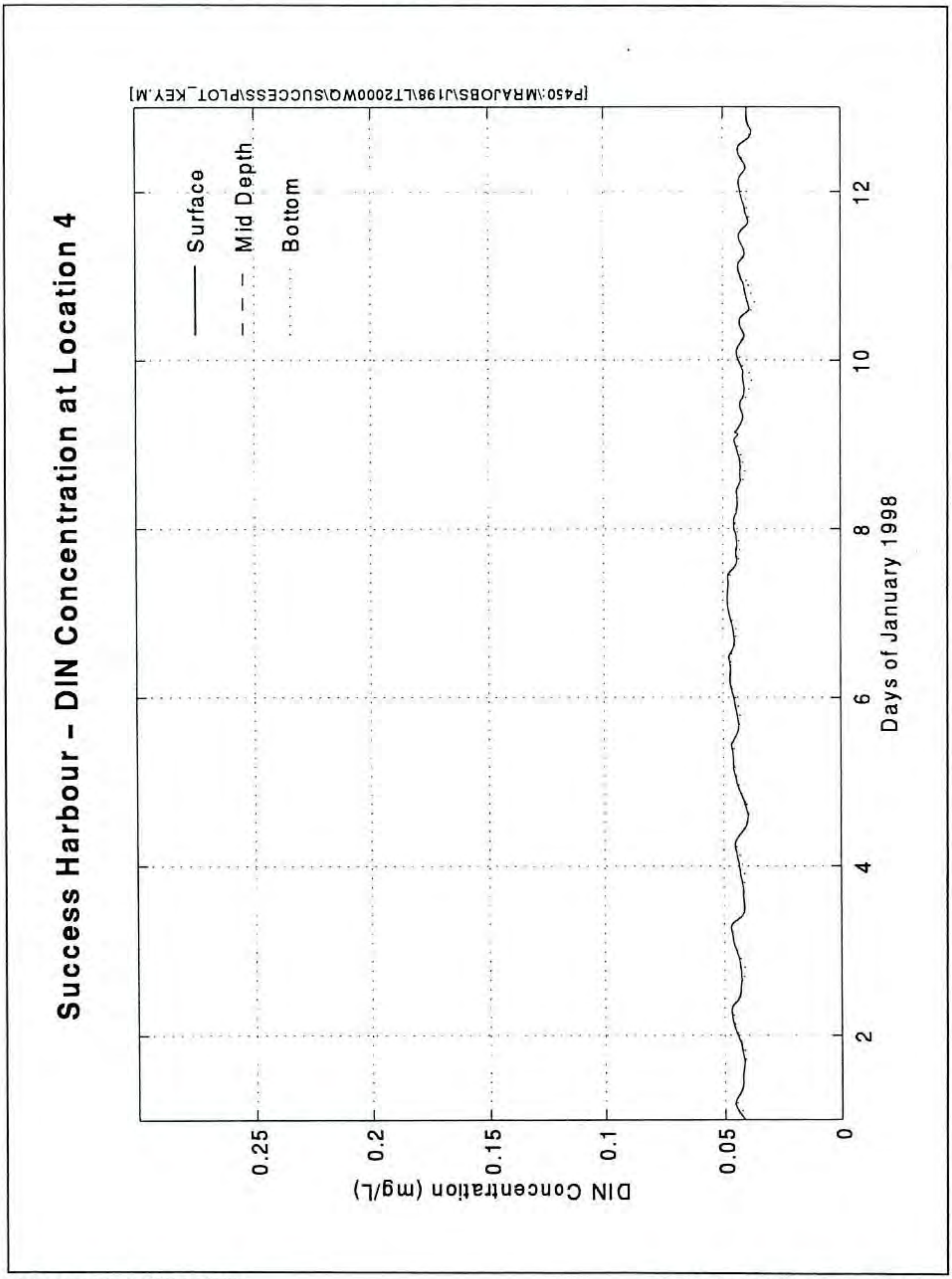
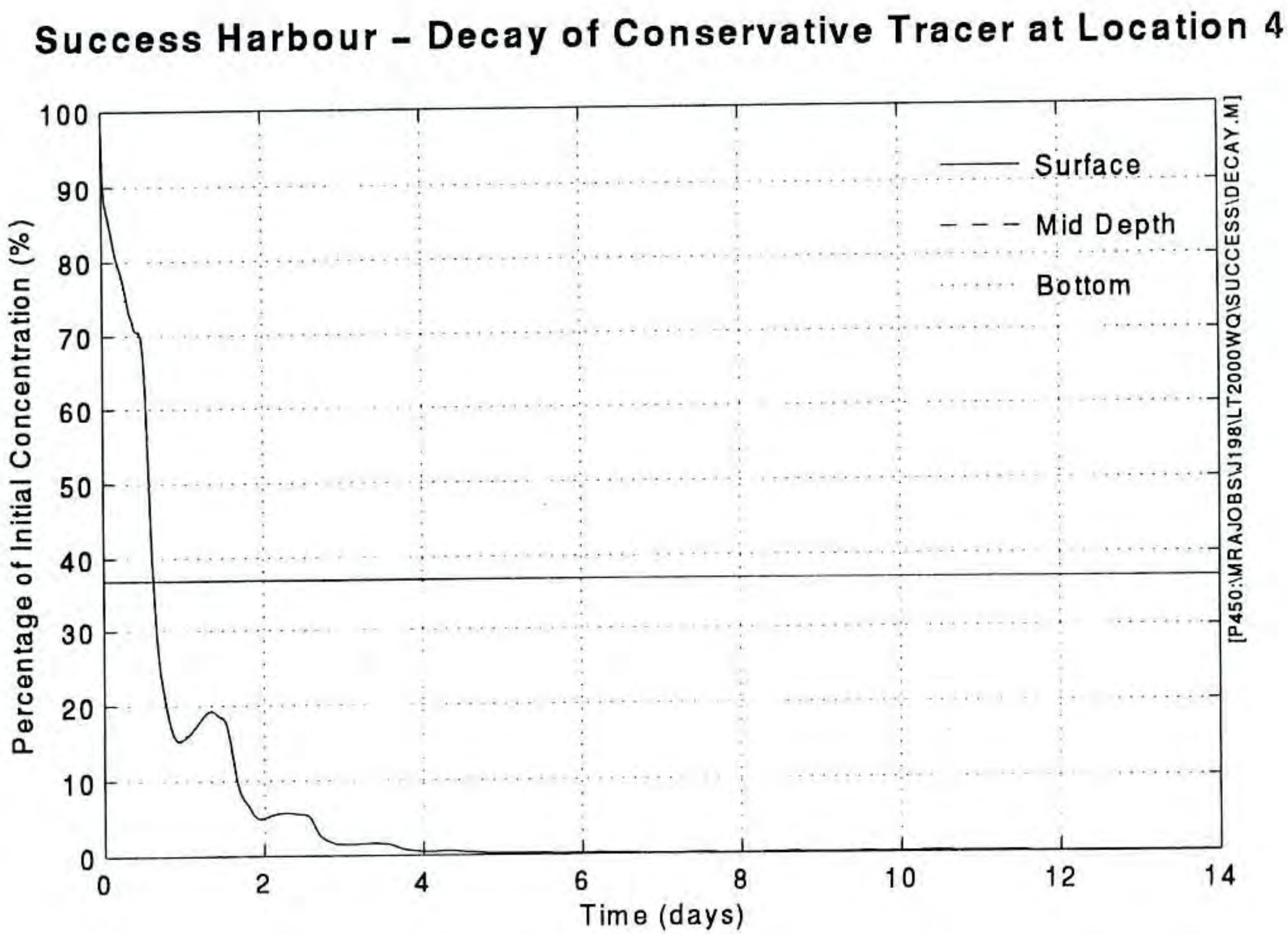


Figure 3.9 – Success Harbour Decay Curves – Location 4



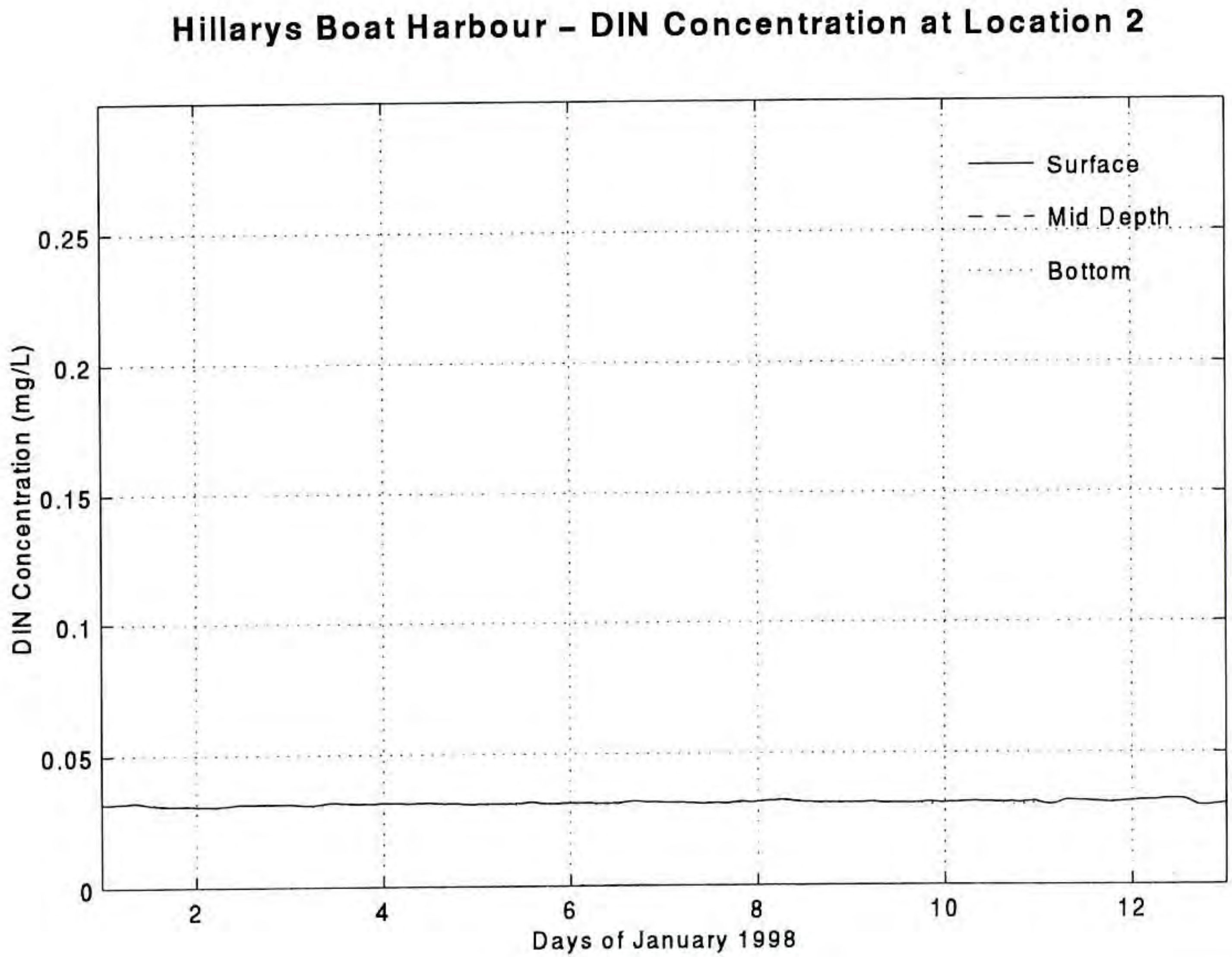


Figure 3.10 – Hillarys Boat Harbour
Time History of DIN – Location 2

Figure 3.11 – Hillarys Boat Harbour
Decay Curves – Location 2

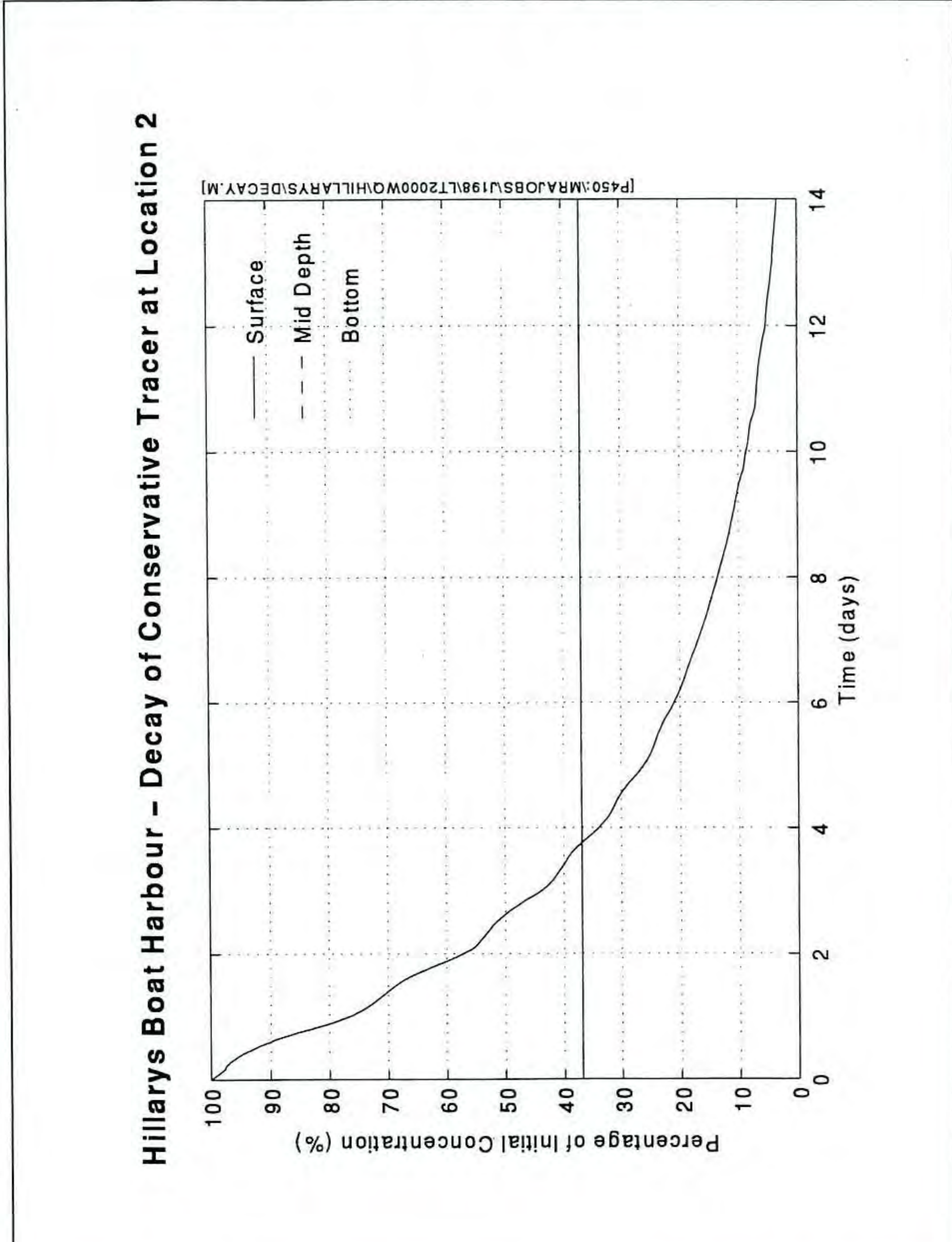


Figure 4.1 – PCD Option 7 – 310 m^3/day Throughflow
Spatial Distribution of DIN – Ebb Tide

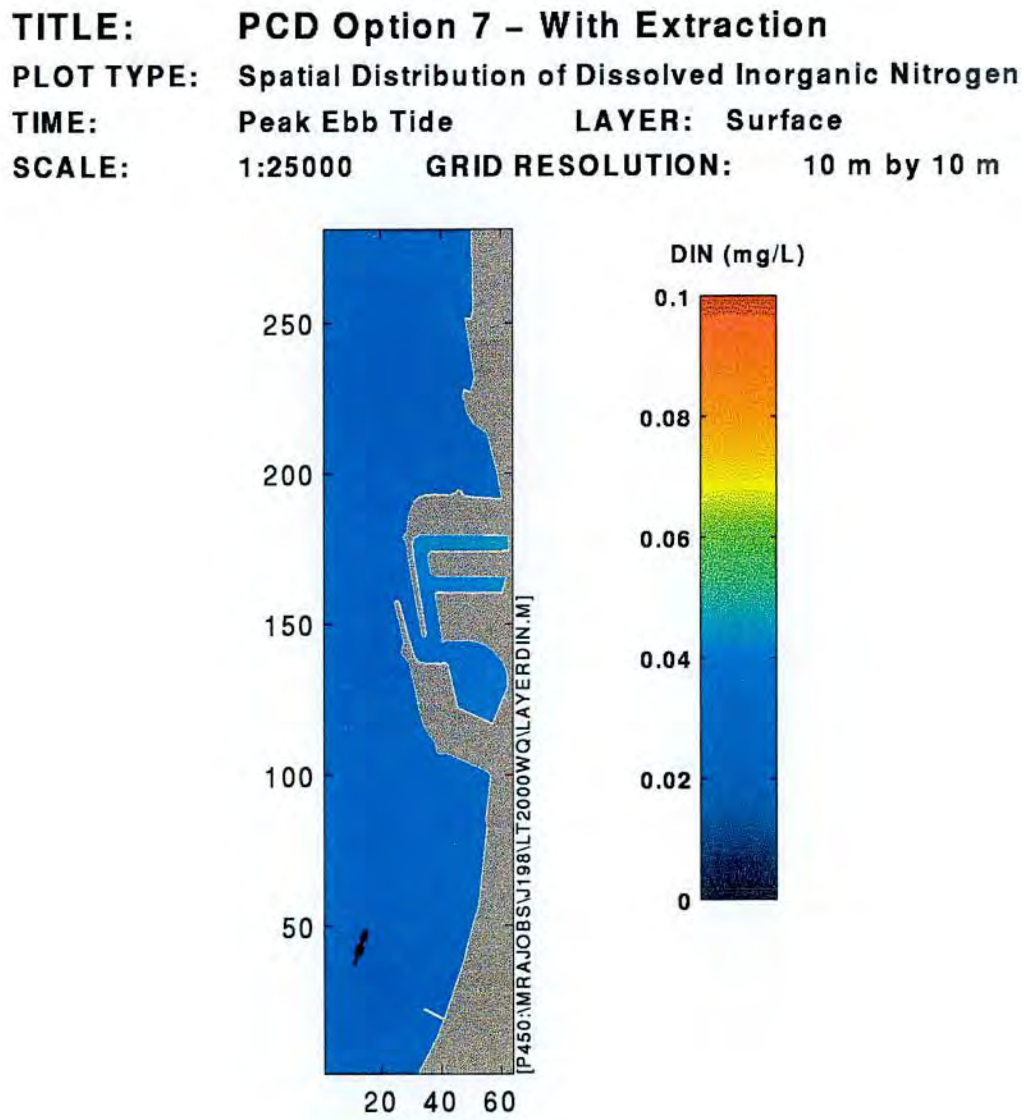


Figure 4.2 – PCD Option 7 – 310 m^3/day Throughflow
Time History of DIN – Location 1

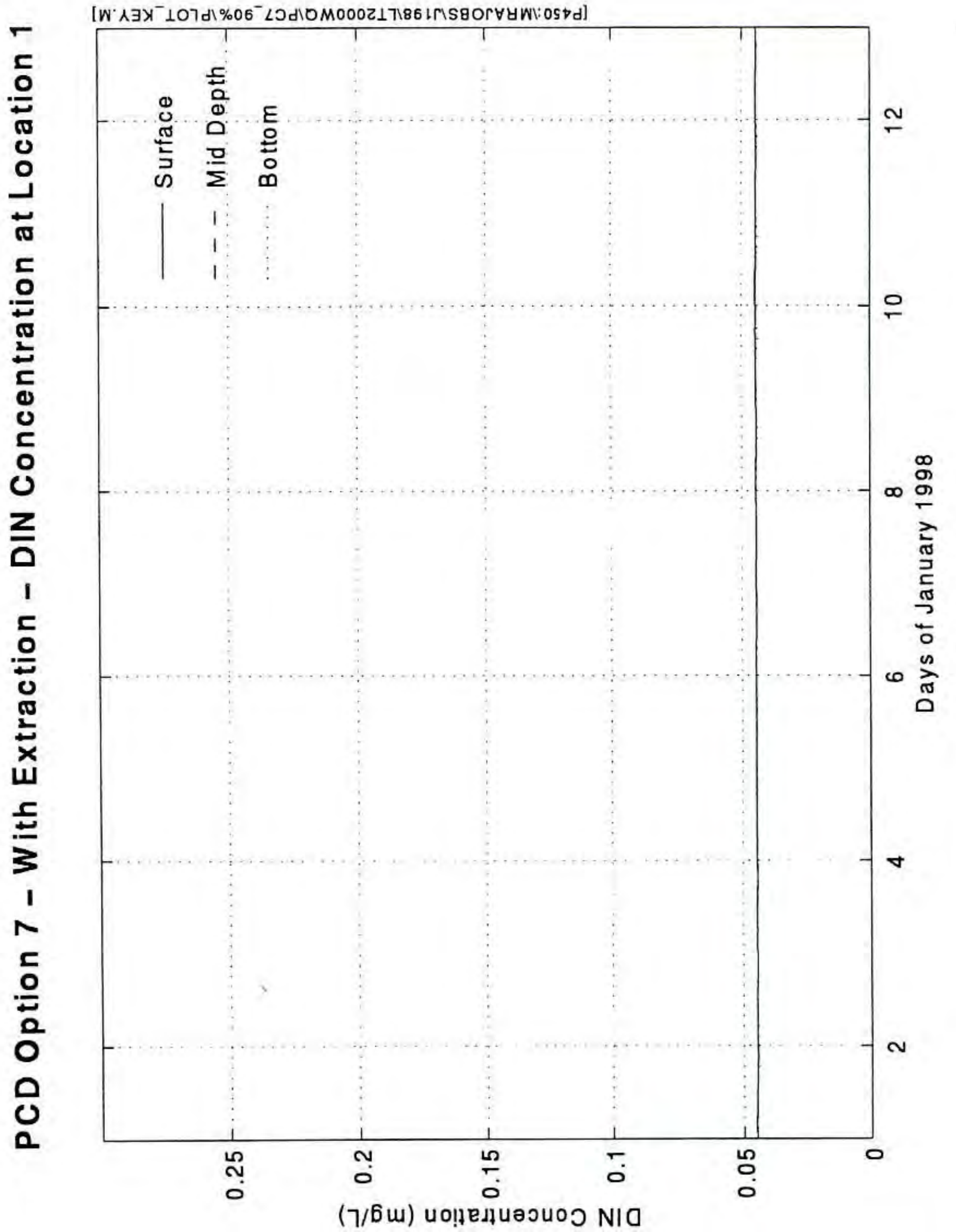


Figure 4.3 – PCD Option 7 – 310 m^3/day Throughflow
Time History of DIN – Location 7

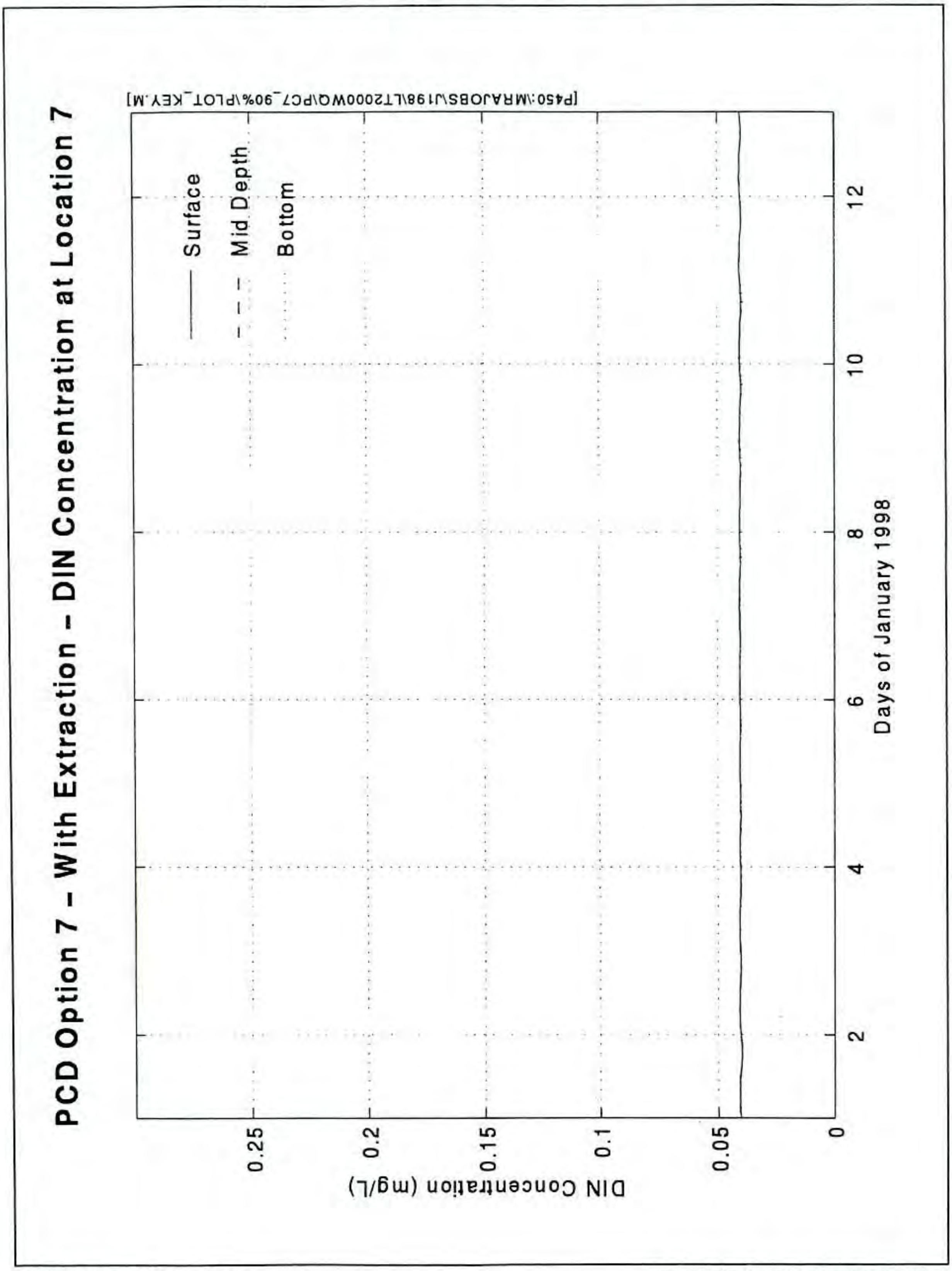
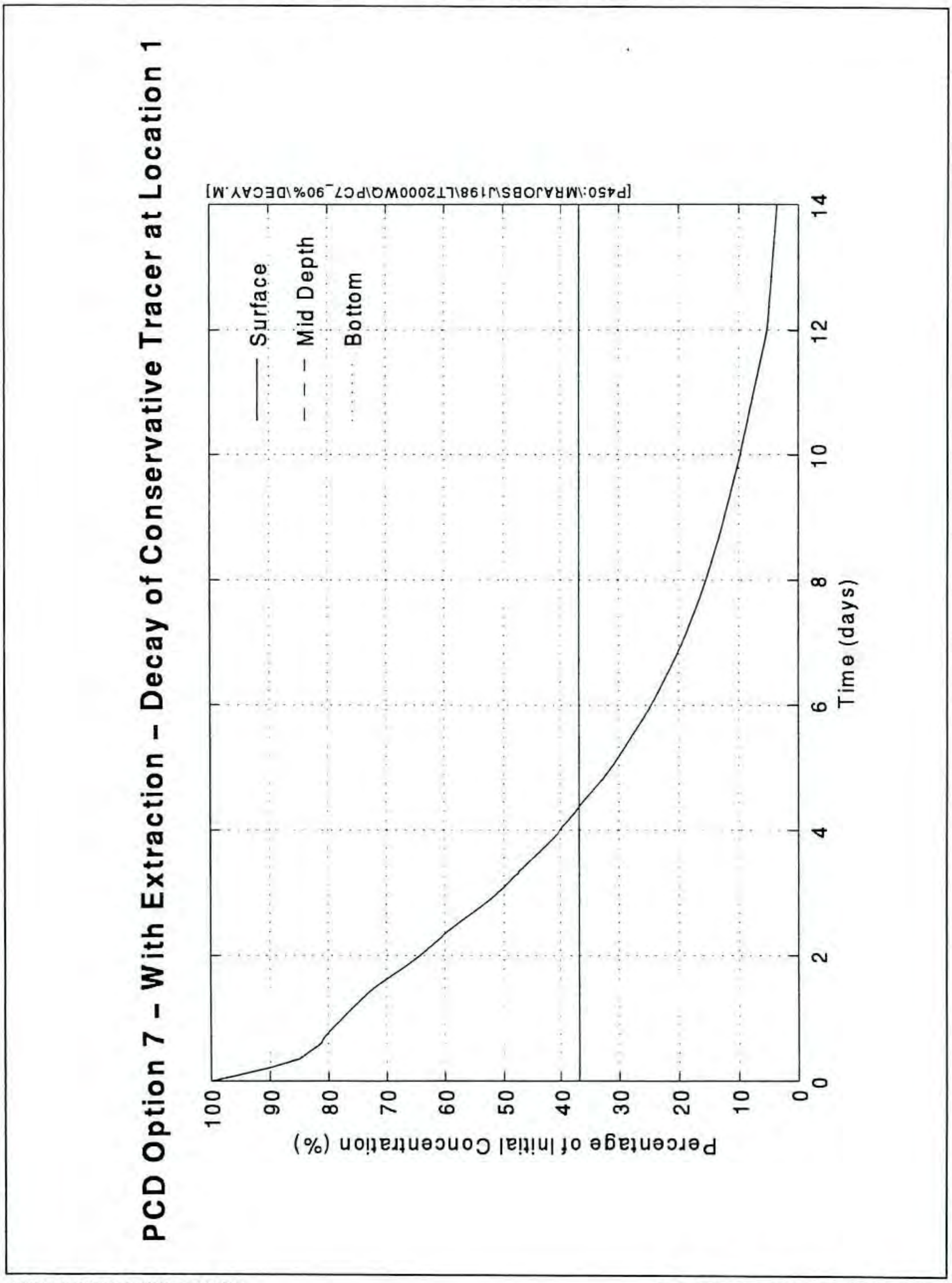


Figure 4.4 – PCD Option 7 – 310 m^3/day Throughflow Decay Curves – Location 1



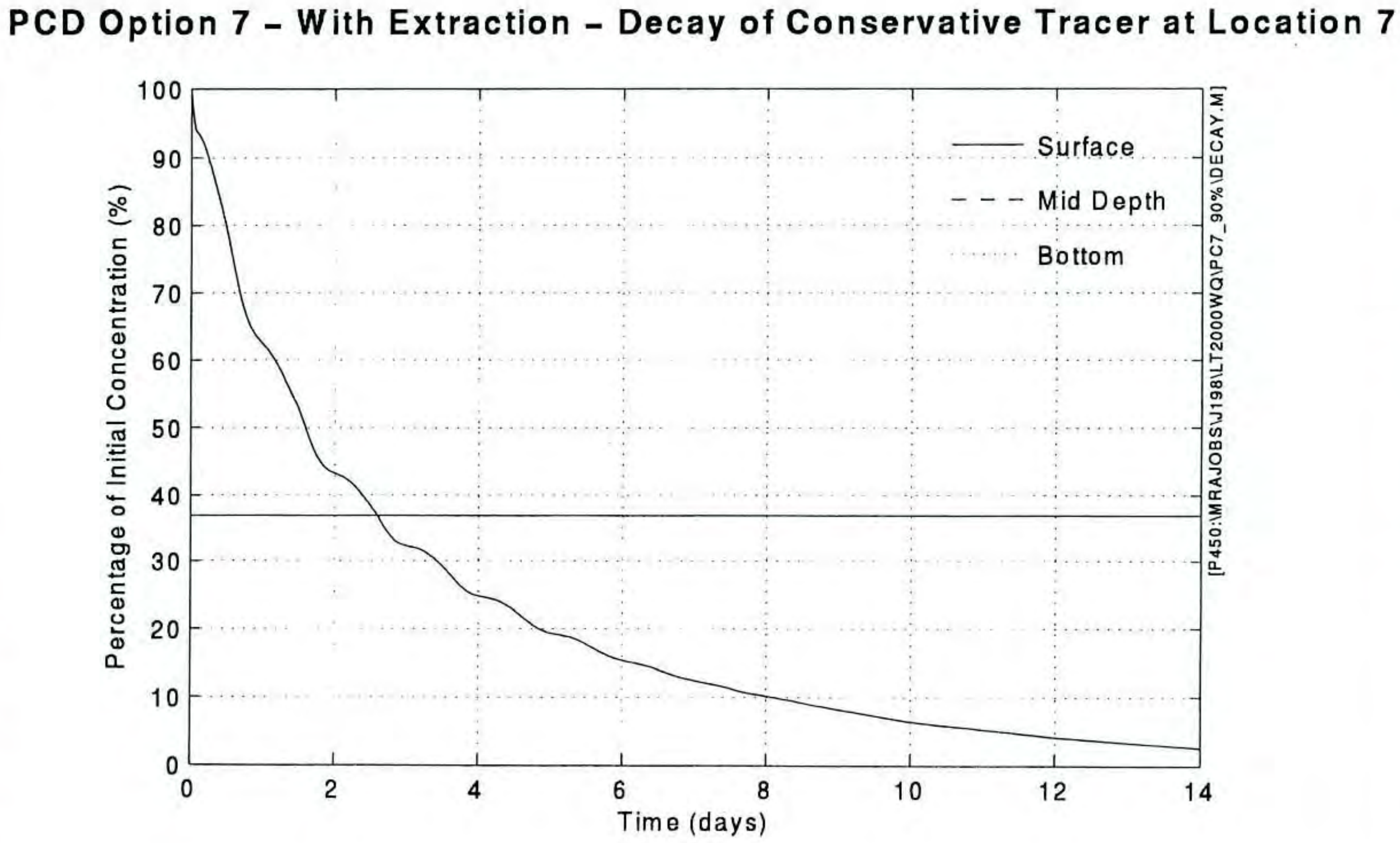


Figure 4.5 – PCD Option 7 – 310 m^3/day Throughflow
Decay Curves – Location 7

Figure 4.6 – PCD Option 7 – 2012 Case
Spatial Distribution of DIN – Ebb Tide

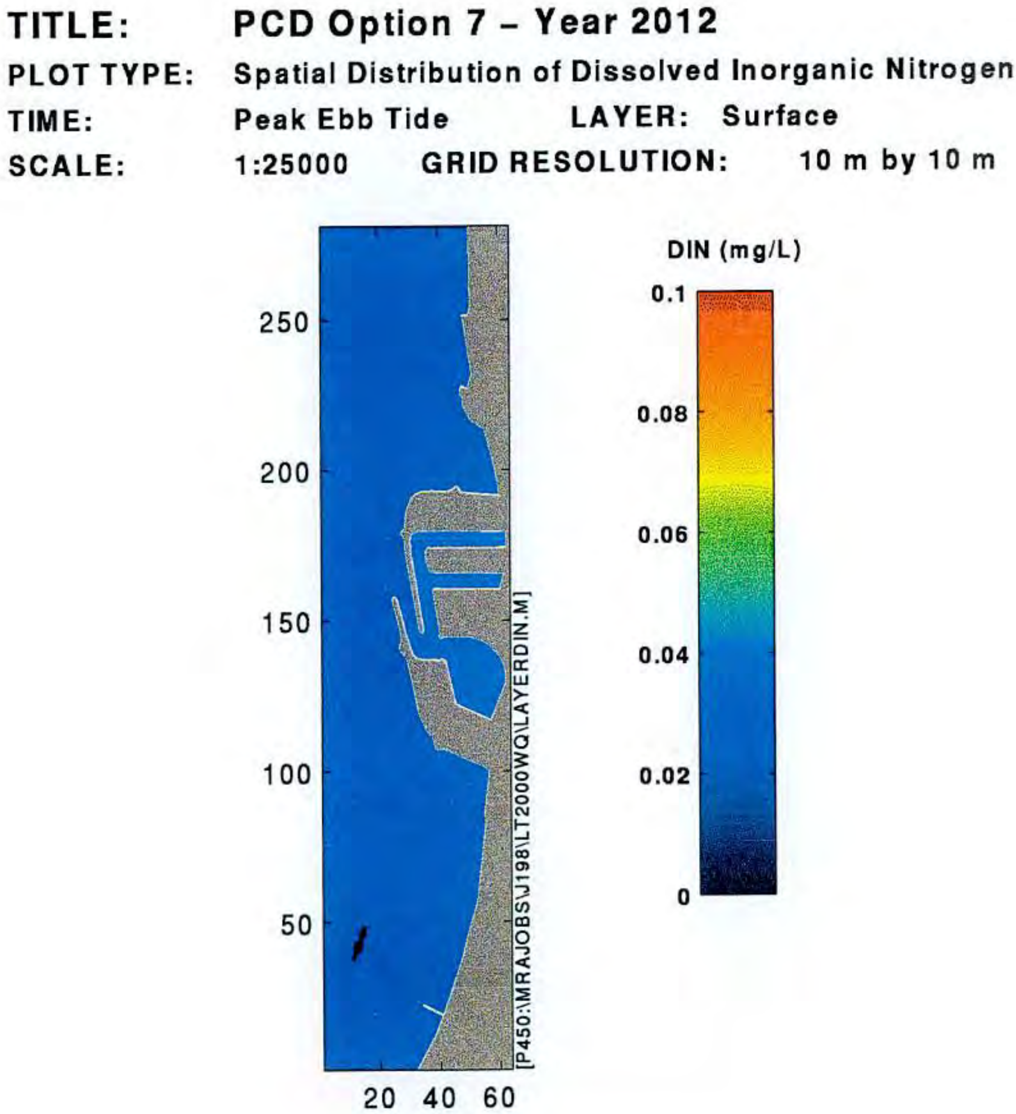


Figure 4.7 – PCD Option 7 – 2012 Case
Time History of DIN – Location 1

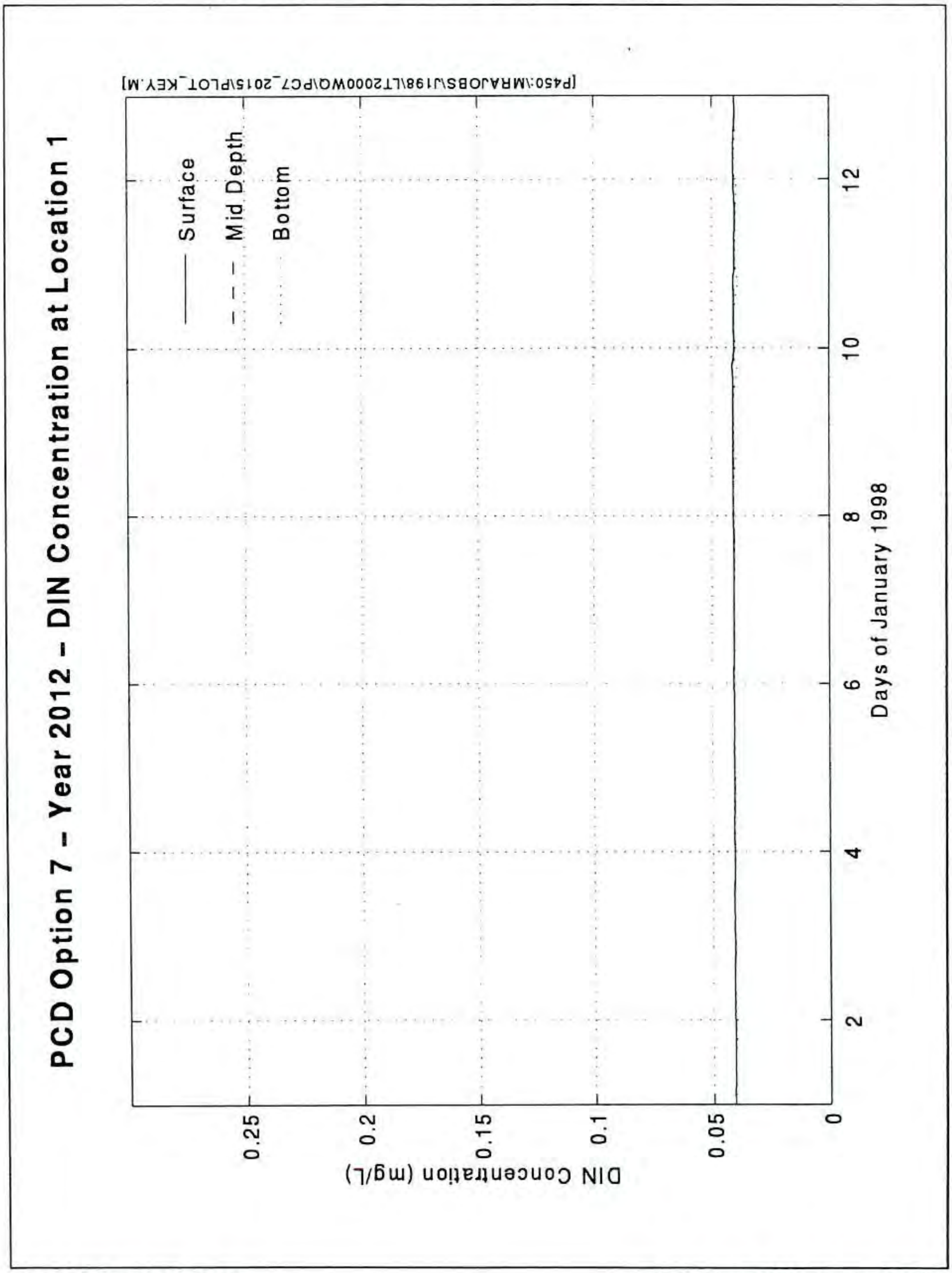
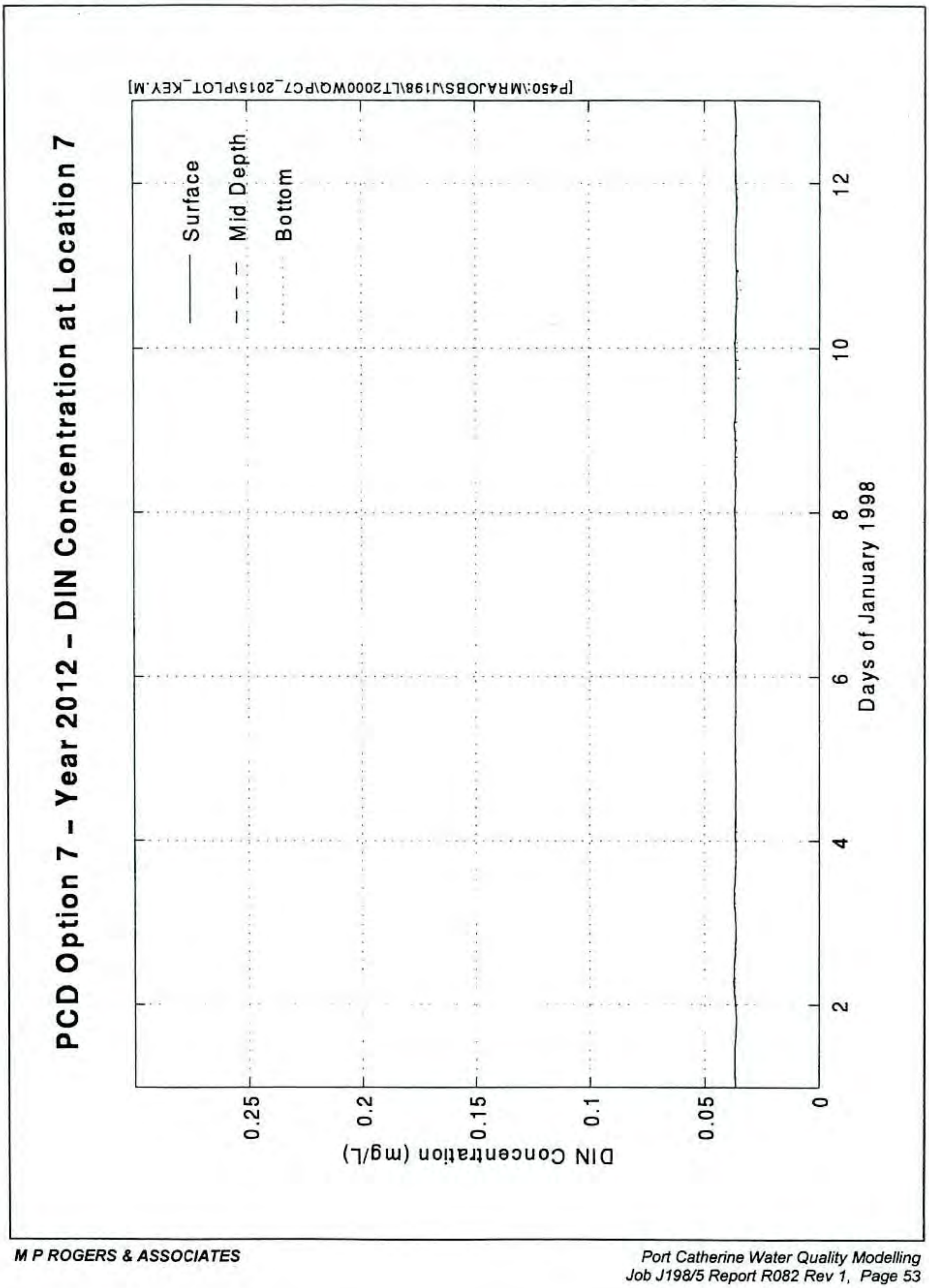


Figure 4.8 – PCD Option 7 – 2012 Case
Time History of DIN – Location 7



Appendices

Appendix A – Description of Delft3D Model

Appendix B – Time History Plots of DIN

Appendix C – Decay Curves

Appendix A Description of Delft3D Model

Delft3D

Functional Specification

March, 2000

Contents

1 Introduction

The Delft3D system is a flexible, modular modelling system capable of simulating:

- Flows due to tide, wind, density gradients and waves induced currents;
- Propagation of directionally spreaded short waves over uneven bathymetries, including wave-current interaction;
- Advection and dispersion of effluents;
- Water quality phenomena;
- Initial and/or dynamic (time varying) 2D-morphological changes, including the effects of waves on sediment stirring and bed-load transport.

Delft3D can switch between the 2D vertically averaged and 3D mode simply by changing the number of layers. This feature enables to set up and investigate the model behaviour in 2D mode before going into full 3D simulations.

All features are embedded in a state-of-the-art Graphical User Interface based on the OSF/MOTIF and X-Windows (Unix workstations) or the MS Windows (Wintel-platforms) standards. An application (model) can be completely defined through this menu-driven, user-friendly, graphical interface.

Furthermore, the system is embedded in a project and scenario management tool to define, select, (de-) archive simulations by referring to project and/or scenario names instead of file names. Consequently, errors in specifying input data are largely prevented, thereby increasing the overall model integrity and user's productivity.

Delft3D is composed of a number of modules, each addressing a specific domain of interest, such as flow, near-field and far-field water quality, wave generation and propagation, morphology and sediment transport, together with pre-processing and post-processing modules. All modules are dynamically interfaced to exchange data and results where process formulations require.

In the following chapters these modules are described in more details.

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Homepage: www.wldelft.nl

2 Hydrodynamic module

The hydrodynamic module, Delft3D-FLOW, is a multi-dimensional hydrodynamic simulation program that calculates non-steady flow and transport phenomena resulting from tidal and meteorological forcing on a curvilinear, boundary-fitted grid. In 3D simulations, the hydrodynamic module applies the so-called sigma co-ordinate transformation in the vertical, which results in a smooth representation of the bottom topography. It also results in a high computing efficiency because of the constant number of vertical layers over the whole computational domain.

2.1 Module description

The hydrodynamic module is based on the full Navier-Stokes equations with the shallow water approximation applied. The equations are solved with a highly accurate unconditionally stable solution procedure. The supported features are:

- Three co-ordinate systems, i.e. rectilinear, curvilinear and spherical in the horizontal directions and a sigma co-ordinate transformation in the vertical;
- Simulation of drying and flooding of intertidal flats (moving boundaries);
- Coriolis force and (optionally) tide generating forces;
- Density gradients due to a non-uniform temperature and salinity concentration distribution;
- Inclusion of density (pressure) gradients terms in the momentum equation (density driven flows);
- Turbulence model to account for the vertical turbulent viscosity and diffusivity based on the eddy viscosity concept;
- Selection from four turbulence closure models: k-epsilon, k-L, algebraic and constant coefficient;
- Shear stresses exerted by the turbulent flow on the bottom based on a quadratic Chézy or Manning's formula;
- Wind stresses on the water surface modelled by a quadratic friction law;
- Simulation of the thermal discharge, effluent discharge and the intake of cooling water at any location and any depth in the computational field (advection-diffusion module).
- Automatic conversion of the 2D bottom-stress coefficient into a 3D coefficient;
- Horizontal turbulent exchange coefficients composed of a 3D turbulence model and a 2D sub-grid turbulence model;
- The effect of the heat flux through the free surface;
- On-line analysis of model parameters in terms of Fourier amplitudes and phases enabling the generation of co-tidal maps;
- Space varying wind and barometric pressure, including the hydrostatic pressure correction at open boundaries (optional);
- Drogue tracks (optional);
- The influence of spiralling motion in the flow (i.e. in river bends). This phenomenon is especially important when sedimentation and erosion studies are performed;
- On-line visualisation of model parameters enabling the production of animations (in preparation).

2.2 Applications areas

Delft3D-FLOW can be applied to the following application areas:

- Salt intrusion in estuaries;
- Fresh water river discharges in bays;
- Thermal stratification in lakes and seas;
- Cooling water intakes and waste water outlets;
- Transport of dissolved material and pollutants;
- Storm surges;
- River flows;
- Wave driven flows.

2.3 Coupling with other modules

The results of the hydrodynamic module are used in all other modules of Delft3D. The results are dynamically exchanged between the modules through the use of a so-called communication file. Basic (conservative) water quality parameters like concentrations of dissolved material and pollutants, can be included in the computations. But, for more dedicated water quality simulations, the hydrodynamic module is coupled with the far-field water quality module (Delft3D-WAQ) and the near-field particle tracking module (Delft3D-PART). A coupling with the sediment transport module (Delft3D-SED) is available to simulate cohesive and non-cohesive sediment transport processes, e.g. in the case of erosion and sedimentation studies. For wave-current interaction a dynamic coupling is provided with the wave module (Delft3D-WAVE) and for morphodynamic simulations the hydrodynamic module is integrated with the wave module and a sedimentation and erosion module into a morphodynamic module (Delft3D-MOR).

To simulate a model defined on a curvilinear grid system, an orthogonal grid must be provided. To generate such a grid the program RGFGRID is provided, though the grid can be generated by any grid generator program as long as the grid is delivered in the prescribed (ASCII) file format. The generation of a curvilinear grid is an important and somewhat complex task. Along with the main model parameters, the grid will ultimately determine the accuracy of the final model results.

To prepare the bottom topography or other grid-related data, such as a non-constant initial condition file, the program QUICKIN is provided. This program interpolates the scattered, digitised chart data to depth-values at the grid points in the model. Many powerful interactive processing options to further adjust the topography are supported, e.g. manual adjustment of the values at individual points, selection of the domain of influence, group adjustments, and smoothing. The output of this program (ASCII-file) can be imported into other Delft3D modules.

Analysis and interpretation of a hydrodynamic simulation in terms of tidal quantities can be performed by the program TRIANA. TRIANA performs off-line tidal analyses of time-series of either water levels and or velocities. The results from these analyses can be subsequently compared with observation data supplied by the user.

3 Water quality module

The transport of substances in surface and ground water is commonly represented by the so-called advection-diffusion equation. The water quality module, Delft3D-WAQ, is based on this equation and it offers different computational methods to solve it numerically (in one, two or three dimensions) on an arbitrary irregular shaped grid, on a grid of rectangles, triangles or curvi-linear computational elements. In order to model waste loads and water quality processes the advection-diffusion equation is extended with an extensive water quality library of source/sink terms. The model is capable of describing any combination of constituents and is not limited with respect to the number and complexity of the water quality processes.

The water quality processes may be described by arbitrary linear or non-linear functions of the selected state variables and model parameters. For many water quality problems, these process formulations have been standardised in the form of a library, which smoothly interfaces with the water quality module. The library contains over 50 water quality processes routines covering 140 standard substances. A graphical user interface within the WAQ module enables the user to select substances and associated water quality processes.

3.1 Module description

In most practical cases Delft3D-WAQ models a physical system that consists of a surface or ground water body. Strictly speaking it models a body of a medium that is able to transport passive constituents. In this respect "passive" means that the influence of the concentration of the constituents on the transport coefficients may be neglected.

The transporting medium is characterised by its spatially and time dependent content (mass) of the modelled constituents. Some of these are transportable, some are non-transportable. An example of the latter is the material in the bottom sediment in a surface water model.
The concentration of the transportable constituents is computed by dividing the mass by the water volume. The mass is the state variable and the model is mass conserving by definition.

Waste disposals are specified either as mass units per time unit or as a combination of waste flow and concentration. They represent either point sources (urban, industrial, rivers) or diffuse sources (run-off, atmospheric deposition). The case of recirculating flows, as with cooling water studies, is also taken care of: the water that was let in, will have the same quality at the outlet.

The hydrodynamic characteristics of the transporting medium are expressed in terms of the volume and the flux of the transporting medium ("flow"). The combination of water volumes and flows must be consistent, i.e. an increase of the water volume must be balanced by a difference between inflow and outflow. As part of Delft3D, the coupling module can derive a set of consistent hydrodynamic flows automatically from Delft3D-FLOW, but the methods involved can be applied equally well to third-party hydrodynamic models outside Delft3D.

In many cases the water quality processes in the model are determined by meteorological conditions, by other (modelled or non-modelled) constituents or by other (modelled or non-modelled) processes. Examples are wind, water temperature, acidity (pH), primary production and the benthic release of nutrients. These entities are referred to as "forcing functions". Water quality process formulations are often of an empirical or semi-empirical nature and contain "model parameters" that are subject to tuning or calibration. Because of this, Delft3D-WAQ allows complete freedom in selecting the set of water quality processes and the relevant forcing functions and model parameters may vary between individual applications. It therefore provides flexible input facilities for constants, spatially varying parameters, functions of time and functions of space and time.

The physical system is affected by two types of processes:
- Transport processes: these processes involve the movement of substances;
- Water quality processes: these processes involve a transformation of one or more substances.

The transport of substances in surface and ground water is commonly represented by the so-called advection diffusion equation, which includes two basic transport phenomena: advection and diffusion. Advection is determined by the velocity field and dispersion by the dispersion coefficient. These basic transport processes operate on all transportable substances in the same way. Delft3D-WAQ offers the possibility to model other transport phenomena as well which may differ between individual substances. Examples are the gravity induced settling of particles and the autonomous motion of fish. These additional transport processes must be expressed as an extra, substance dependant, velocity or dispersion coefficient.

Water quality processes are incorporated in the advection diffusion equation by adding an additional source in the mass balance. Examples of water quality processes are:
- Exchange of substances with the atmosphere (oxygen, volatile organic substances, temperature);
- Adsorption and desorption of toxicants and ortho-phosporous;
- Deposition of particles and adsorbed substances to the bed;
- Re-suspension of particles and adsorbed substances from the bed;
- The mortality of bacteria;
- Biochemical reactions like the decay of BOD and nitrification;
- Growth of algae (primary production);
- Predation (e.g. zooplankton on phytoplankton).

Special attention is paid to the treatment of the interaction with the bottom:
- All suspended sediment is modelled as cohesive sediment that can be transported with the water flow just like a dissolved substance;
- All particulate inorganic matter can be represented by three size fractions or components;
- All particulate organic matter is represented by separate components, namely detritus carbon, other organic carbon, diatoms, non-diatom algae (Green), adsorbed phosphorus and organic carbon from loads;
- The bottom sediment is modelled via two separate layers. Each layer is considered homogeneous (well mixed). The different layers can have different compositions. The density of a layer is variable depending on the sediment layer composition, which is also variable. The porosity within a given layer is constant (user defined);
- A third (deeper) layer exists (but is not explicitly modelled) which can supply sediment for upward sediment transport 'digging';
- Sedimentation and resuspension are modelled using the Krone-Partheniades approach (see the description of the sediment transport module Delft3D-SED).

3.2 Application areas

Delft3D-WAQ can be applied to the following application areas:

- Bacterial decay processes;
- Chemical processes;
- Nutrient cycling and eutrophication processes;
- Sedimentation and resuspension of particulates;
- Interaction between water and bottom (including diffusive and benthic mixing);
- Evaporation, re-aeration and other surface processes;
- Transport and chemical processes regarding heavy metals and organic micropollutants;
- Recirculation of cooling water.

These processes hold for such substances as:
- Chloride/salinity;
- Up to five different conservative substances;
- Up to five different first order decaying substances;
- Coliform bacteria (E.coli, faecal coliforms and total coliforms);
- Oxygen and BOD;
- Excess temperature;
- Dissolved nutrients and nutrients in organic material;
- Various fractions of inorganic phosphorus;
- Up to three fractions of suspended sediment (both in water phase and bottom);
- Up to three algae species (diatoms, greens, bluegreens);
- Heavy metals like cadmium, copper, zinc, mercury, nickel, lead, chromium;
- Organic micropollutants like PCB-153, HCB, lindane, fluoranthene and benzo(a)pyrene.

The processes always require input in the form of rate constants and/or simulation results from other substances. The input could come from:
- One of the other modelled substances;
- A user specified spatially distributed time function;
- A user specified time function for the whole area;
- A user specified spatially distributed constant;
- A user specified constant for the whole area;
- A process flux originating from one of the water quality processes from the library;
- Output from one of the other processes in the library;
- A default value from the database containing default values.

The pre-processor will report the origin of the input for each process. If information for a process is missing, so that the process can not be evaluated, it will detail what information is actually required in addition.

4 Sediment transport module

The sediment transport module, Delft3D-SED, can be applied to model the transport of cohesive and non-cohesive sediments, i.e. to study the spreading of dredged materials, to study sedimentation/erosion patterns, to carry out water quality and ecology studies where sediment is the dominant factor.

It is in fact a sub-module of the water quality module, that is all processes contained in the sediment transport module are also present in the water quality module. For a detailed description of the general aspects we refer to the description of the water quality module.

4.1 Module description

4.1.1 Cohesive sediment

This section describes the implementation of the physical processes in some detail. For cohesive sediment transport sedimentation, erosion, burial and digging are taken into account.

For sedimentation the following assumptions apply:

- Sedimentation takes place when the bottom shear stress drops below a critical value;
- There is no correlation between the sediment components (i.e. each of the particulate fractions can settle independently);
- Sedimentation always results in an increase of sediment in the uppermost sediment layer;
- The total shear stress is the linear sum of the shear stresses caused by water velocity and wind effects. Effects of shipping and fisheries can also be included.

The effects of 'hindered settling' (i.e. decrease in sedimentation velocity at very high suspended solids concentration) can be included.

For resuspension the assumptions are:

- The bottom sediments are homogenous within a layer. Therefore, the composition of the resuspending sediment is the same as that of the bottom sediment;
- The resuspension flux is limited based on the available amount of sediment in a sediment layer for the variable layer option. The resuspension is unlimited if the fixed layer option is used;
- As long as mass is available in the upper sediment layer, resuspension takes place from that layer only;
- Resuspension flux is zero if the water depth becomes too small.

Burial is the process in which sediment is transferred downward to an underlying layer. The sediment layer is assumed to be homogeneous, therefore the composition of the sediment being buried is the same as that of the (overlying) sediment layer.

Digging is the process in which sediment is transferred upward from an underlying layer. The sediment layers are homogeneous, therefore the composition of the sediment being transported upwards is the same as that of the (underlying) sediment layer. A third and deeper layer allows for an unlimited 'digging' flux to the second layer. The quality of this third layer must be defined by the user and is not modelled by Delft3D-SED.

4.1.2 Non-Cohesive sediment

For non-cohesive sediment (sand) the transport rate is calculated according to the transport formulae of Engelund-Hansen and Ackers-White. These (semi-)empirical relation describes the total transport (bed load and suspended load) in the situation of local equilibrium.

The implementation recognises two options: unlimited supply of sand via the boundaries and the presence or absence of bedrock.

4.1.3 Limitations

To apply the sediment transport module the following limitations must be observed:

- In the sedimentation process, there is no correlation between the cohesive and non-cohesive components, i.e. between sand and silt; each is treated independently;
- The effect of short waves must be taken into account through the hydrodynamic module or through a localised wave effect estimation (that is, the waves are considered to be in equilibrium with local circumstances);
- Delft3D-SED should only be used for short- or medium-term (days, weeks, months) modelling of erosion and sedimentation process as the changes on bottom topography and its effects on the flow are neglected. For long-term processes (years), whereby the flow changes induced by changing bottom topography is significant, the separate morphological and sediment module (Delft3D-MOR) should be used. This module has advanced on-line coupling capabilities with the hydrodynamic flow and wave modules.

4.2 Application areas

Delft3D-SED can be applied to the following application areas:

- Effects of dredging on the environment;
- Sedimentation and resuspension of sediment in general;
- Sand transport.

5 Particle tracking module

The particle tracking module, Delft3D-PART, is a 3-dimensional near-field water quality model. It estimates a dynamic concentration distribution by following the tracks of thousands of particles in time. The model is fit for a detailed description of concentration contours of instantaneous or continuous releases of salt, oil, temperature or other conservative or simple decaying substances. This section gives a brief introduction to the computer module and its applications.

5.1 Module description

Delft3D-PART simulates transport processes and simple chemical reactions of substances. The present release also allows for red tide modelling. The module allows the simulation of detailed shapes of patches of wasted material.

Delft3D-PART can operate in various modes:

- Standard mode: 3D or 2.5DH mode: Delft3D-PART is coupled to Delft3D-FLOW in 2D or 3D mode (one layer model or multi-layer model), and extended with an analytical vertical velocity profile for bottom shear and wind;
- Temperature model: Delft3D-PART in 2.5DH mode with two layers. Exchange between the layers is done with a finite volume method in order to account for stratification. Buoyancy of plumes of heat is included with a simple approximation of horizontal dispersion;
- Red Tide model: Delft3D-PART in 3D mode, with transport and growth kinetics of red tides and nutrients, including light effects and settling (special license required);
- Oil spill module: simulation of oil spills with floating and dispersed oil fractions (special license required).

The physical components in the system are:

- The water system: a lake, estuary, harbour or river, possibly with open boundaries to other water systems. Tidal variations are included;
- Outfalls due to human activities;
- Chemical substances like rhodamine dyes, salt, oil or a demand of oxygen due to fast chemical reactions;
- Physical quantities like temperature and density;
- Wind fields;
- Stratification of the water column in two layers;
- Red Tides, nutrients and sun light;
- Settling velocities.

In terms of physical processes or phenomena Delft3D-PART can represent:

- The dynamics of patches close to an outfall location;
- Simple first-order decay processes like the decay of several fractions of oil;
- Vertical dispersion for well-mixed systems;
- Limited vertical dispersion due to stratification. Stratification may occur near outfall locations due to a waste of heat or a waste of salt;

- Horizontal dispersion due to turbulence. According to turbulence theory this dispersion increases in time;
- Horizontal dispersion that decreases in time due to buoyancy-driven currents near an outfall of heat or salt;
- The effects of time-varying wind fields on the patches;
- The effects of bottom-friction on the patches;
- The existence of a plume at the outfall (rather than a point-source) by starting the simulation from a circular plume with an estimated or field-measured radius.
- The transport and growth of red tides, steered by nutrients and light;
- Settling of particles;
- Floating of oil at the water surface, and dispersion of oil induced by wind waves (depending on wind speed and oil characteristics). Evaporation of floating oil is modelled as well.
- The model may be started from a known initial distribution of material, e.g. a remote sensing image of an oil spill.

Delft3D-PART can simulate up to 400,000 particles with a maximum of 8 substances. This requires about 64 Mbyte internal (hard core) computer memory. A computer simulation requires for most applications less one hour, and takes most often less 200 Mbyte of disk space. Post-processing is done with the general postprocessing program GPP. Graphical maps can also be generated with advanced methods like point spread functions. Visualisation is off-line. The coupling between the hydrodynamic module, Delft3D-FLOW, and Delft3D-PART is fluent, but is off-line.

5.2 Application areas

Delft3D-PART can be applied to the following applications. Note that in all applications a dynamic two- or three-dimensional flow calculation (including an accurate description of tidal variations) with a water quantity model has been done first.

- Study of outfall of Coliform Bacteria in an estuary.
- Study of the initial stages of dispersion in the vicinity of outfalls. Dye measurements were performed in order to calibrate and verify the simulation results. Important quantities from the field experiment are concentrations of dye, recovery rates and wind data. The module is calibrated on dispersion coefficient parameters and a wind drag coefficient.
- Outfall of a pipe-discharge in the sea from an oil terminal. At the outfall location oil-residues are wasted. The residues contain a high salt- and H_2S concentration and heavy metals. An oxygen demand is modelled because H_2S is immediately oxidised. Heavy metals are modelled as conservative substances. The oil is an assembly of different fractions that decay according to first order kinetics. Since a high salt load is wasted, a stratified system is modelled. The thickness of the bottom layer is estimated for two different prototypes of the pipe, using a near-field model. The two situations have a significant difference in concentration distributions. The model simulates a period of about 4 days.
- Outfall of heat for a power station in an estuary with natural areas, oyster beds and recreation areas. Since a high thermal load is wasted, a stratified system is modelled. The thickness of the top layer is estimated from near-field theory for two different

outlet situations (at two different depth contours). Density currents due to buoyancy effects are modelled as time-dependent dispersion.

- Red Tide simulations in an estuary. Nutrient concentration have been obtained from a water quality simulation based on the finite volume method (WAQ-module). The effects of light are incorporated in the model. In this application algae growth may continue during night time.
- Oil spill modelling. Hindcast of an oil spill model, starting from an initial distribution of oil that was obtained from photography from an aeroplane.

6 Ecological module

The far-field water quality module Delft3D-WAQ models algae using an approach based on Monod kinetics and is routinely included in the process library. The Delft3D-ECO module contains the more sophisticated algae model BLOOM II (Los, 1991) that is based on an optimisation technique.

6.1 Module description

Delft3D-ECO distributes the available resources (nutrients and light) in an optimal way among the different types of algae. A large number of groups and/or species of algae and even different phenotypes within one species can be considered. In the same way, algae living in the water column (phytoplankton) and algae and water plants living on the sediment (benthic species) can be included with their specific ecophysiological characteristics. With BLOOM II, apart from the calculation of biomass concentrations, the dynamics of algae communities including competition for light and nutrients, adaptation to environmental conditions and species composition can be simulated. The same water quality processes are available in Delft3D-ECO as are in Delft3D-WAQ. As it is a superset of Delft3D-WAQ, Delft3D-ECO includes all processes considered by Delft3D-WAQ and more.

Delft3D-ECO can be used to calculate eutrification phenomena, including:

- The competition between several groups of algae species;
- Adaptation of algae to changes in the environment, in terms of stochiometry and growth characteristics, (This can be of particular importance if the simulation of possible development of nuisance algae is an aim of the modelling.);
- Steep gradients in algae biomass due to temporal or spatial variations;
- Phytoplankton blooms;
- Chlorophyll concentrations;
- Species composition;
- Limiting factors for algae growth;
- Oxygen kinetics, including daily cycles;
- Nutrient concentrations.

Algae blooms usually consist of various species of phytoplankton belonging to different taxonomic or functional groups such as diatoms, microflagellates and dinoflagellates. They have different requirements for resources (nutrients; light) and they have different ecological properties. Some species are considered to be objectionable for various reasons. Among these are *Phaeocystis*, which causes foam on the beaches and various species of dinoflagellates, which among others may cause diurethic shell fish poisoning. To deal with these phenomena it is necessary to distinguish different types of phytoplankton in the algae model.

Delft3D-ECO is based upon the principle of competition between different species, or groups of species. The basic variables of this module are called types. A type represents the physiological state of a species under strong conditions of limitation. Usually a distinction is made between three different types: an N-type for nitrogen limitation, a P-type for phosphorus limitation and an E-type for light energy limitation. Usually for each (group of) species the three different types are modelled.

The solution algorithm of the model considers all potentially limiting factors and first selects the one, which is most likely to become limiting. It then selects the best adapted type for the prevailing conditions. The suitability of a type (its fitness) is determined by the ratio of its requirement and its growth rate. This means that a type can become dominant either because it needs a comparatively small amount of a limiting resource (it is efficient) or because it grows rapidly (it is opportunistic). Then the algorithm considers the next potentially limiting factor and again selects the best adapted phytoplankton type. This procedure is repeated until it is impossible to select a new pair of a type and limiting factor without violating (= over-exhausting) some limiting factor. Thus the model seeks the optimum solution consisting of n types and n limiting factors. The optimal distribution of biomass over the types cannot always be reached within one time step due to growth and mortality limitations.

As they represent different stages of the same species, the transition of one type to another is a rapid process with a characteristic time step in the order of a day. Transitions between different species is a much slower process as it depends on mortality and net growth rates.

It is interesting that the principle just described, by which each phytoplankton type maximises its own benefit, effectively means that the total net production of the phytoplankton community is maximised.

6.2 Applications

The BLOOM model has been extensively used to model the Southern North Sea and has been calibrated to 20 years of data in the Dutch coastal zone. Furthermore the model results have been validated for a wide range of both freshwater and marine systems. The following (groups of) algae or macrophyte species have been modelled using the BLOOM module for salt waters:

- Diatoms;
- Flagellates;
- Dinoflagellates;
- *Phaeocystis;*
- Ulva (on the bottom);
- Ulva (floating).

For Ulva two life forms are distinguished: Ulva that is rooted in the sediment and Ulva that floats on the water after it has been cut loose by strong winds or currents. The process of cutting loose has been incorporated in the model.

Up to now 6 types of algae or macrofytes have been modelled and calibrated. As in BLOOM the properties of the algae are adjusted to the light climate and nutrient availability, the user does not need to adjust the parameters for this by calibration. The default parameter values obtained by calibration of one model can therefore be applied in a wide range of other model applications. For this reason, if one needs to model an area that resembles a water system that has been modelled with BLOOM II before, choosing the model that has proven successful under those conditions can be particularly helpful.

7 Chemical module

In the chemical module, Delft3D-CHEM, the water quality module (Delft3D-WAQ) is coupled to the chemical equilibrium model CHARON. CHARON calculates the distribution of elements over a pre-specified set of chemical species. The model is based on two principles: the conservation of mass and the minimisation of the Gibbs free energy. Delft3D-CHEM enables the user to perform a CHARON calculation in a Delft3D-WAQ environment. In this way a powerful tool is created to assess both common water quality and more complicated chemical reactions in one model.

7.1 Module description

A simple example of the CHARON possibilities is the occurrence of inorganic carbon, which in water exists in different forms, like CO_2, HCO_3^-, and $CO_3^=$. Besides speciation in the water phase, CHARON is also able to calculate speciation between water and solid phases, which can occur by means of adsorption (e.g. heavy metals, and phosphorous) and/or precipitation (e.g. $CaCO_3$, Iron oxides and sulphides, but also sulphides of heavy metals).

CHARON has been used for a variety of problems, such as modelling the behaviour of phosphorous in eutrophication studies, modelling the behaviour of heavy metals, both in fresh surface waters, in estuarine and salt water conditions, as well as in ground waters.

Currently, the coupling in Delft3D-CHEM is limited to speciation and adsorption in the water column. Solid phases could be modelled but are not handled correctly with respect to sedimentation and erosion processes in Delft3D-WAQ. Consequently, only a small part of CHARON's capabilities are exploited in Delft3D-CHEM at the moment. Presently work is being done to expand the possibilities of Delft3D-CHEM.

The hydrodynamic conditions as calculated by the hydrodynamic module (Delft3D-FLOW) are coupled to Delft3D-CHEM and provide the advective transport of constituents.

Delft3D-CHEM is used in conjunction with the water quality module (Delft3D-WAQ) and runs on the same computational grid. There is dynamic interaction between the two modules so that constituents calculated in one module are automatically incorporated in the calculations of the other module.

7.2 Application areas

DELFT3D-CHEM may be applied to areas where hydrolysis-, redox- and/or solid phase reactions of substances of interest play a role.

DELFT3D-CHEM is a general module that is not devoted to a particular system. In principle, various complicated processes can be prescribed by editing a separate input file which contains information about the species to be modelled. However, construction of such a file requires an experienced chemist. The input processor contains most of the chemical substances used in standard applications.

8 Wave module

To simulate the evolution of random, short-crested wind-generated waves in coastal waters (which may include estuaries, tidal inlets, barrier islands with tidal flats, channels etc.) the wave module Delft3D-WAVE can be used. This wave module computes wave propagation, wave generation by wind, non-linear wave-wave interactions and dissipation, for a given bottom topography, wind field, water level and current field in waters of deep, intermediate and finite depth.

8.1 Module description

At present two wave models (both of the phase-averaged type) are available in the wave module of Delft3D. They are the second-generation HISWA wave model (Holthuijsen et al., 1989) and - its successor - the third-generation SWAN wave model (Ris, 1997; Booij et al., 1999).

The HISWA wave model is presently the **standard** wave model for the wave module of Delft3D. A limited version of the SWAN model is presently optionally available in an experimental version of Delft3D. (We would like to stress out here that the SWAN model is still undergoing further enhancements. It is therefore that also the implementation of SWAN in Delft3D is still under development and that presently not all features of SWAN are available under Delft3D. It is expected that the SWAN model will be fully operational under Delft3D (including userinterface etc.) at the end of 1999.)

HISWA

The HISWA wave model is a ***second generation stationary*** wave model (see Holthuijsen et al., 1989). The model has been developed at Delft University of Technology, Delft (the Netherlands). It has been operational in Delft3D for many years and is - at present - the default option. HISWA is computationally very efficient and the results are fairly reasonable in many practical applications.

HISWA accounts for the following physics:

- Wave generation by wind;
- Wave refraction over a bottom of variable depth and/or a spatially varying ambient current;
- Dissipation by wave breaking (Battjes-Janssen type dissipation) and/or bottom friction;
- Wave blocking by flow;
- Shoaling;
- Current driving process determined directly from radiation stress gradients or by a (more robust) formulation based on energy dissipation;
- Directional wave spreading;
- Two way wave current interaction, i.e. the effect of waves on current via forcing, enhanced turbulence and enhanced bed shear stress and the effect of flow on waves, via set up, current refraction and enhanced bottom friction.

The solution technique applied marches forward row by row over the grid beginning at the incident wave boundary where the wave characteristics can be defined. The propagation of energy is modelled using energy balance equation adapted to include terms for wave growth by wind action or dissipation due to bottom friction/wave breaking. The time variation is implemented in a quasi-stationary manner whereby sequences of conditions (input waves, water level and flow field) can be specified within a single run.

Non-stationary situations are simulated with the HISWA model as quasi-stationary with repeated model runs. This implies that as e.g. the flow computations progresses in time, a (stationary) wave computation is performed at time level t. Such stationary wave computations are considered to be acceptable since the travel time of the waves from the seaward boundary to the coast is mostly relatively small compared to the time scale of variations in incoming wave field, the wind or tidal induced variations in depth and currents.

Although the HISWA model performs fairly well in many complex field situations for which it has been developed, it has a number of limitations. The most important limitations are that a) wave propagation is limited to a directional sector of less than 180°, b) the computational grid has to be oriented in the mean wave direction, which is operationally inconvenient, c) the frequency spectrum is parameterized and d) the modification and addition of physical processes is rather difficult due to the highly parameterized formulations that are used. These limitations are to a large extent overcome by the new wave model SWAN.

SWAN

The SWAN model, which is an acronym for Simulating **WA**ves Nearshore, is a ***spectral third-generation*** wave model (see e.g. Holthuijsen et al. 1993; Ris, 1997). The SWAN model is the successor of the stationary second-generation HISWA model (Holthuijsen et al., 1989) and has the great advantage, compared to HISWA, that the physics are explicitly represented with state-of-the-art formulations and that the model is unconditionally stable (fully implicit schemes). Moreover, the SWAN model can perform computations on a curvilinear grid (better coupling with the flow-module of Delft3D) and it can - for instance - generate output in terms of one- and two-dimensional wave spectra. In addition, the wave forces, as computed by SWAN on the basis of the gradient of the radiation stress tensor (instead of the dissipation rate as in HISWA), can be used as driving force to compute the wave-induced currents and set-up in the flow module.

The SWAN model is based on the discrete spectral action balance equation and is fully spectral (in all directions and frequencies). This latter implies that short-crested random wave fields propagating simultaneously from widely different directions can be accommodated. SWAN computes the evolution of random, short-crested waves in coastal regions with deep, intermediate and shallow water and ambient currents. The SWAN model accounts for (refractive) propagation - as the HISWA model - and represents the processes of wave generation by wind, dissipation due to white-capping, bottom friction and depth-induced wave breaking and non-linear wave-wave interactions (both quadruplets and triads) explicitly with state-of-the-art formulations. To avoid excessive computing time and to achieve a robust model in practical applications, fully implicit propagation schemes have been applied. It should be noted here, however, that although an efficient numerical technique has been implemented in SWAN the computing time for a typical computation is about 20 times longer (or even more) than that of the HISWA model. This should be considered if many wave computations are to be performed (i.e. for instance for morphological studies). The SWAN model has successfully been validated and verified in several laboratory and (complex) field cases (see e.g. Ris, 1997). It is noted that the SWAN model (as the HISWA model) does not account for diffraction effects.

The SWAN model was developed at Delft University of Technology (the Netherlands) and it is undergoing further enhancements. It is specified as the new standard for nearshore wave modelling and coastal protection studies Therefore, WL | DELFT HYDRAULICS is integrating the SWAN model into Delft3D and is applying SWAN (as a stand-alone model) in its consultancy projects. The SWAN model has been released under *public domain*.

8.2 Application areas

The wave module can be used for harbour and offshore installation design and for coastal development and management related projects. It can also be used as a wave hindcast model. Typical areas for the application of the wave module lie in the range between 2 by 2 km to 50 by 50 km.

The wave module can optionally be coupled with the other modules of Delft3D. By this an efficient and a direct coupling is obtained between e.g. the flow module (wave driven currents) and the sediment transport module (stirring by wave breaking).

8.3 Coupling with other modules

The wave computations are carried out in Delft3D on a rectangular grid for the HISWA and SWAN model (and optionally on a curvilinear grid for the SWAN model) to be specified by the user. The Delft3D system will then automatically transfer all the relevant information to and from (2-way coupling) the hydrodynamic module Delft3D-FLOW, which simulates the flow on a curvilinear grid.

9 Morphodynamic module

The morphological module, Delft3D-MOR, integrates the effects of waves, currents, sediment transport on morphological development, related to sediment sizes ranging from silt to gravel. It is designed to simulate the morphodynamic behaviour of rivers, estuaries and coasts on time-scales of days to years.

The typical problems to be studied using this system involve complex interactions between waves, currents, sediment transport and bathymetry. To allow such interactions, the individual modules within Delft3D all interact through a well-defined common interface; a flexible steering module controls the calling sequence of the individual modules.

The computational modules within Delft3D are identical to their stand-alone counterparts and each offer the full range of physical processes. In this way, WL | DELFT HYDRAULICS combined experience of over thirty years in computer modelling is built into this system.

A morphological simulation in Delft3D is defined as a tree structure of processes and sub-processes down to elementary processes which contain calls to the computational modules. The user is free to build up processes of increasing complexity, from a single call to the flow model to morphodynamic simulations spanning years, with varying boundary conditions.
This module simulates the processes on a curvilinear grid system used in the hydrodynamic module, which allows a very efficient and accurate representation of complex areas.

9.1 Module description

Delft3D-MOR contains or is able to utilise the following components:

Steering module
Allows the user to link model inputs for the module components. The morphological process can be specified as a hierarchical tree structure of processes. Time intervals for the elementary processes are defined. Processes may be executed a fixed number of times, for a given time span or as long as a certain condition is not satisfied. A variety of options are available to specify the time progress.

Waves
The wave module (Delft3D-WAVE) is built around the stationary short-crested wave model HISWA (Holthuijsen et al., 1989). This model computes the effects of refraction, shoaling, wave dissipation by bottom friction and breaking and wave blocking for a discrete directional wave spectrum, over a two-dimensional bathymetry. Within the module the user can specify several HISWA computations in one run, with varying boundary conditions, and for each boundary condition various nested runs can be executed. Flow and water level information can be used from a flow run, and the results can be passed on to the flow module.

At present, a project is carried out to implement the SWAN model (which is the successor of the HISWA model, see Holthuijsen et al., 1993; Ris, 1997) in the wave module. The SWAN model is fully spectral (in all directions and frequencies) and computes the evolution of random, short-crested waves in coastal regions with shallow water and ambient currents. The SWAN model accounts for (refractive) propagation - as the HISWA model - and represents the processes of wave generation by wind, dissipation due to white-capping, bottom friction and depth-induced wave breaking and non-linear wave-wave interactions (both quadruplets and triads) explicitly with state-of-the-art formulations. It is noted that the SWAN model (as the HISWA model) does not account for diffraction effects.

Hydrodynamics
The hydrodynamic module (Delft3D-FLOW) used by Delft3D-MOR is based on the shallow water equations, including effects of tides, wind, density currents, waves, and turbulence models up to k-eps. The module includes a transport solver for salinity, temperature and conservative substances. The effects of salinity and temperature on the density and on the momentum balance are taken into account automatically.

The module uses a curvilinear grid in the horizontal plane. The vertical grid sizes are proportional to the local water depth.

For efficient morphological computations a one-layer, depth-averaged approach is used. The effects of spiral flow, i.e. in river bends, are computed by a secondary flow module which takes into account the advection of spiral flow intensity and the effect of the secondary flow on the primary current.

Wave effects in the model include radiation stress gradients associated with wave dissipation, wave-induced mass flux and enhanced bed shear stress, computed by a choice of formulations.

Sediment transport
The sediment transport module computes the bed-load and suspended-load sediment transport field over the curvilinear model grid, for a given period of time.

The bed-load transport is computed as a local function of wave and flow properties and the bed characteristics. The equilibrium suspended load is also computed as a local function of these parameters. The module then recognises two modes of transport: total transport (equilibrium) mode, or suspended load mode. In the first, the total transport is simply the addition of bed-load and equilibrium suspended-load transport. In the second mode, the entrainment, deposition, advection and diffusion of the suspended sediment is computed by a transport solver. Here, a quasi-3D approach is followed, where the vertical profiles of sediment concentration and velocity are given by shape functions.

The bed-load and equilibrium suspended-load transport can be modelled by a range of formulations, among which are Engelund-Hansen, Meyer-Peter-Muller, Bijker, Bailard and Van Rijn for sand, and a separate formulation for silt transport.

Effects of the bed slope on magnitude and direction of transport, and effects of un-erodible layers can be taken into account for all formulations.

Bottom change
The bottom update module contains several explicit schemes of Lax-Wendroff type for updating the bathymetry based on the sediment transport field. Options are available for fixed or automatic time-stepping, fixed (non-erodible) layers, various boundary conditions, and dredging.

9.2 Numerical aspects

All modules except the wave module operate on the same rectangular or curvilinear, orthogonal grid. Fully implicit ADI or AOI schemes are applied in the hydrodynamic module for the momentum and continuity equations. The solver has robust drying and flooding procedures for both 2D and 3D cases. In the transport solver a Forrester filter can be applied which guarantees positive concentrations throughout.

The same transport solver is applied for suspended sediment computations.

The wave model HISWA operates on rectangular grids, and uses an implicit scheme in propagation direction, combined with a forward marching technique. The wave module takes care of all transformations and interpolations between these rectangular grids and the curvilinear flow and transport grid. The wave model SWAN can perform computations directly on a curvilinear grid.

The bottom update model uses an explicit scheme of Lax-Wendroff type. This leads to a Courant type stability criterion. However, cheap intermediate "continuity correction" steps keep the computational effort at a reasonable level.

9.3 Application areas

Delft3D-MOR is designed to simulate wave propagation, currents, sediment transport and morphological developments in coastal, river and estuarine areas.

Coastal areas including beaches, channels, sand bars, harbour moles, offshore breakwaters, groynes and other structures. The coastal areas may be intersected by tidal inlets or rivers; parts of it may be drying and flooding.

Rivers including bars, river bends (spiral flow effect), bifurcations, non-erodible layers, dredging operations and having arbitrary cross-sections (with overbank flow). Various structures may be represented. Special features for 2-D river applications are presently being developed and validated, such as a bottom-vanes and graded-sediment.

Estuarine areas including estuaries, tidal inlets and river deltas influenced by tidal currents, river discharges and density currents. Sediment can be sandy or silty. The areas may include tidal flats, channels and man-made structures, e.g. docks, jetties and land reclamations.

10 Pre- processing and post-processing

In this chapter several pre- and postprocessing programs available in Delft3D are described in some details. These programs concern visualisation, grid generation, manipulation of grid related data and data analysis and manipulation.

10.1 Visualisation

The general post-processor (GPP) module of Delft3D allows uniform access to all kinds of data files to select and visualise simulation results and measurement data. More specifically the program allows to:

- Select the map and/or time histories you want to visualise;
- Select the lay-out and composition of the plot figure to be produced;
- Select the type of output medium, i.e. screen for inspection, plotter or printer for hard copy output.

The type of presentation depends on the character of the data set:

- *vector plots* for flow velocities, bottom shear stress and other vector quantities, with automatic or user-defined scaling of x-axis, y-axis and vector scale;
- *time history plots*, from a single run, from various runs in the same plot or simulation results in combination with measurement data. Depending on the data files, these can be typical hydrodynamic quantities, such as water levels, velocity magnitude and direction, but also water quality parameters like salinity, temperature and E.coli concentration. The scaling can be determined automatically or set by the user;
- *contour and isoline plots* of scalar quantities like the depth, water levels or algae growth rates. Again the user can choose automatic scaling or set the contour classes manually;
- *vertical profiles* for quantities defined on a three-dimensional grid;
- *geometric plots* of the grid itself, tidal flats, land boundaries;
- *mass balances and limiting factors* for displaying the details of water quality models.

Datasets can be plotted in any (sensible) combination, as long as there is a common co-ordinate system. Layouts may contain more than one viewport, allowing several independent plots on one page. It is noted that the overview above is by no means complete but it gives a general idea about the possibilities.

The program has been designed to be general enough to handle different kinds of underlying geometries and data files of widely varying formats.

The program is capable of producing high quality colour plots. It is also able to produce a plot file in various standard formats. At the same time a print-out of the results in ASCII format can be made, enabling the data to be imported in other post-processing programs.

10.2 Grid generation

RGFGRID is a program to generate orthogonal, curvilinear grids of variable grid size, that are to be used in combination with the hydrodynamic module Delft3D-FLOW. The grid-generator includes a graphical interface and an orthogonalisation module, providing easy control of the grid generation process.

RGFGRID supports the following features:
- Graphical user interface;
- Display of grid features as orthogonality, smoothness, aspect ration etc.;
- Several user functions have been implemented to provide easy control over the grid shape;
- Keyboard and mouse driven events are supported;
- Iterative way of working, each cycle providing more definition in the grid shape.

10.3 Grid data manipulation

To create, visualise and modify grid based data, such as bathymetries, and other grid related data the program QUICKIN is provided. QUICKIN is used in combination with the modules of Delft3D.

QUICKIN support the following features:
- Graphical user interface;
- Several interpolation options;
- Suitable for different ratios of grid-density vs. sample-density;
- Various display possibilities: isolines, dots, perspective, etc.;
- Implementation of various user functions to provide easy control over the final bathymetry;
- Sample data from different sources can be interpolated in sequence, thus, starting with the best quality data available, an optimal bathymetry can be created.

10.4 GRID aggregation

The program DIDO enables the user to span coarser, irregularly shaped, grid segments for water quality modelling, starting from the fine grid of e.g. the grid used by the hydrodynamic model. For ecological modelling with large numbers of state variables, a coarser schematisation, following ecological and transport separation lines rather than grid lines, is often preferable. The fine grid of the hydrodynamic model serves as input, integer multiples of the input grid are used for the description of the coarse grid. The procedure is fully mass-conserving. Aggregation is only supported in a plane surface.

DIDO provides the following features
- Zoom in locally;
- Separate a working area from the remainder of the schematisation;
- Aggregate regularly (e.g. every 2 segments in the one and 3 in the other direction);
- Aggregate irregularly (by rubber band lines comparable to the bulls hide);
- Fine tune by point and click on single elements;
- Select a subset of the hydrodynamic area for water quality modelling;
- Display information of a selected segment;

- Save intermediate results on the fly;
- Resume unfinished work from saved files;
- Save the final result for water quality simulation.

The final result of DIDO will be used as input to the coupling program between the hydrodynamic module Delft3D-FLOW and the water quality module Delft3D-WAQ enabling the latter to run on a coarser grid using the fine grid hydrodynamic database. Water quality simulations are converted back to the fine grid in post-processing software. This gives spatial plots with the fine resolution (although aggregated areas will still show equal concentration values).

10.5 Tidal analysis

The program GETIJSYS (acronym for GETIJ SYSteem, Dutch for tidal system) system is used for the analysis of tidal recordings and the preparation of tidal predictions.

The main module GETIJSYS/ANALYSIS performs tidal analysis on time-series of water levels or currents. A variety of features is included, such as:

- The coupling of closely positioned astronomical components;
- The simultaneous analysis of successive records of different instruments;
- The discrimination of sub-series to account for gaps in measurement recordings;
- The appreciation of linear trends and an accuracy analysis.

In a tidal analysis of a time-series of one year with a 10 minutes interval, 100 or more tidal constituents can be prescribed simultaneously. The constituents are selected from the internal database that contains 234 constituents that may be important at locations world-wide.

The module GETIJSYS/FOURIER performs Fourier-analyses on any type of time-series. This feature can be used to investigate the series of residual levels or velocities which has been identified during the tidal analysis on remaining tidal components.

Using a set of tidal constants, such as computed in the analysis module, the GETIJSYS/PREDICT module predicts water levels or tidal currents as a function of time.

The module GETIJSYS/HILOW may provide the production of tide tables with the dates, times and heights of the High and Low Waters. Using a word-processor or desktop publishing software package, the basic tide tables can be processed further and combined with other relevant information like tidal stream data.

Whereas in the regular analysis part of the package the user pre-defines the constituents that will be considered, the program also features an option (GETIJSYS/ASCON) to compute the astronomic arguments and node amplitude factors for all 234 internally defined constituents.

The package is accompanied with an comprehensive Users' Manual, exemplifying the use of the program and its scientific backgrounds. A number of examples is added in the form of input and data files.

11 Hardware configuration

Delft3D and its accompanying programs is supported on the following platforms:

- UNIX workstations (HP, SUN and SG);
- WINTEL platform (W95 and Windows NT).

The minimal and preferred configuration are:

Configuration item	Minimal	Preferred
Processor speed	166 Mhz	333 Mhz or more
Internal memory	64 Mb	128 Mb
Swap space	1.5 * internal memory	2.5 * internal memory
Hard disk	2 Gb	10 Gb
Monitor	17 inch colour	19 inch colour
CD-ROM	standard	standard
Printer	PCL, HPCL	PostScript

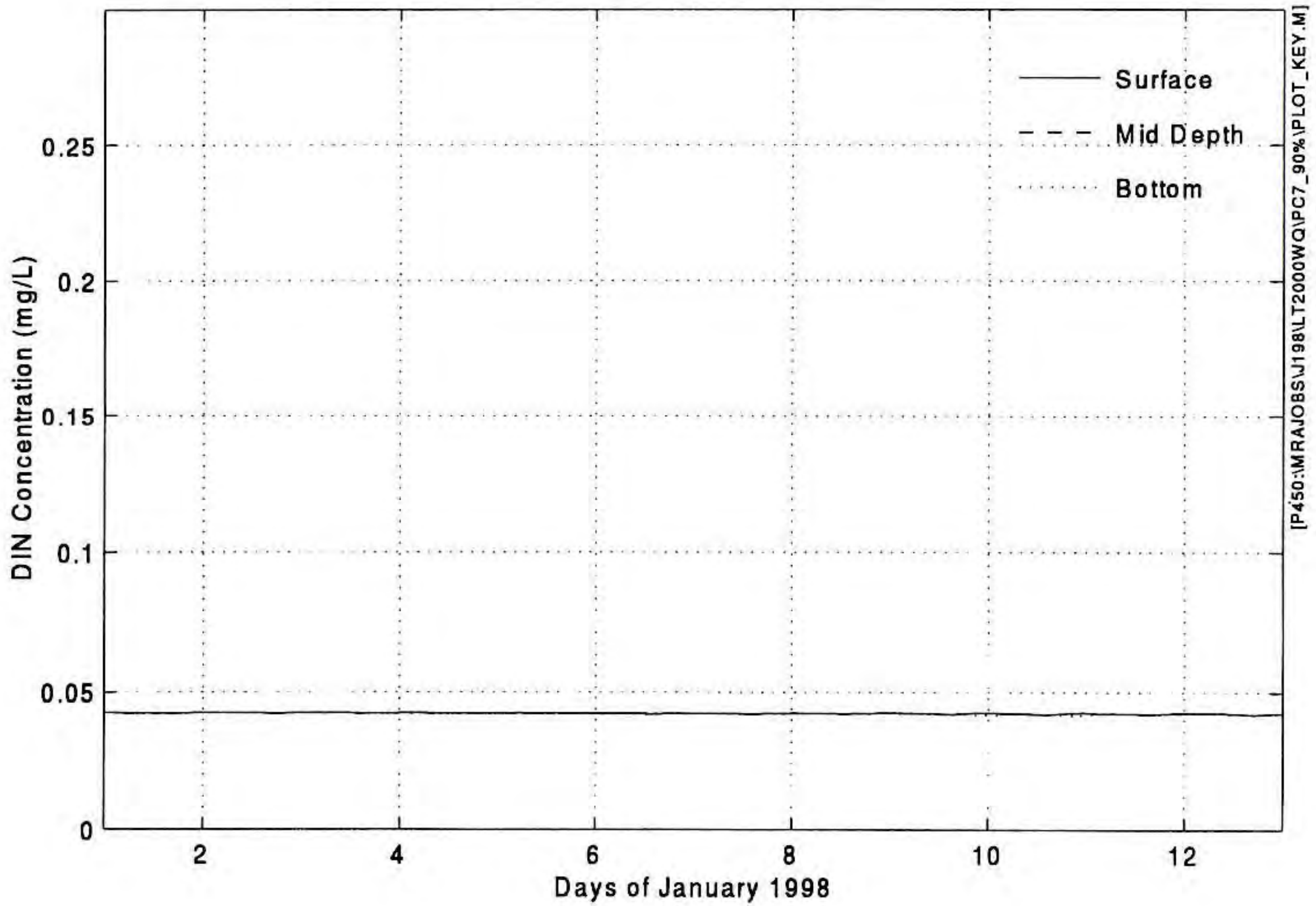
For the UNIX workstations the following operating systems are supported:

Workstation	Supported operating systems
HP	HP-UX 10.2 or higher
SUN	SOLARIS 2.6 or higher
SG RS10000	IRIX 6.5 or higher

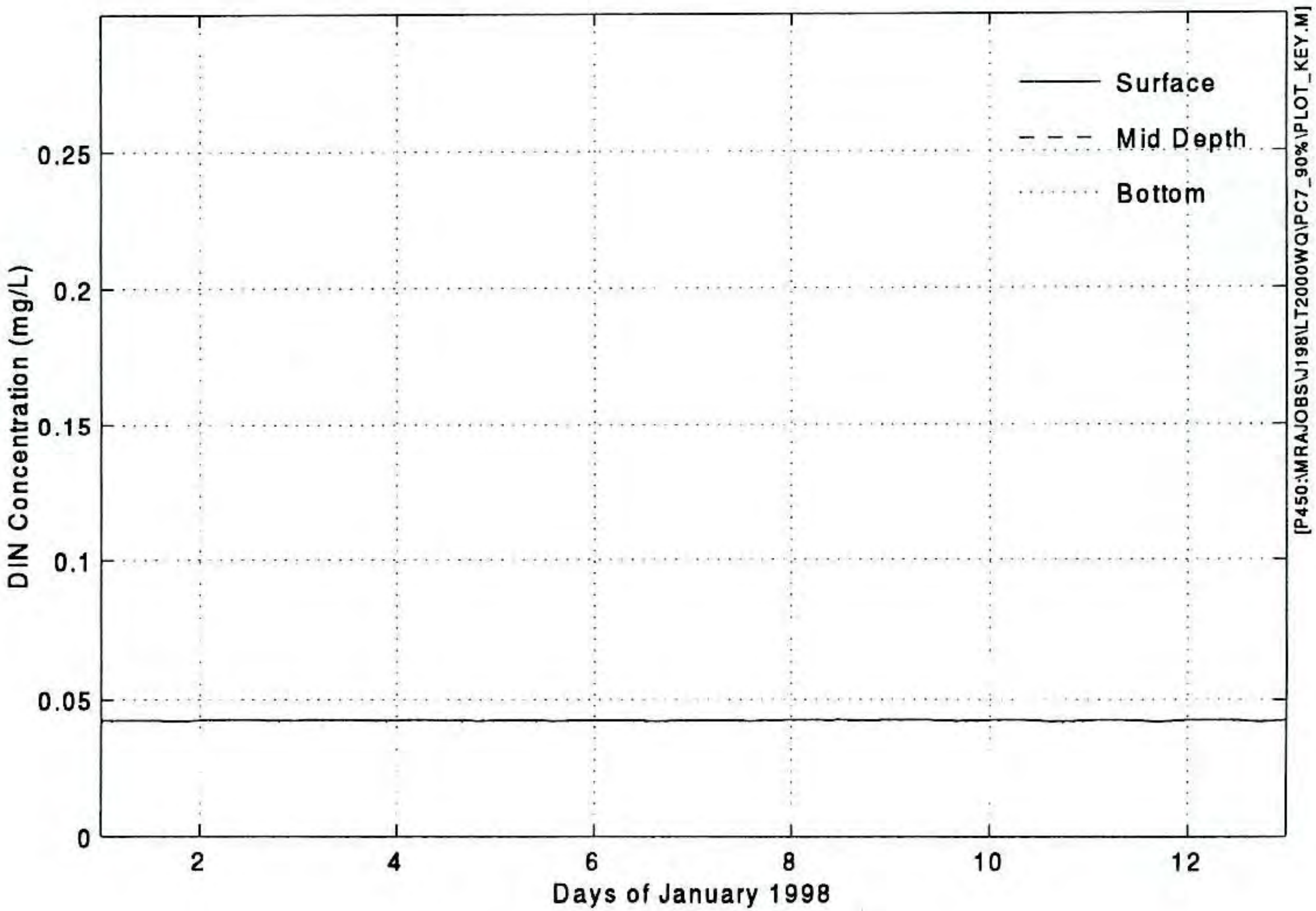
Other hardware platforms or operating systems can be supported on request.

Appendix B Time History Plots of DIN

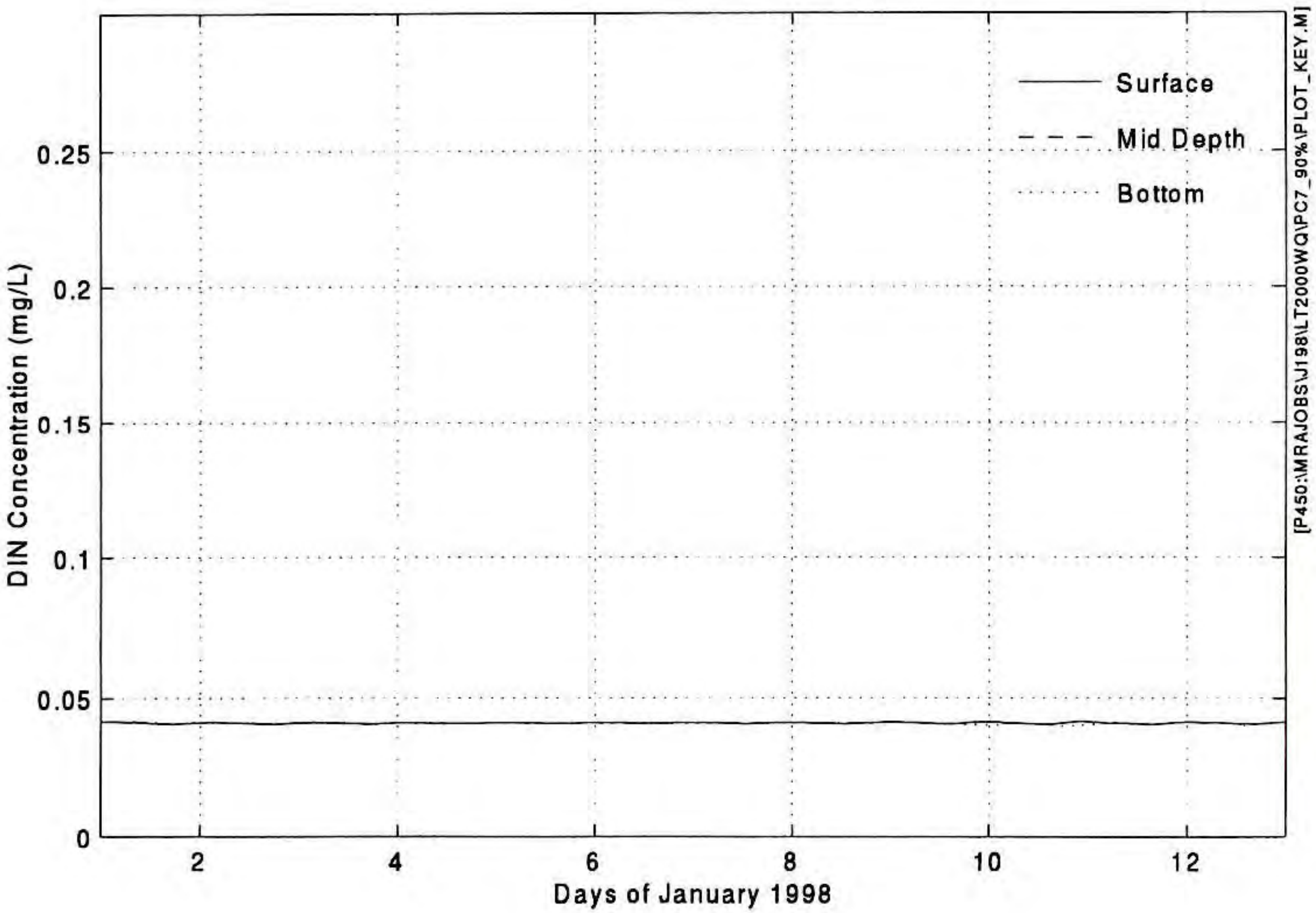
PCD Option 7 - With Extraction - DIN Concentration at Location 2



PCD Option 7 - With Extraction - DIN Concentration at Location 3



PCD Option 7 - With Extraction - DIN Concentration at Location 4



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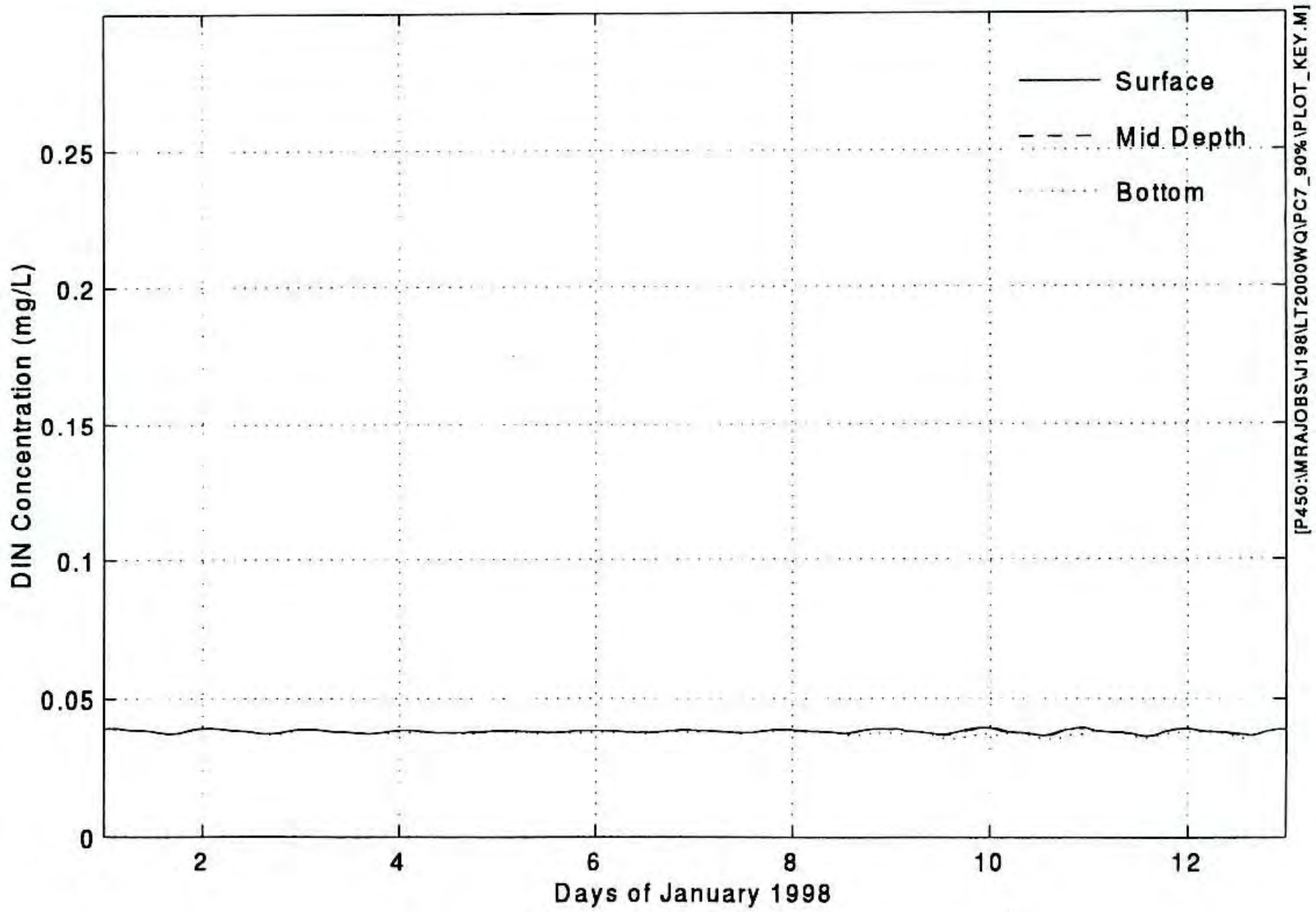
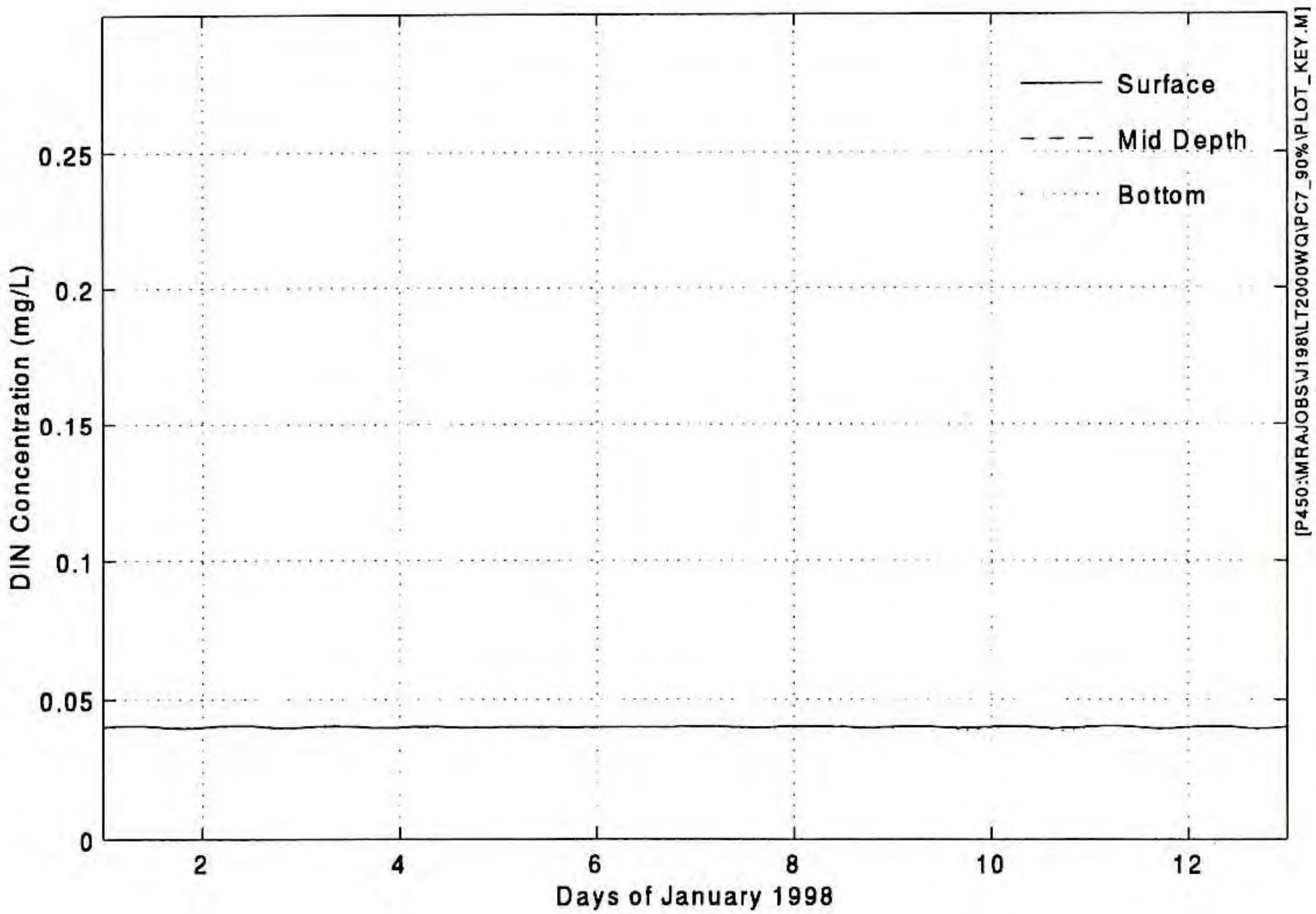
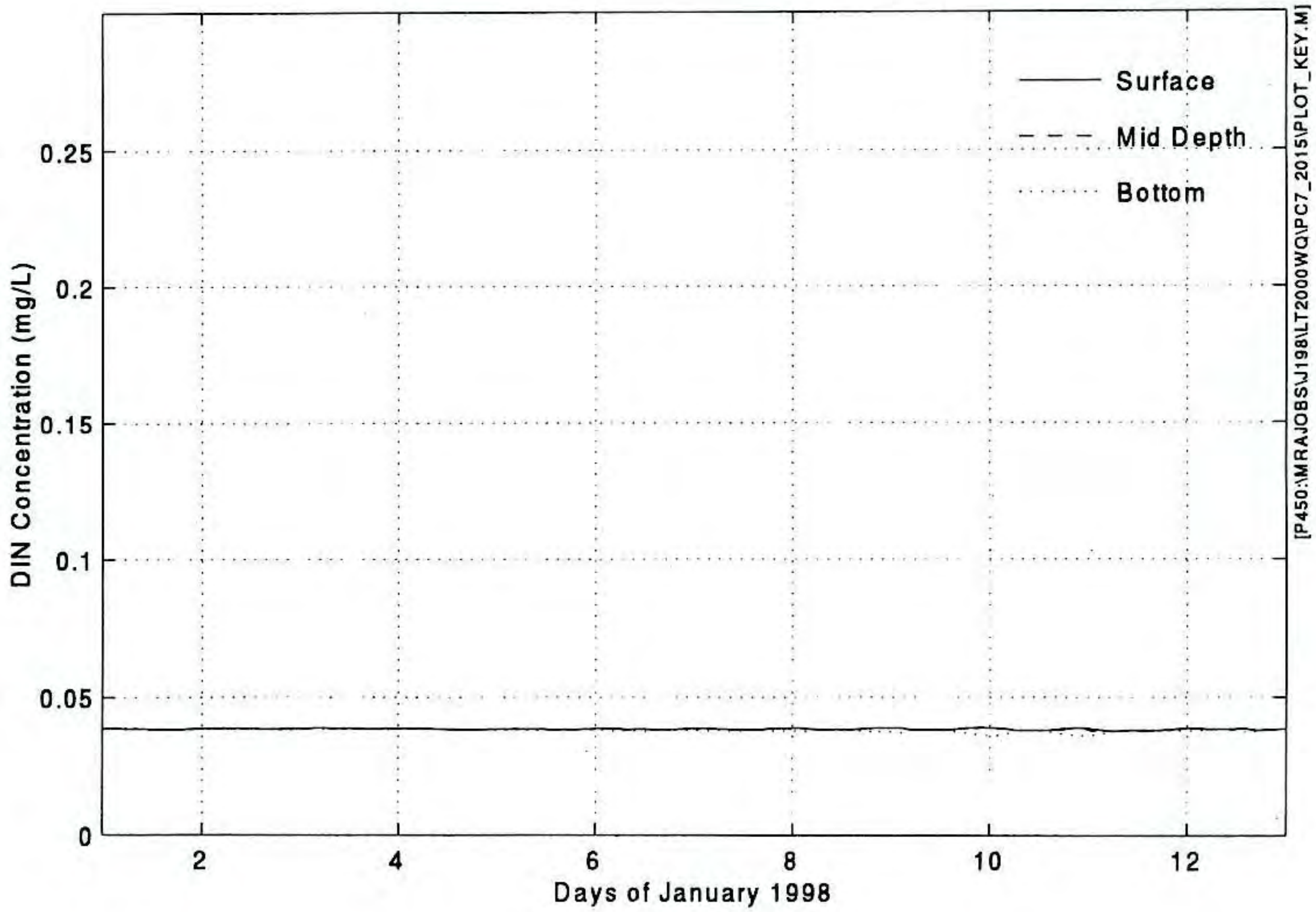


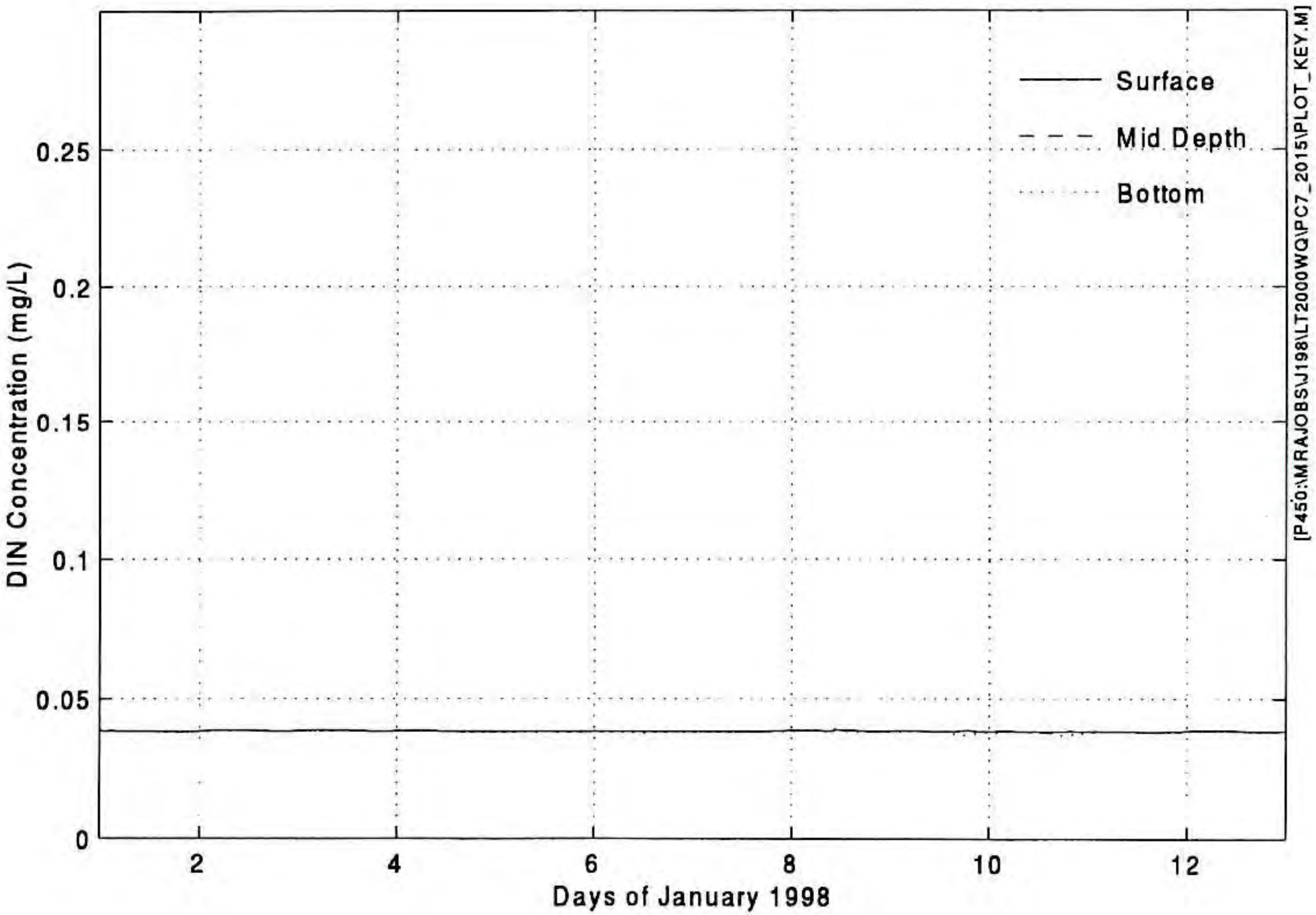
PCD Option 7 - With Extraction - DIN Concentration at Location 6



PCD Option 7 – Year 2012 – DIN Concentration at Location 2



PCD Option 7 - Year 2012 - DIN Concentration at Location 3



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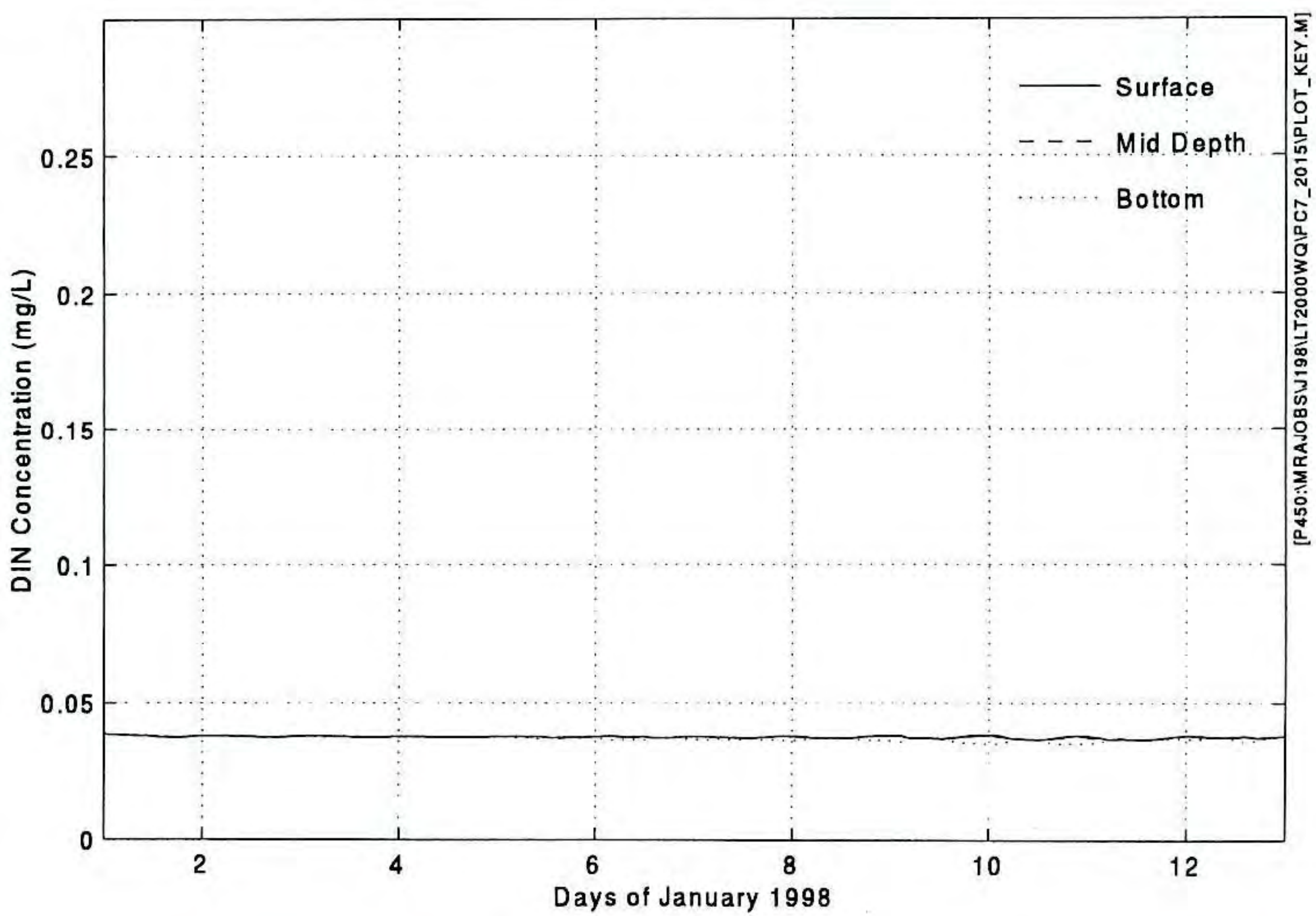
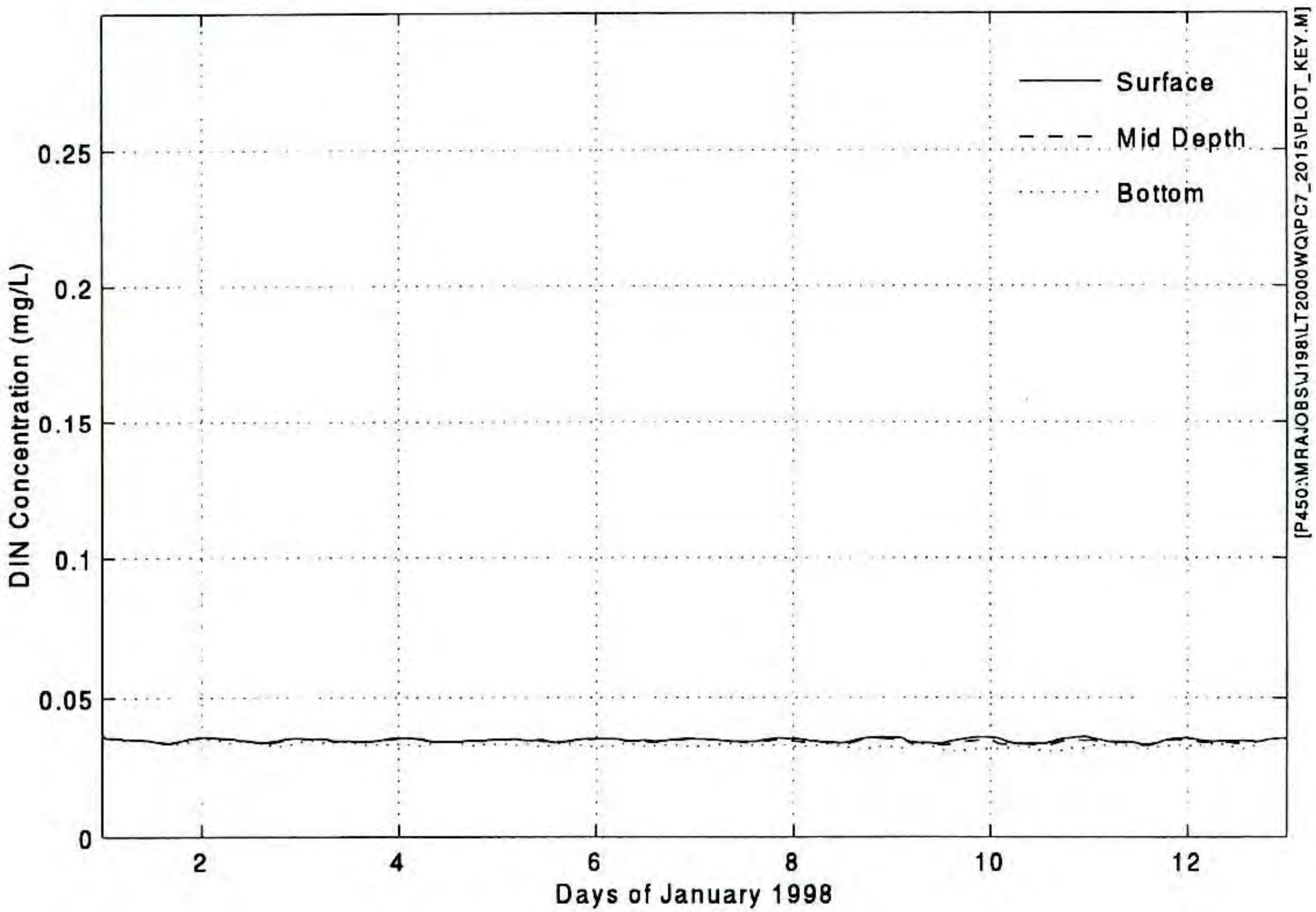
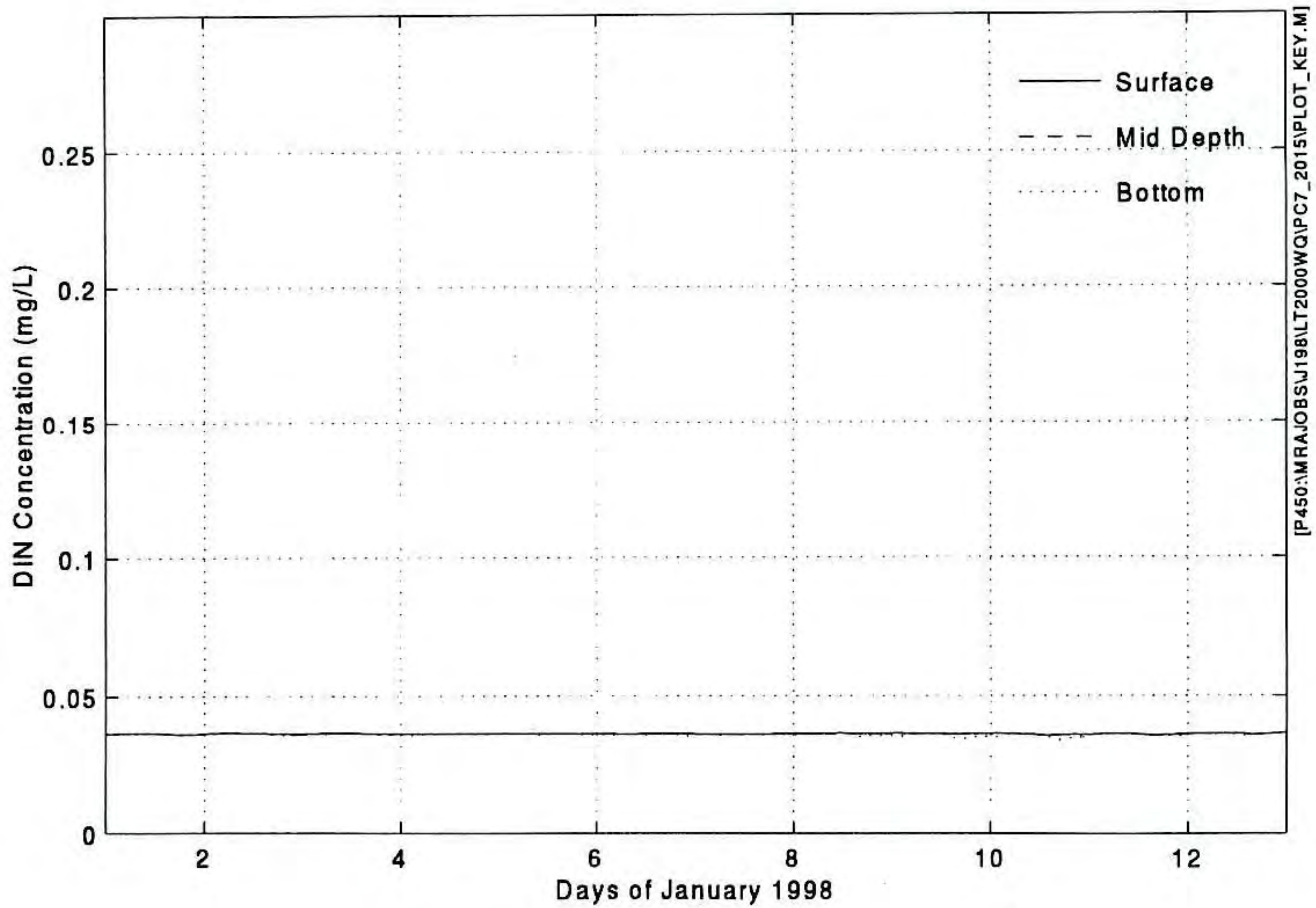


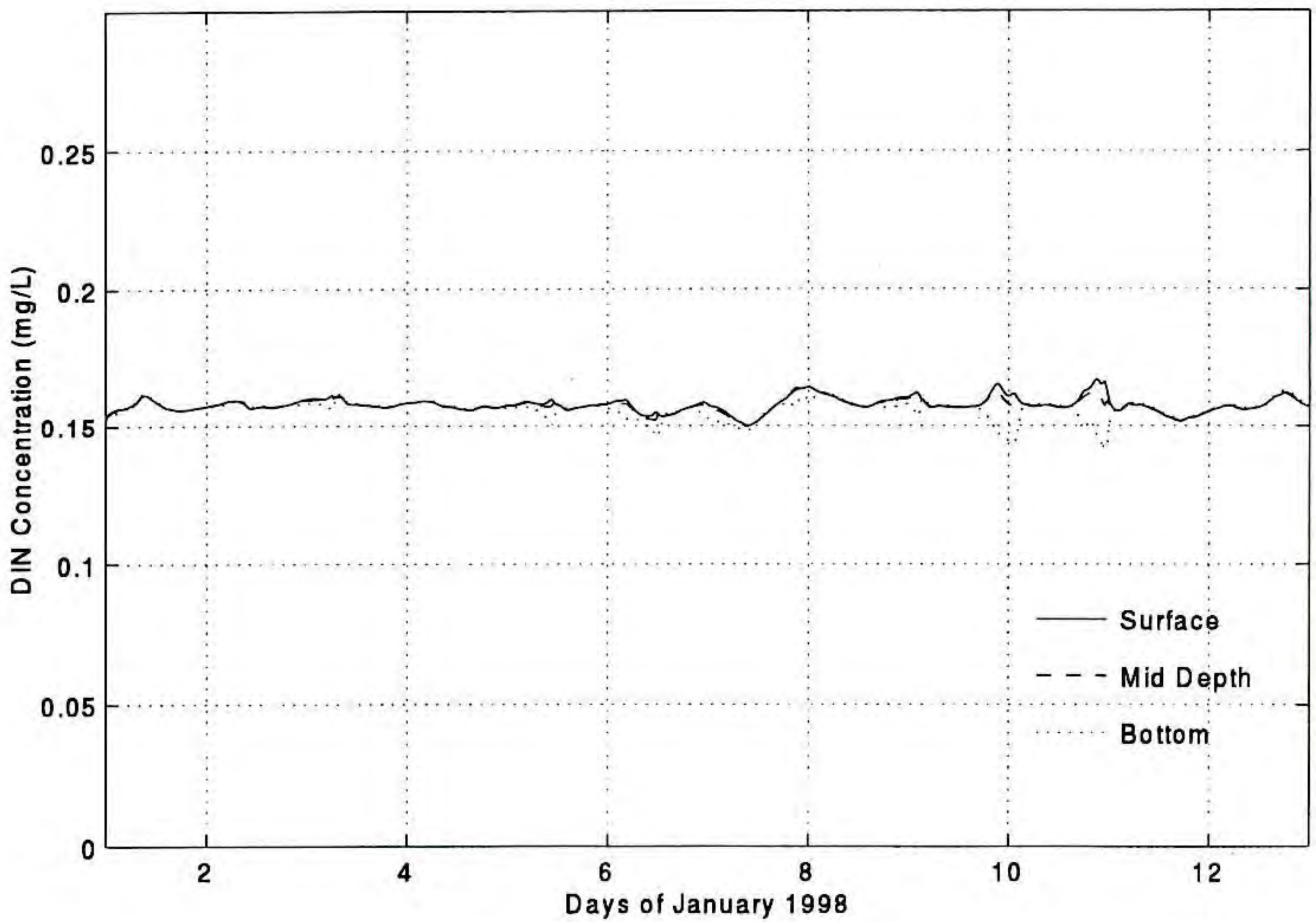
PCD Option 7 - Year 2012 - DIN Concentration at Location 5

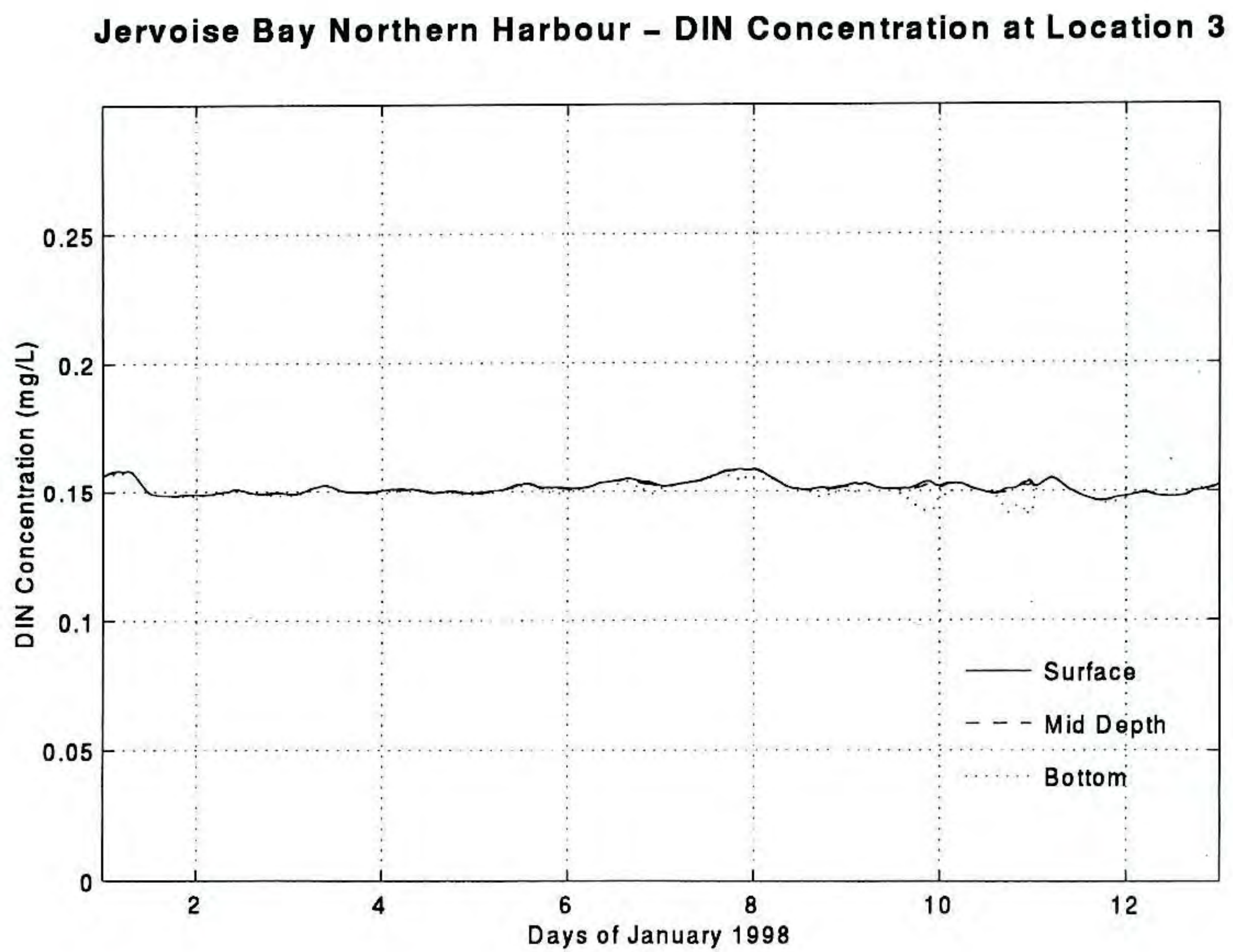


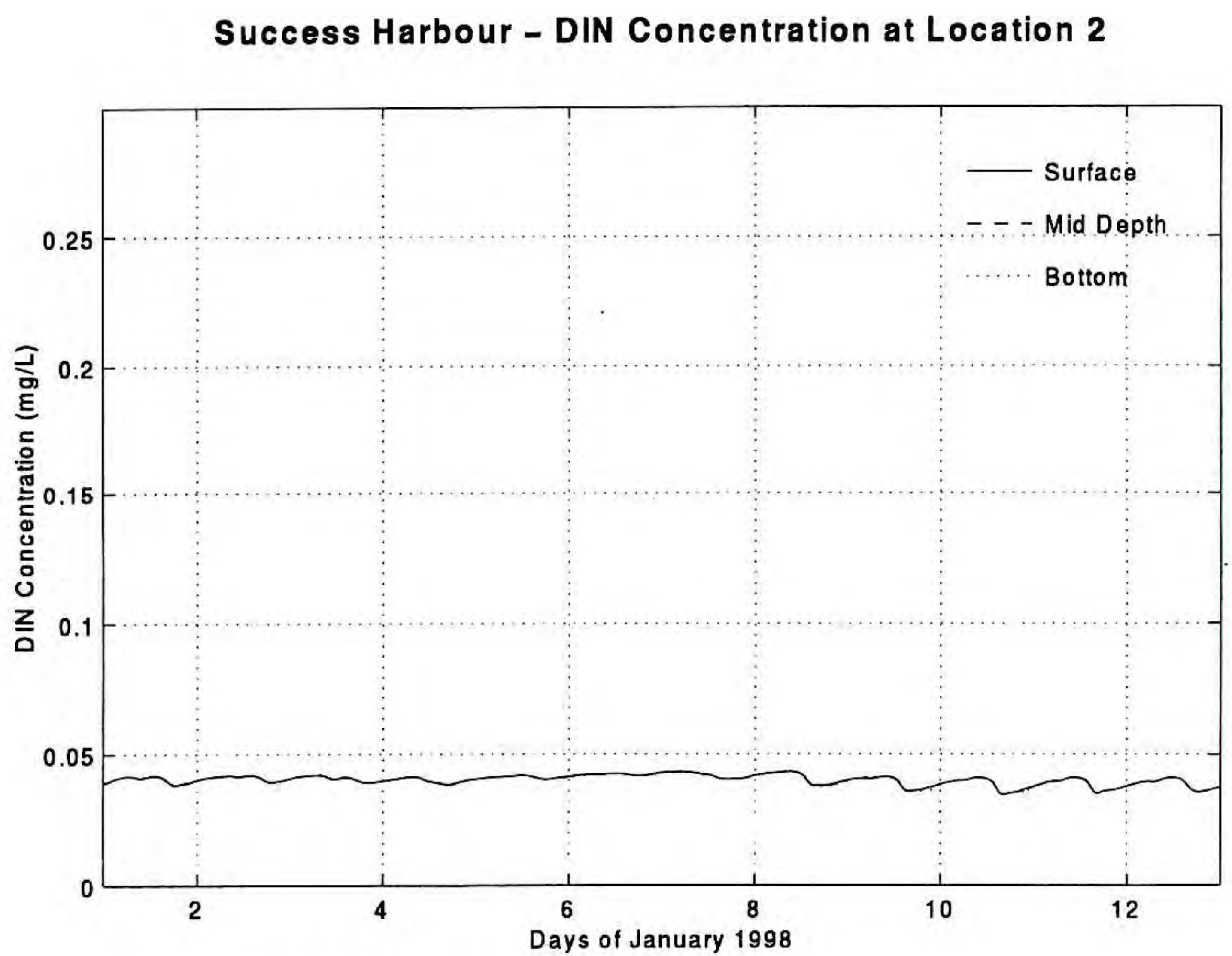
PCD Option 7 – Year 2012 – DIN Concentration at Location 6



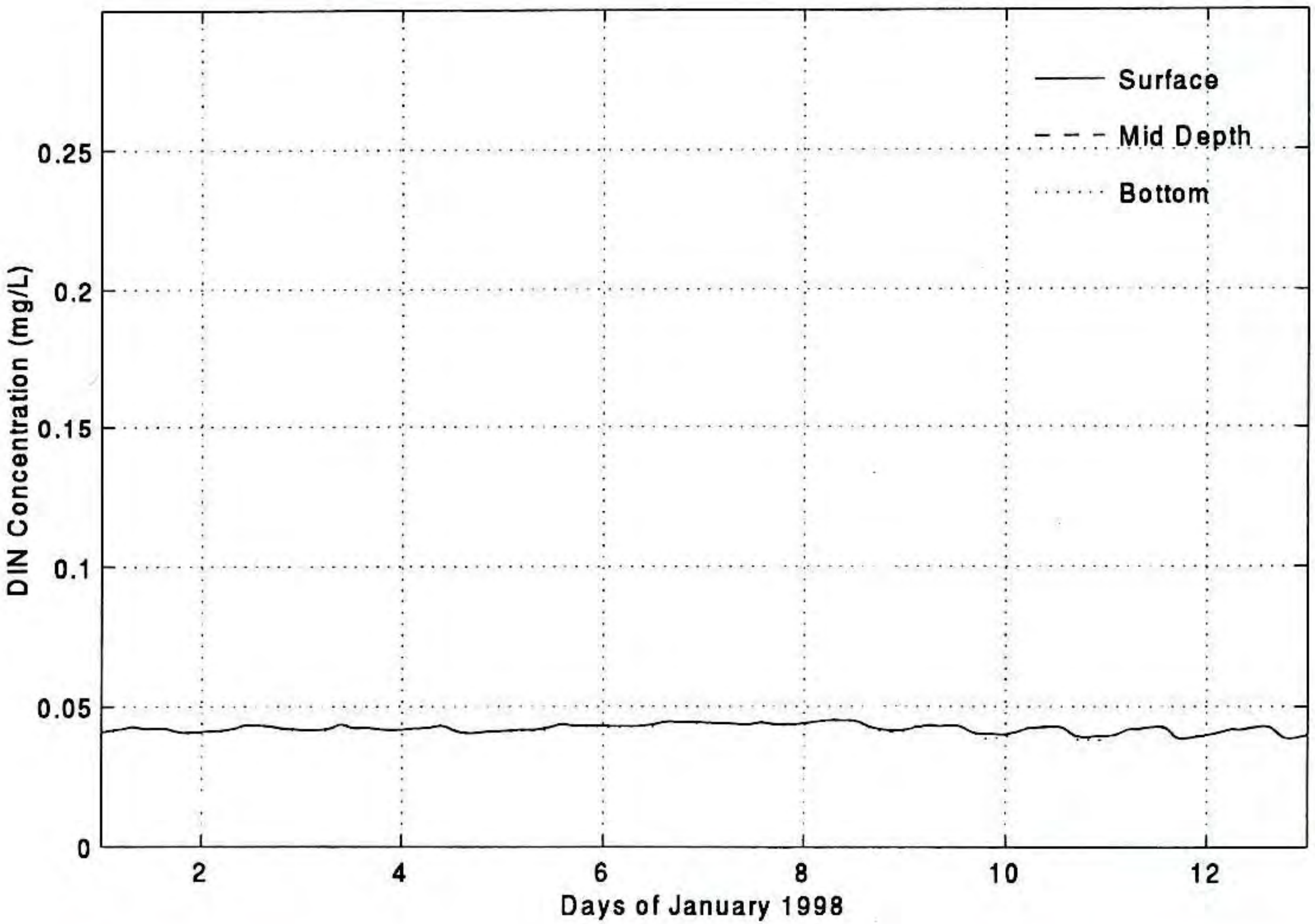
Jervoise Bay Northern Harbour - DIN Concentration at Location 2

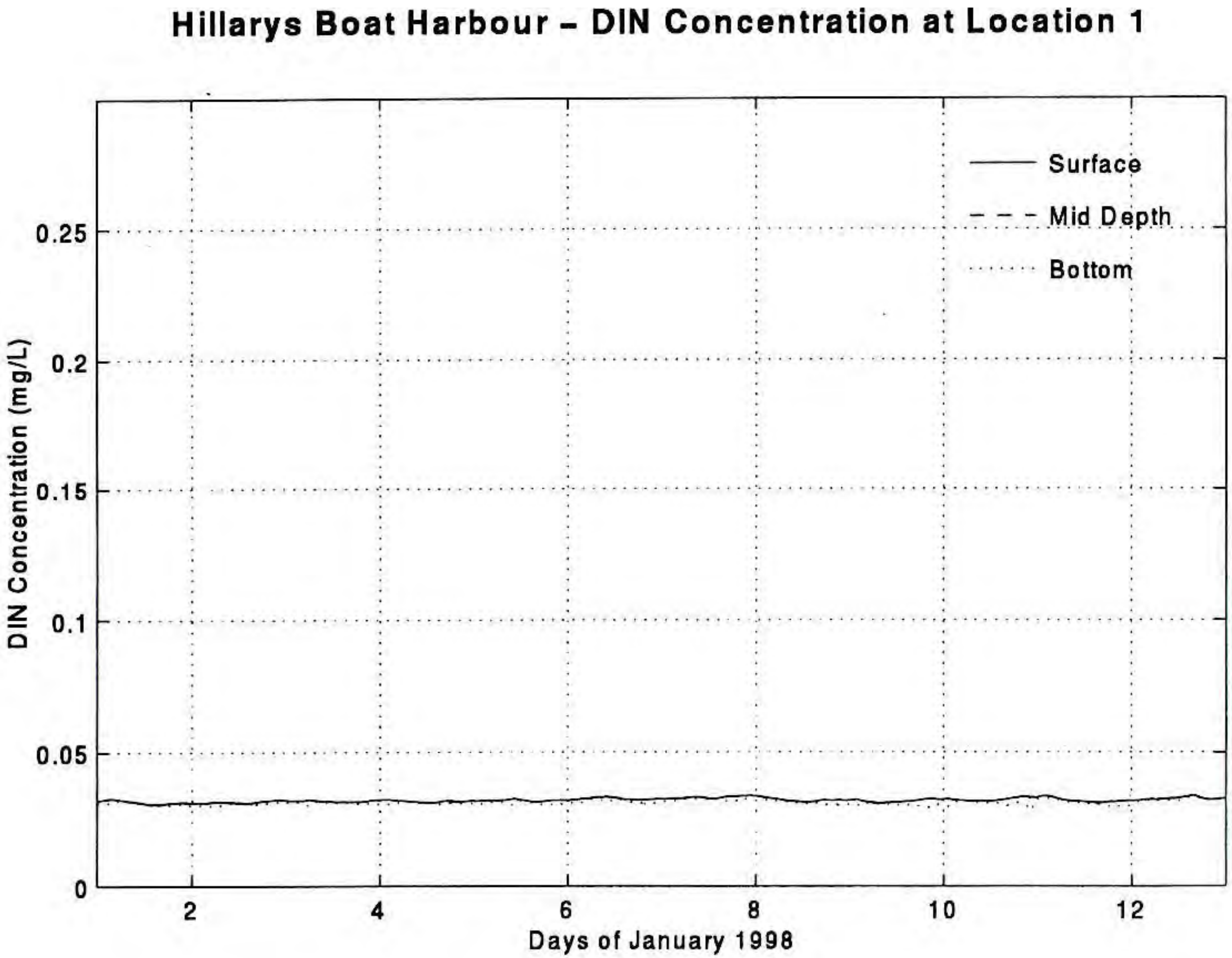


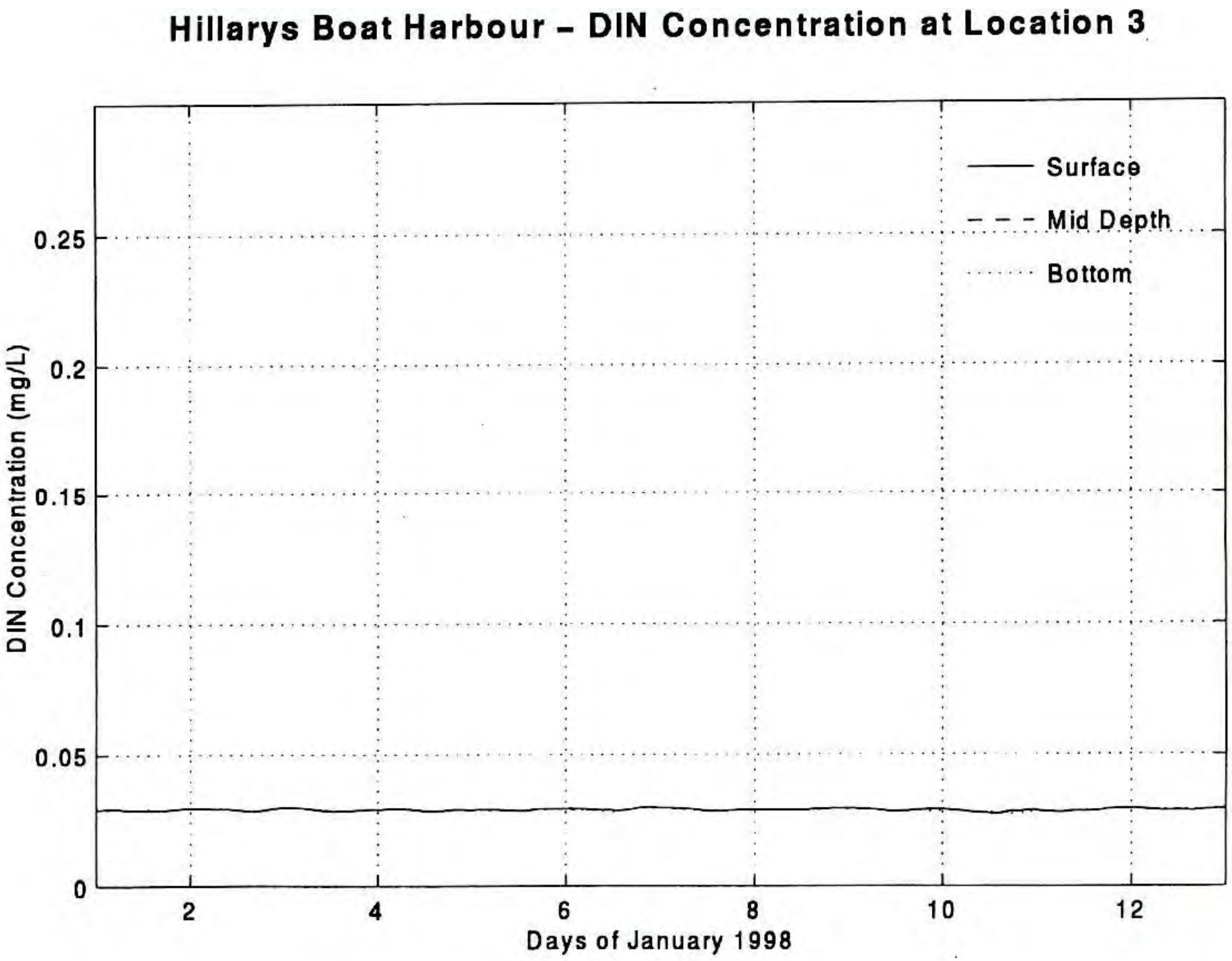

Jervoise Bay Northern Harbour - DIN Concentration at Location 3
DIN Concentration (mg/L)
0.25
0.2
0.15
0.1
0.05
0
2
4
6
8
10
12
Days of January 1998
Surface
Mid Depth
Bottom


Success Harbour - DIN Concentration at Location 2
Surface
Mid Depth
Bottom
DIN Concentration (mg/L)
0
0.05
0.1
0.15
0.2
0.25
2
4
6
8
10
12
Days of January 1998

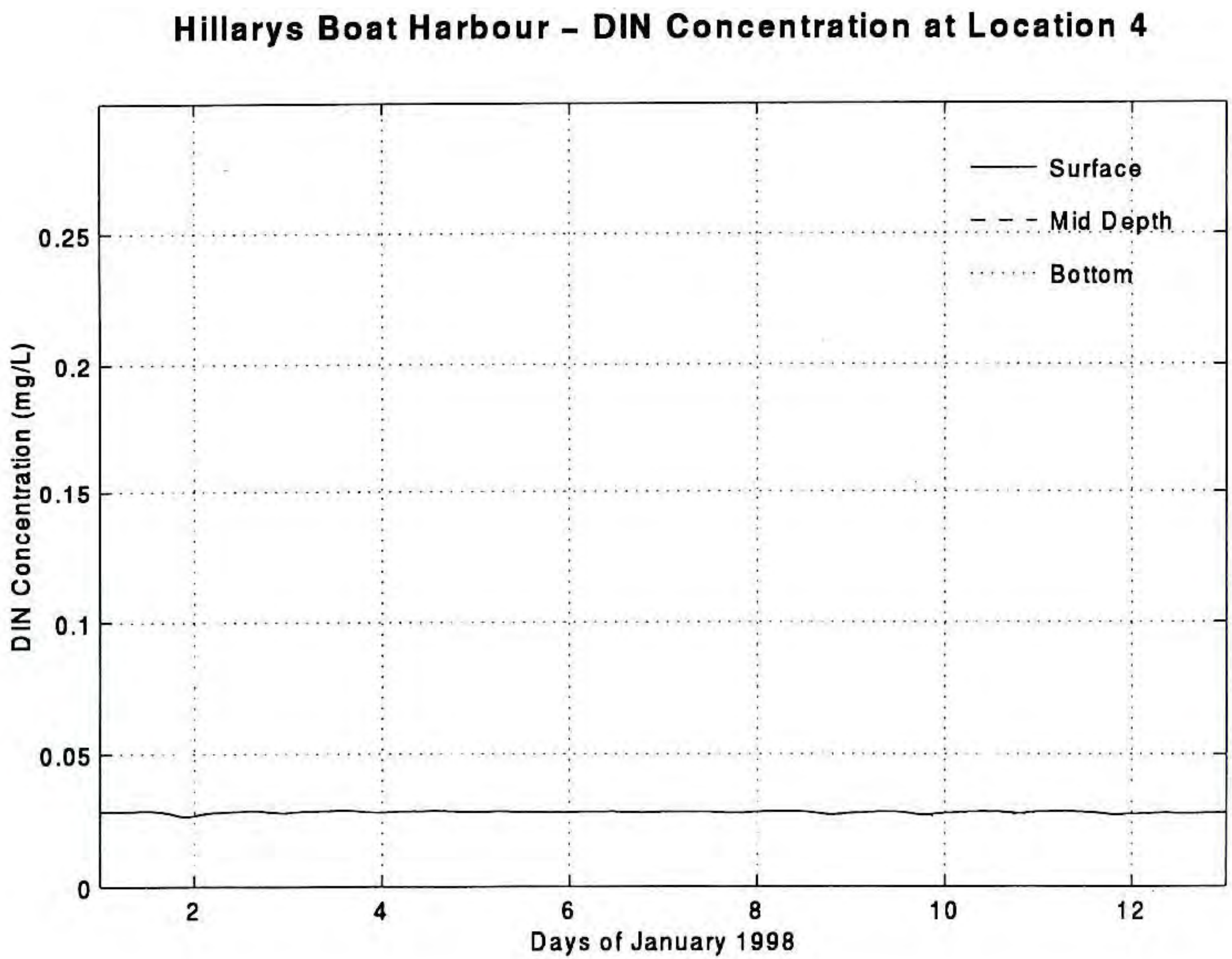
Success Harbour - DIN Concentration at Location 3



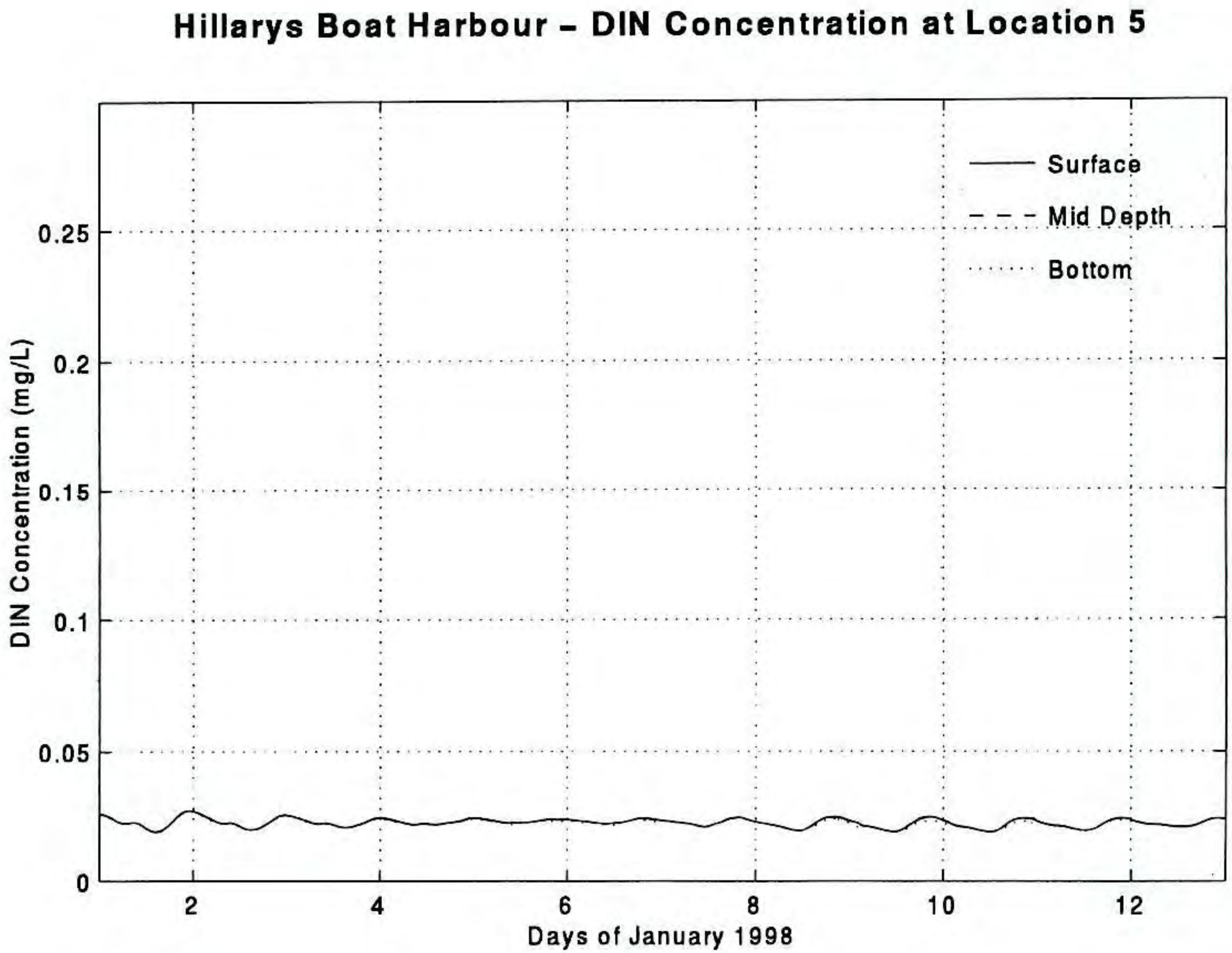

Hillarys Boat Harbour - DIN Concentration at Location 1
Surface
Mid Depth
Bottom
DIN Concentration (mg/L)
0
0.05
0.1
0.15
0.2
0.25
2
4
6
8
10
12
Days of January 1998



Hillarys Boat Harbour - DIN Concentration at Location 3
Surface
Mid Depth
Bottom
DIN Concentration (mg/L)
0.25
0.2
0.15
0.1
0.05
0
2
4
6
8
10
12
Days of January 1998

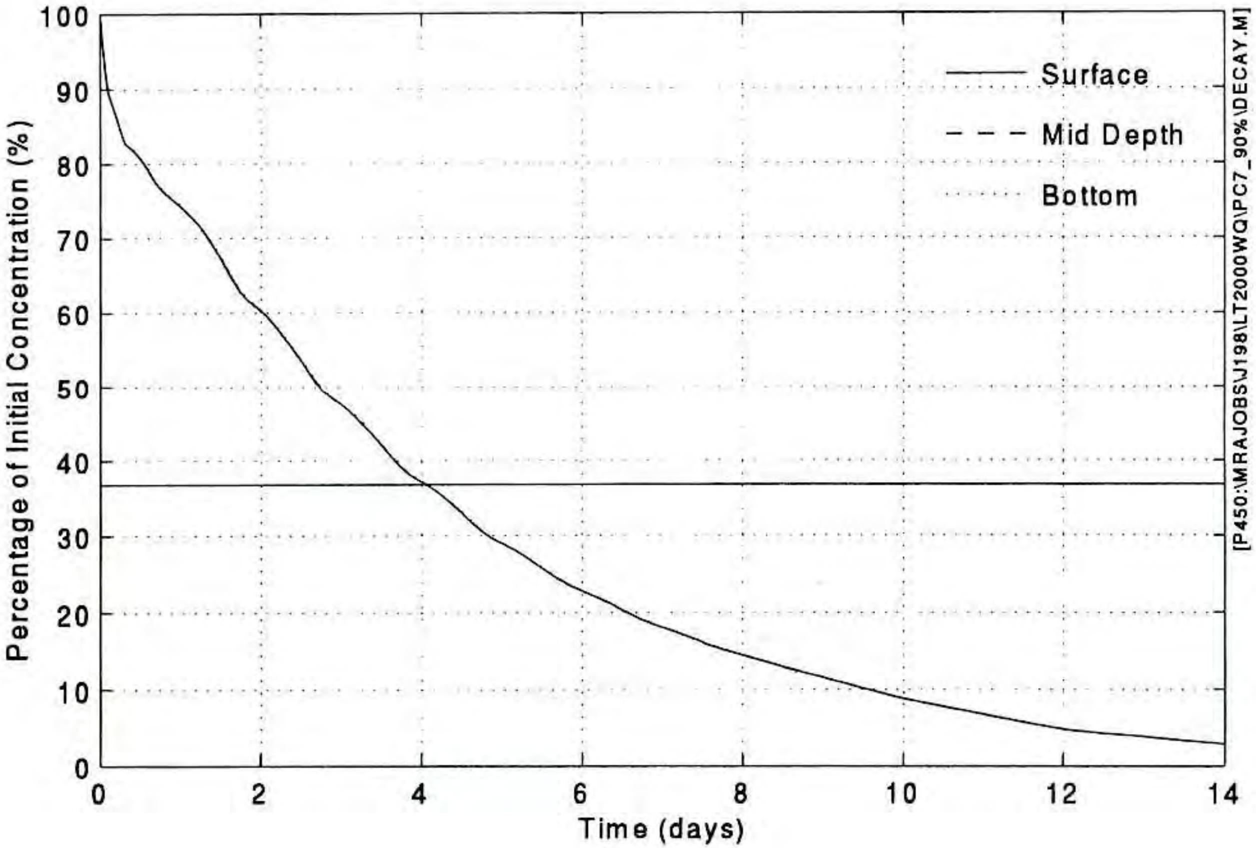


Hillarys Boat Harbour - DIN Concentration at Location 4
Surface
Mid Depth
Bottom
DIN Concentration (mg/L)
0.25
0.2
0.15
0.1
0.05
0
2
4
6
8
10
12
Days of January 1998

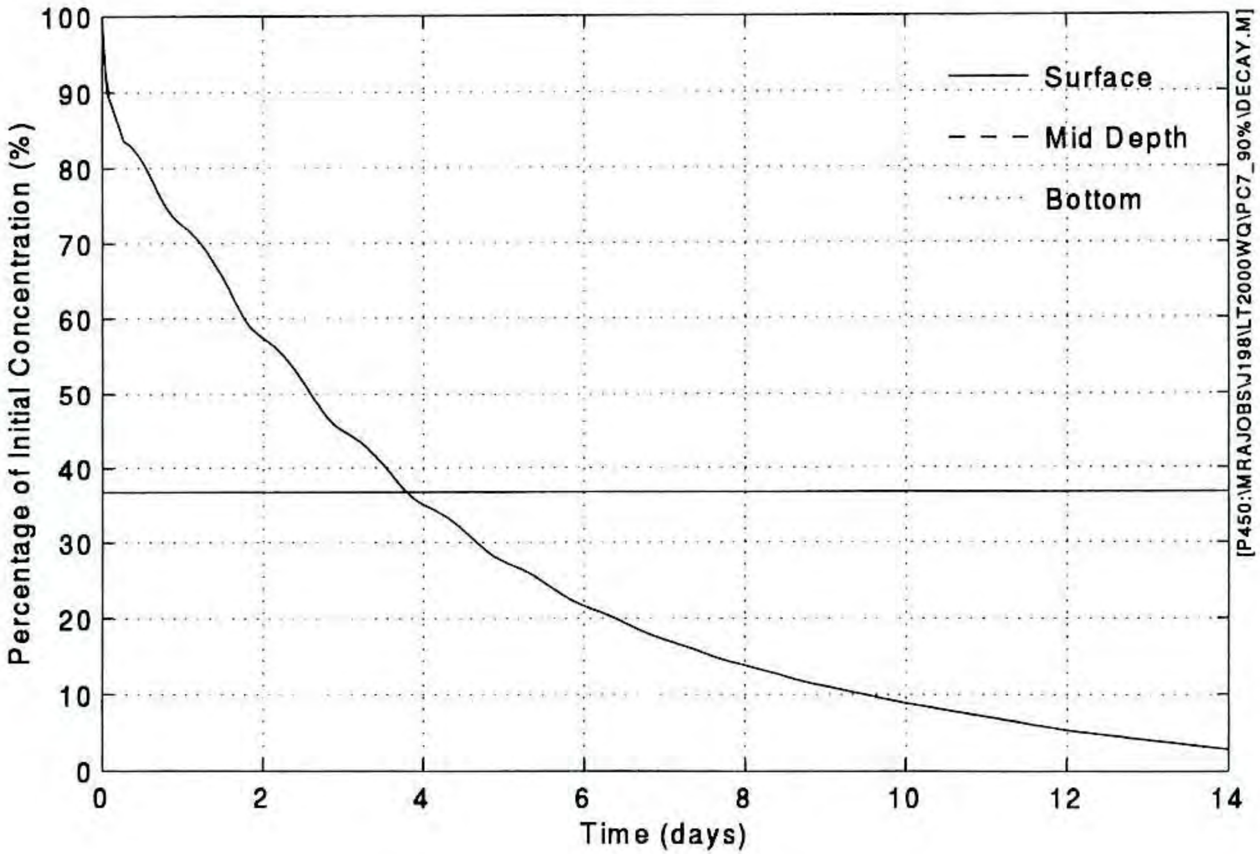

Hillarys Boat Harbour - DIN Concentration at Location 5
Surface
Mid Depth
Bottom
DIN Concentration (mg/L)
0.25
0.2
0.15
0.1
0.05
0
2
4
6
8
10
12
Days of January 1998

Appendix C Decay Curves

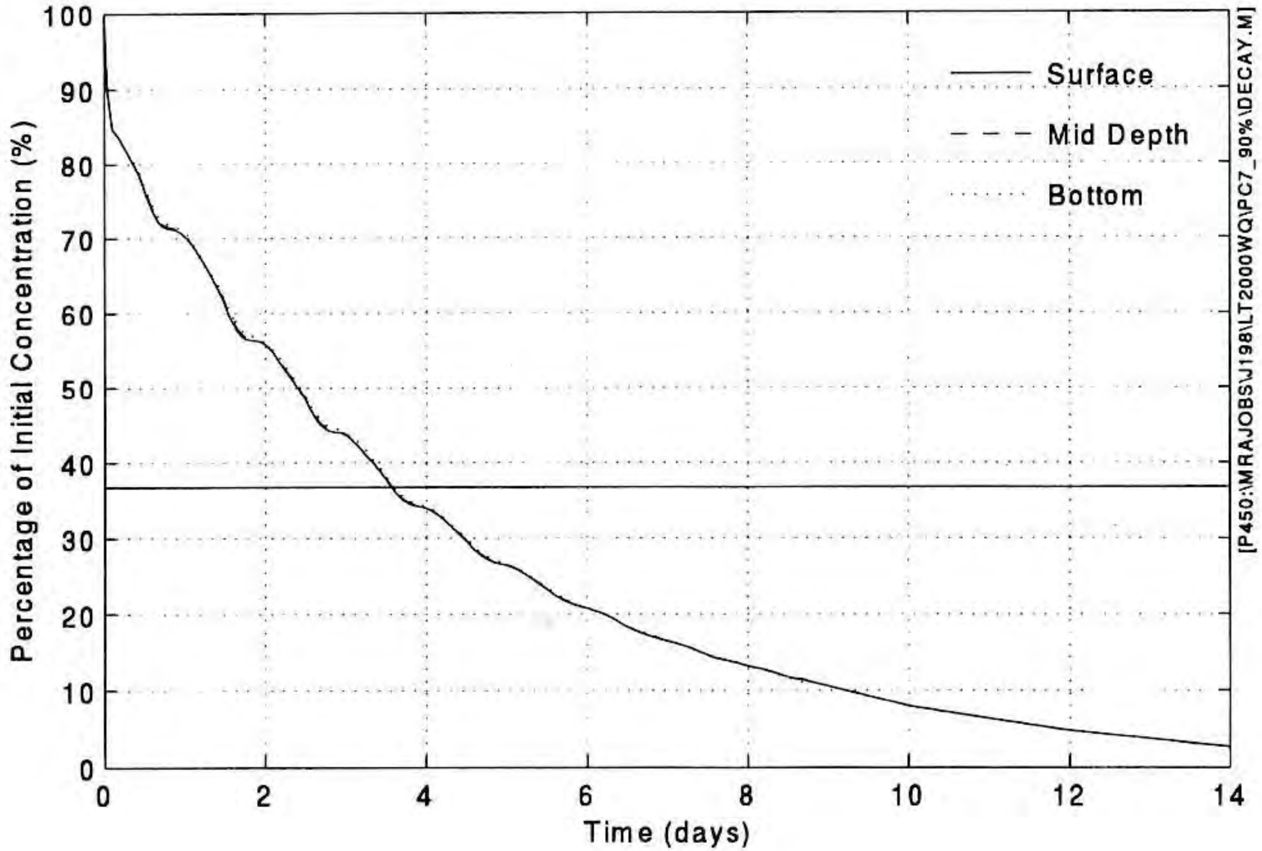
PCD Option 7 - With Extraction - Decay of Conservative Tracer at Location 2



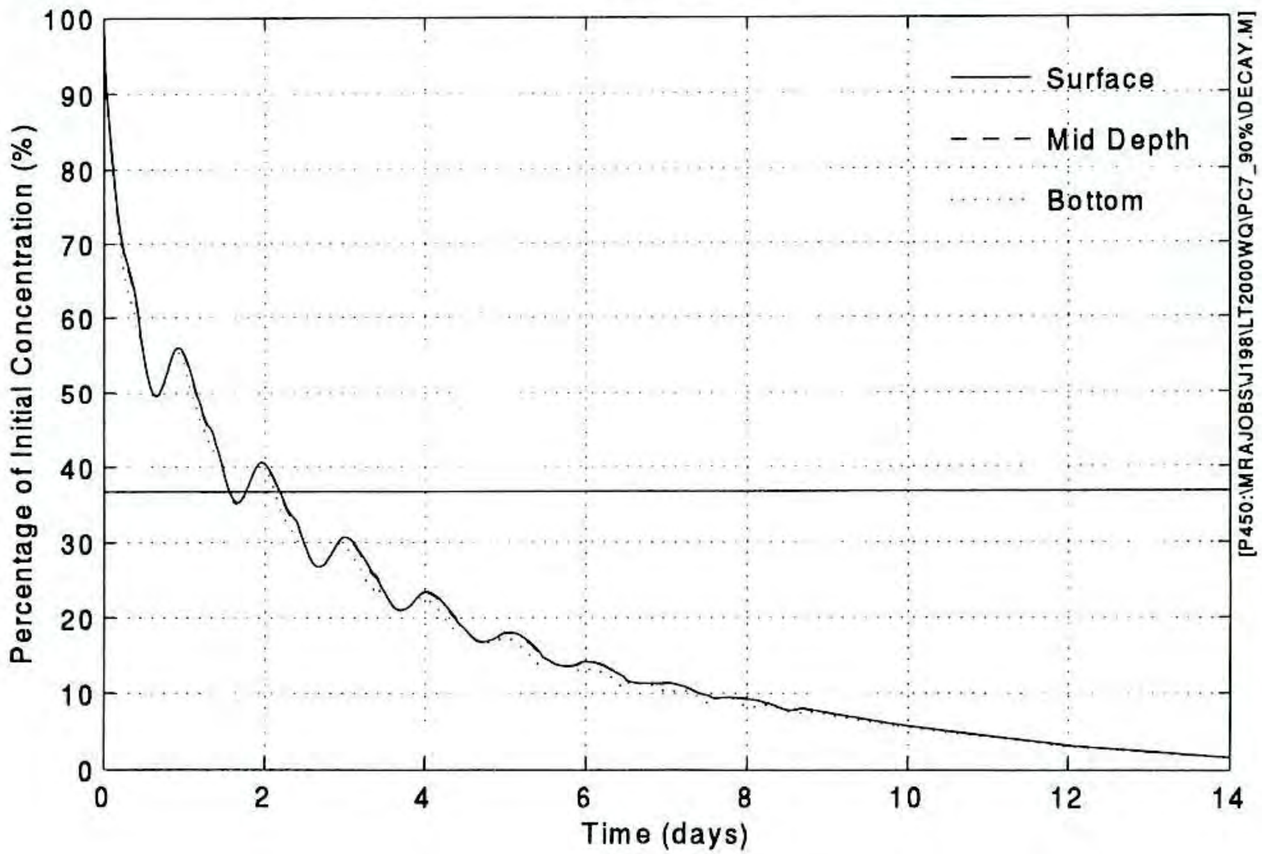
PCD Option 7 - With Extraction - Decay of Conservative Tracer at Location 3



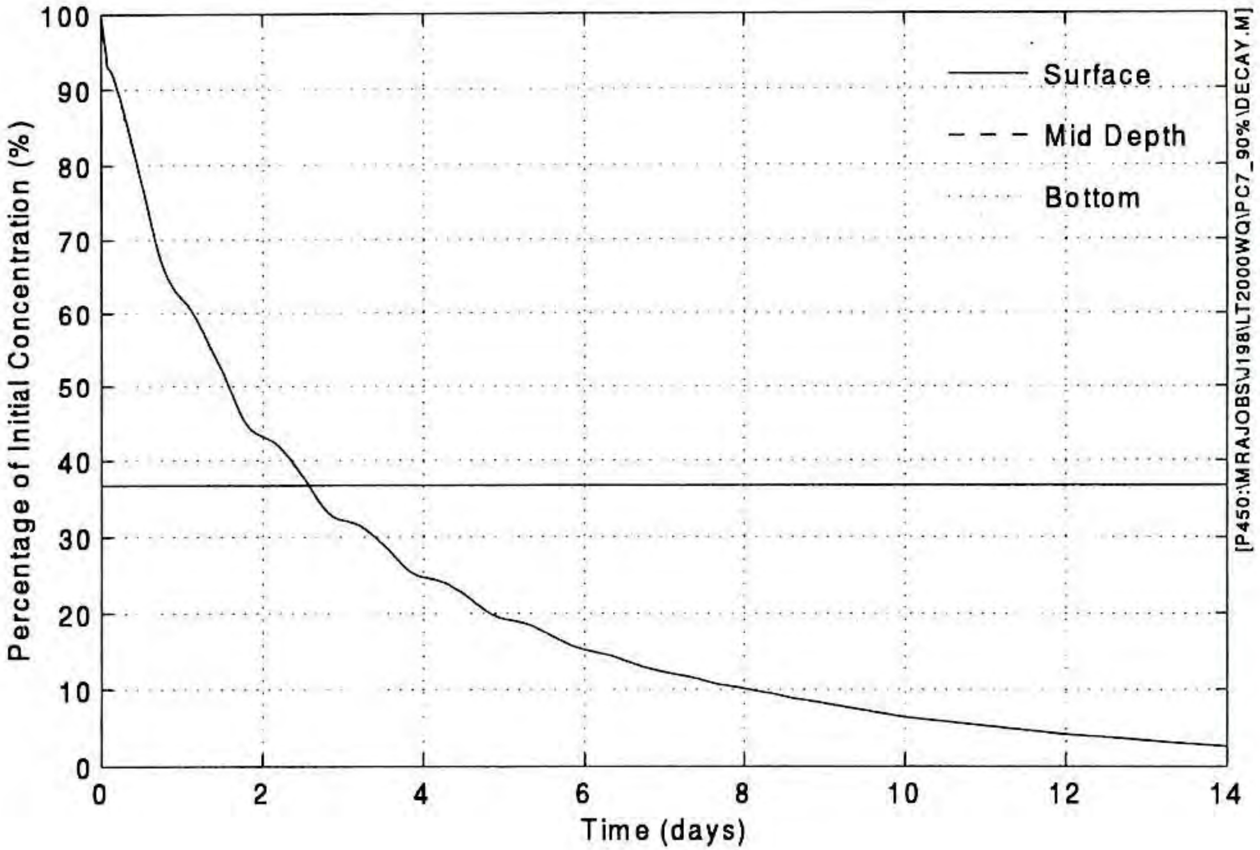
PCD Option 7 - With Extraction - Decay of Conservative Tracer at Location 4



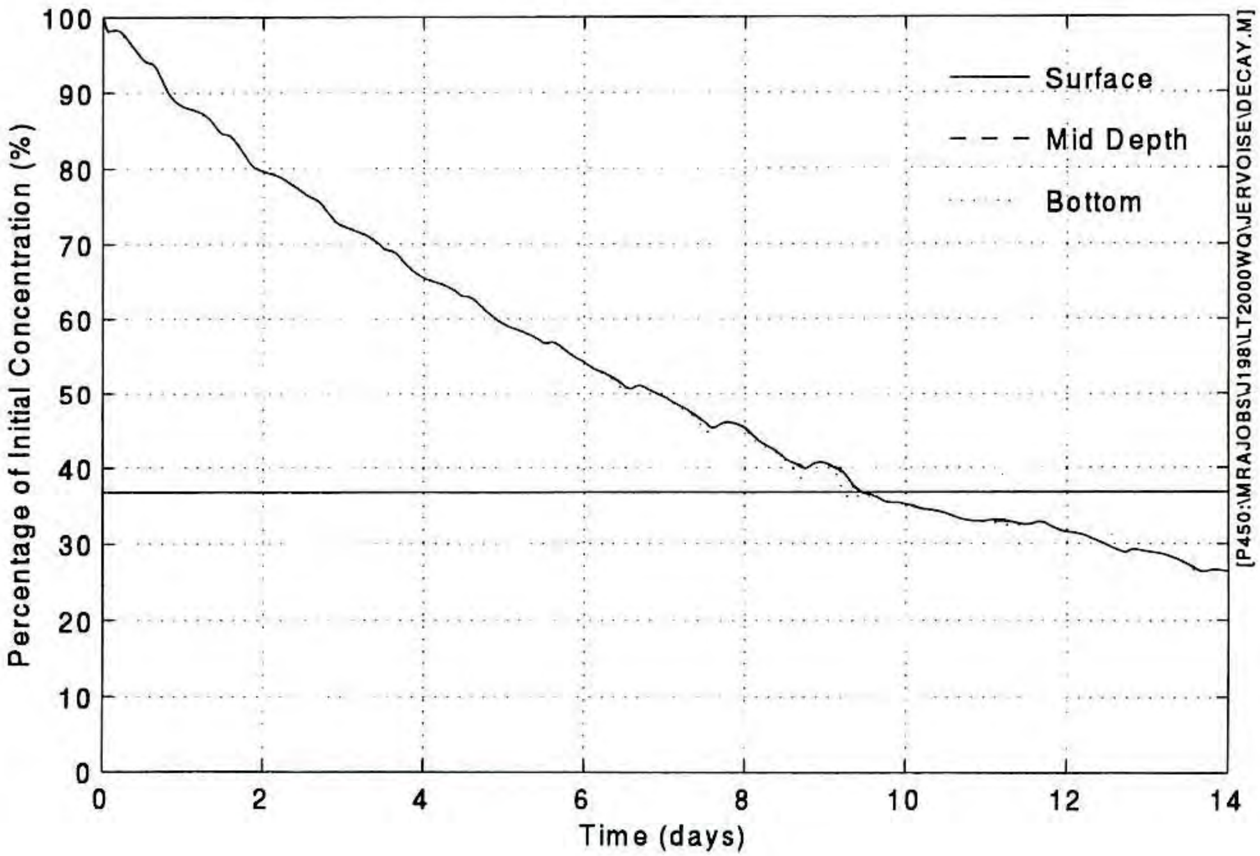
PCD Option 7 – With Extraction – Decay of Conservative Tracer at Location 5



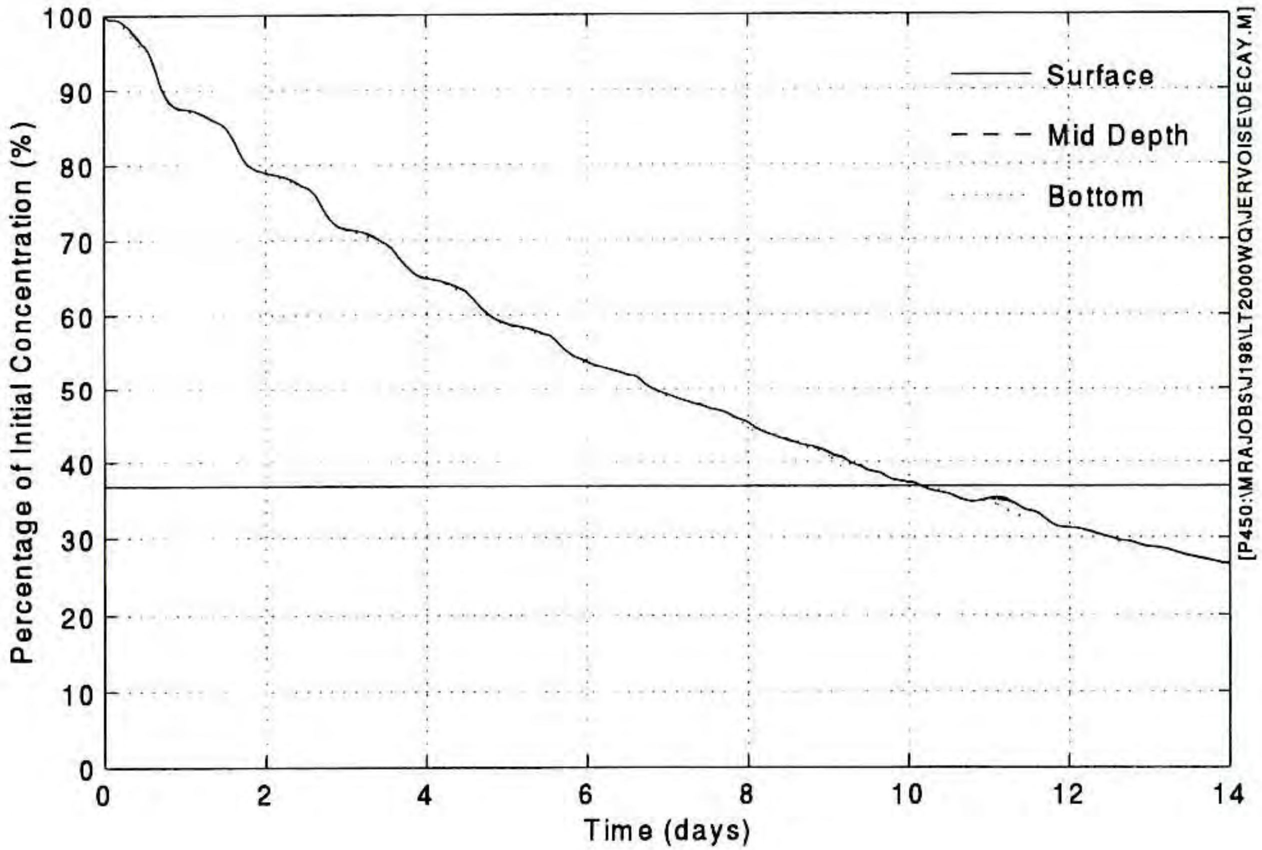
PCD Option 7 - With Extraction - Decay of Conservative Tracer at Location 6



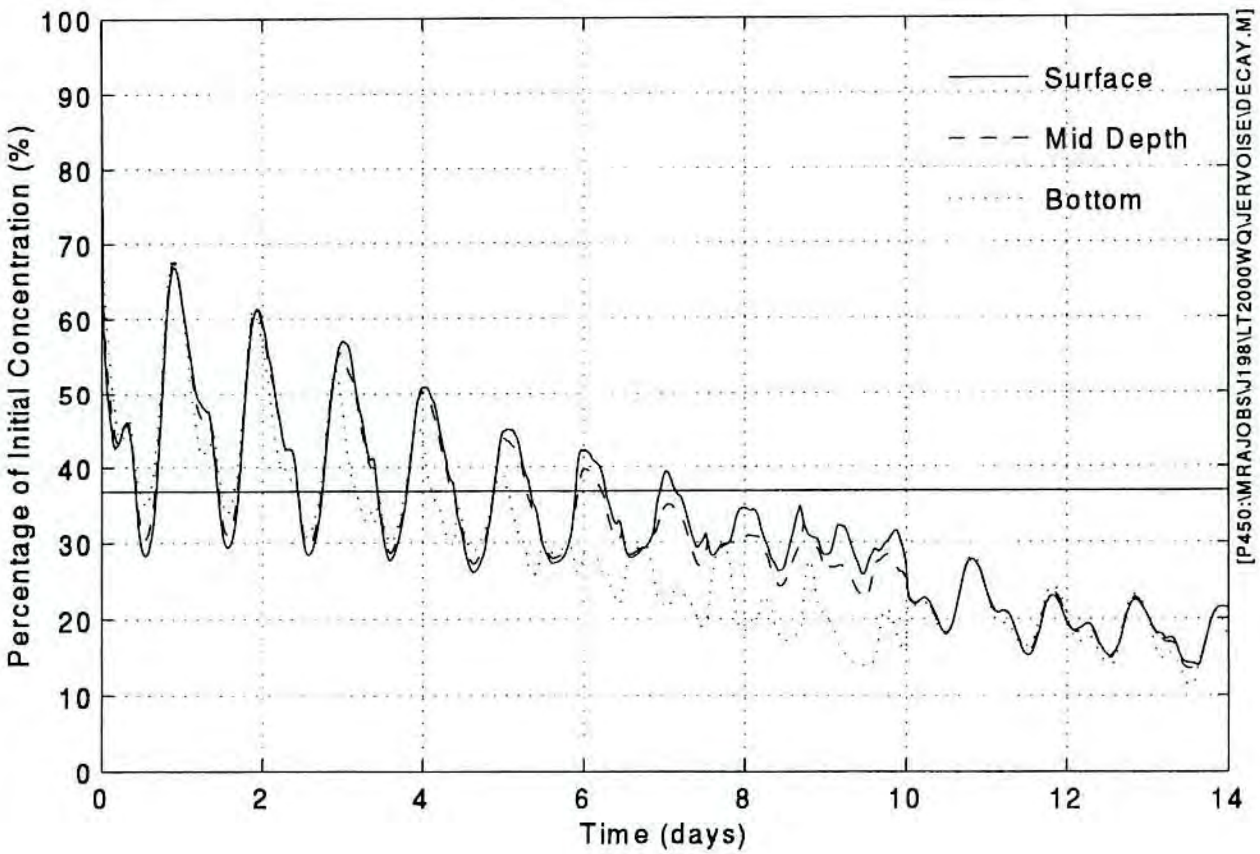
Jervoise Bay Northern Harbour - Decay of Conservative Tracer at Location 2



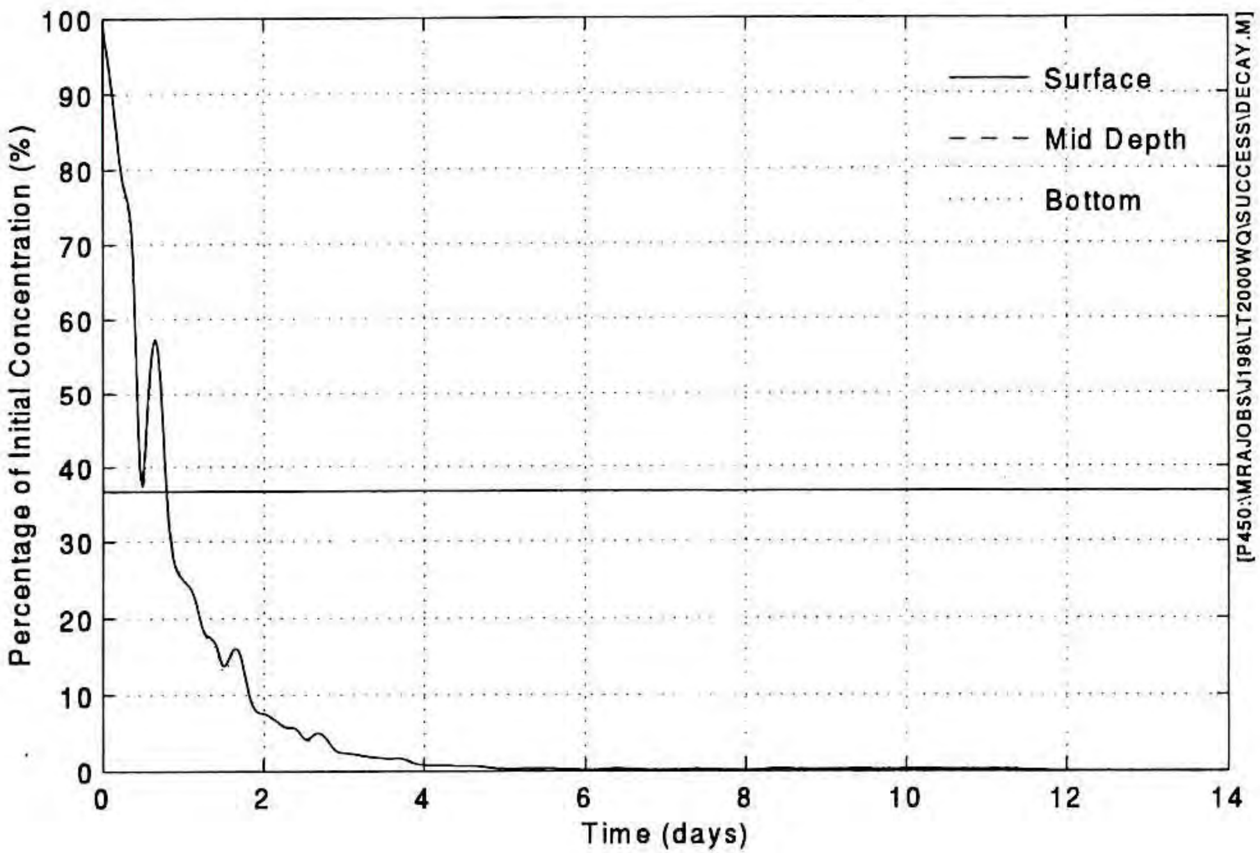
Jervoise Bay Northern Harbour - Decay of Conservative Tracer at Location 3



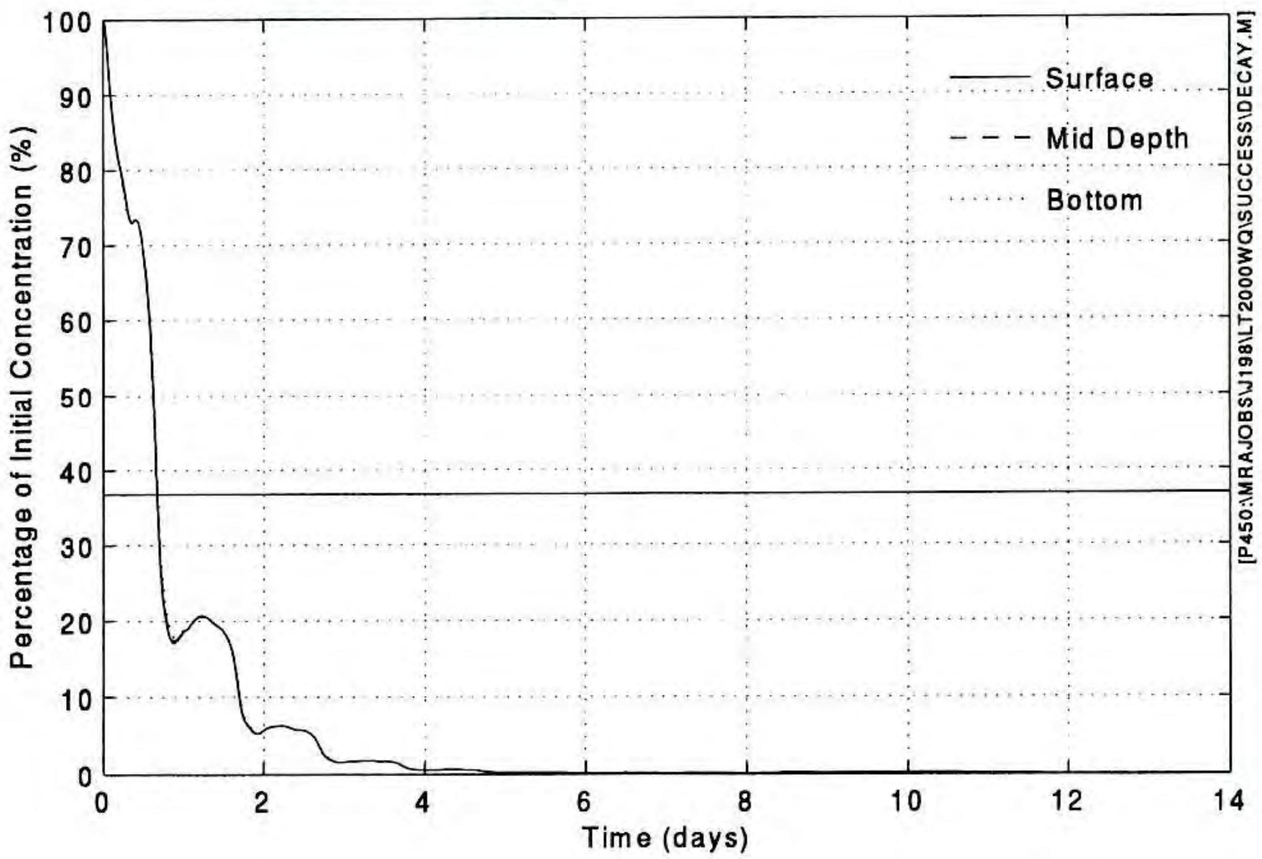
Jervoise Bay Northern Harbour - Decay of Conservative Tracer at Location 5



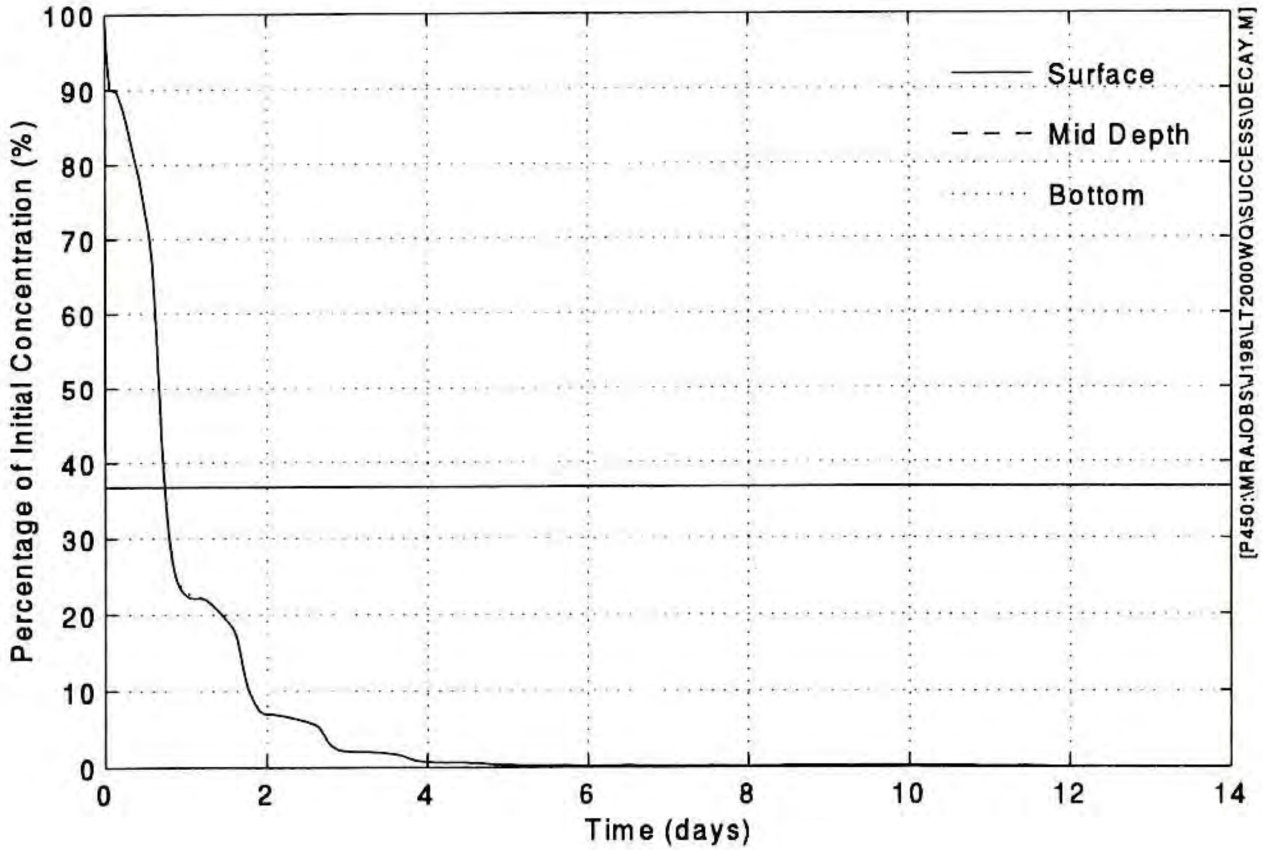
Success Harbour - Decay of Conservative Tracer at Location 1



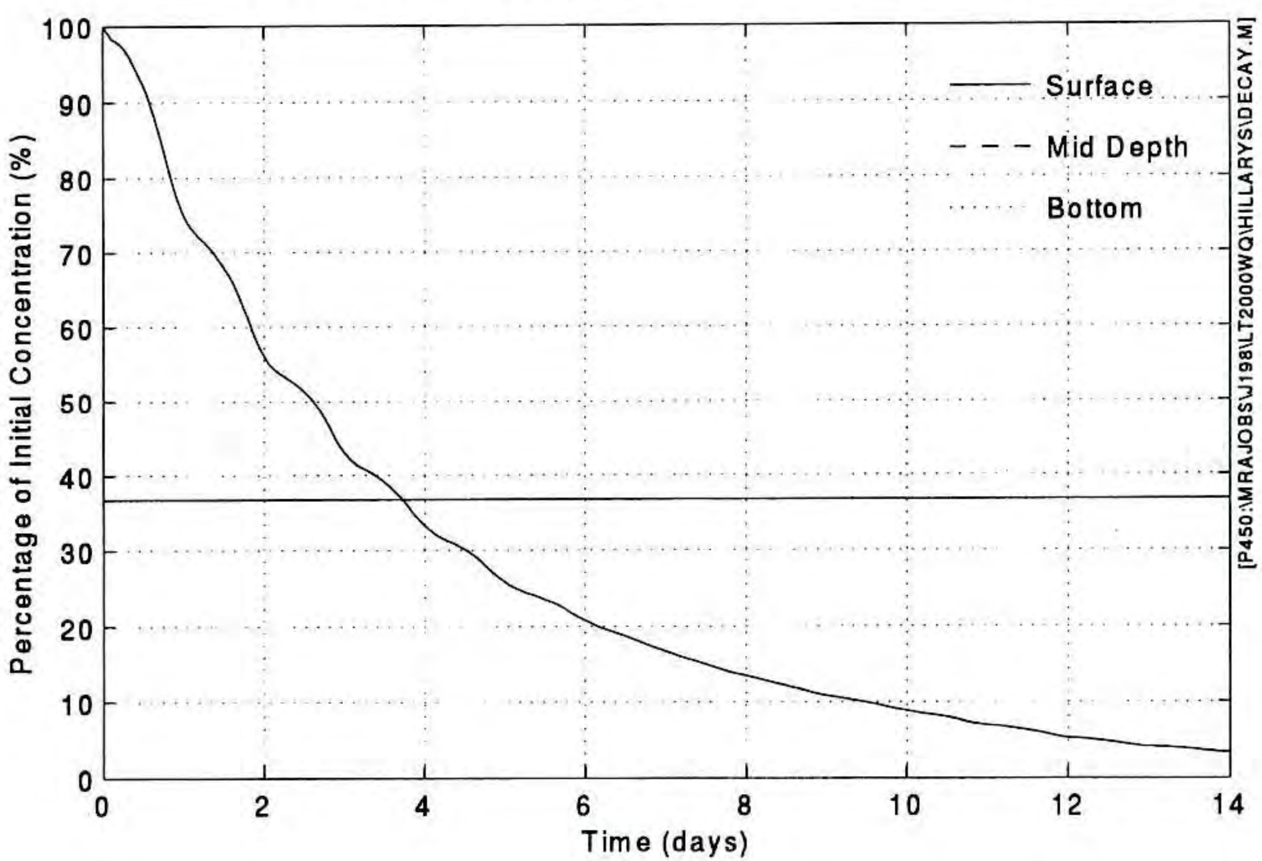
Success Harbour – Decay of Conservative Tracer at Location 2



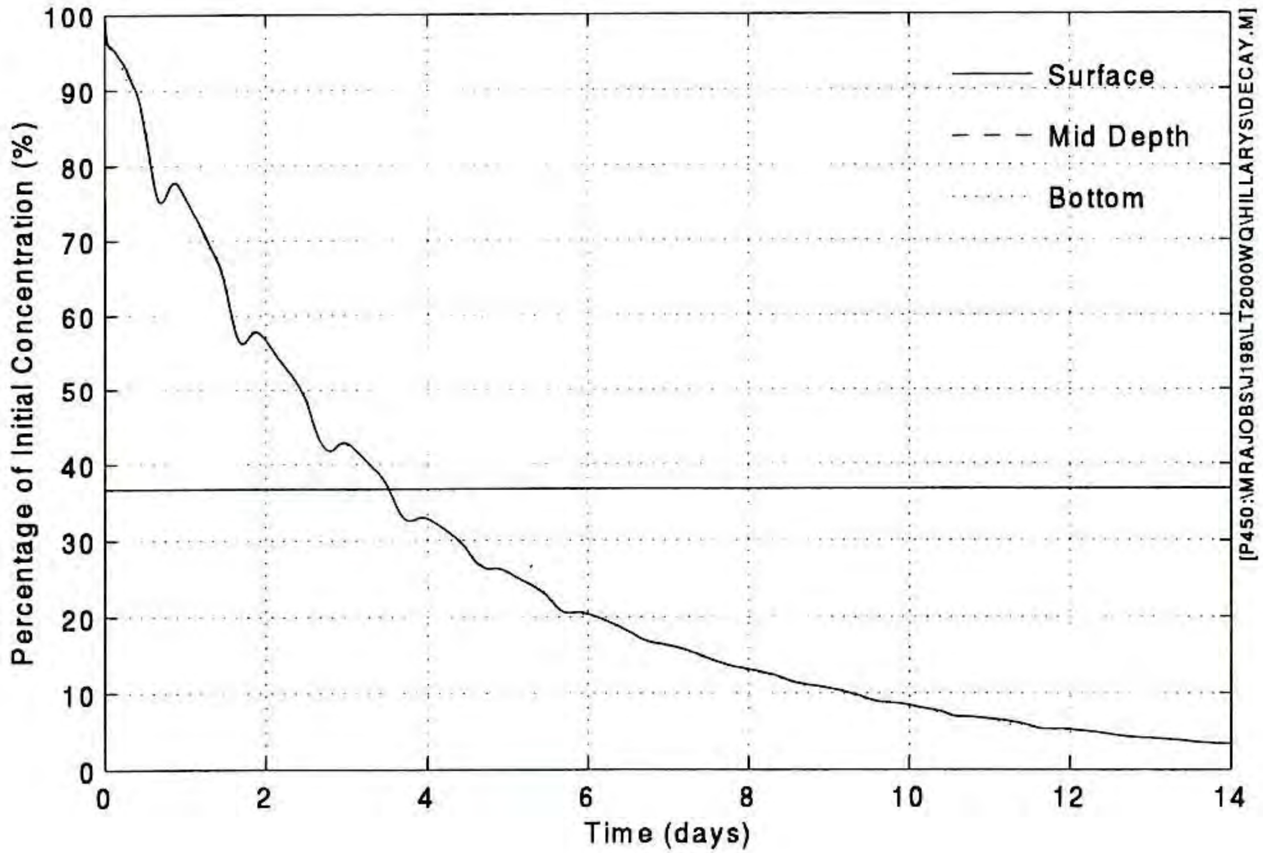
Success Harbour - Decay of Conservative Tracer at Location 3



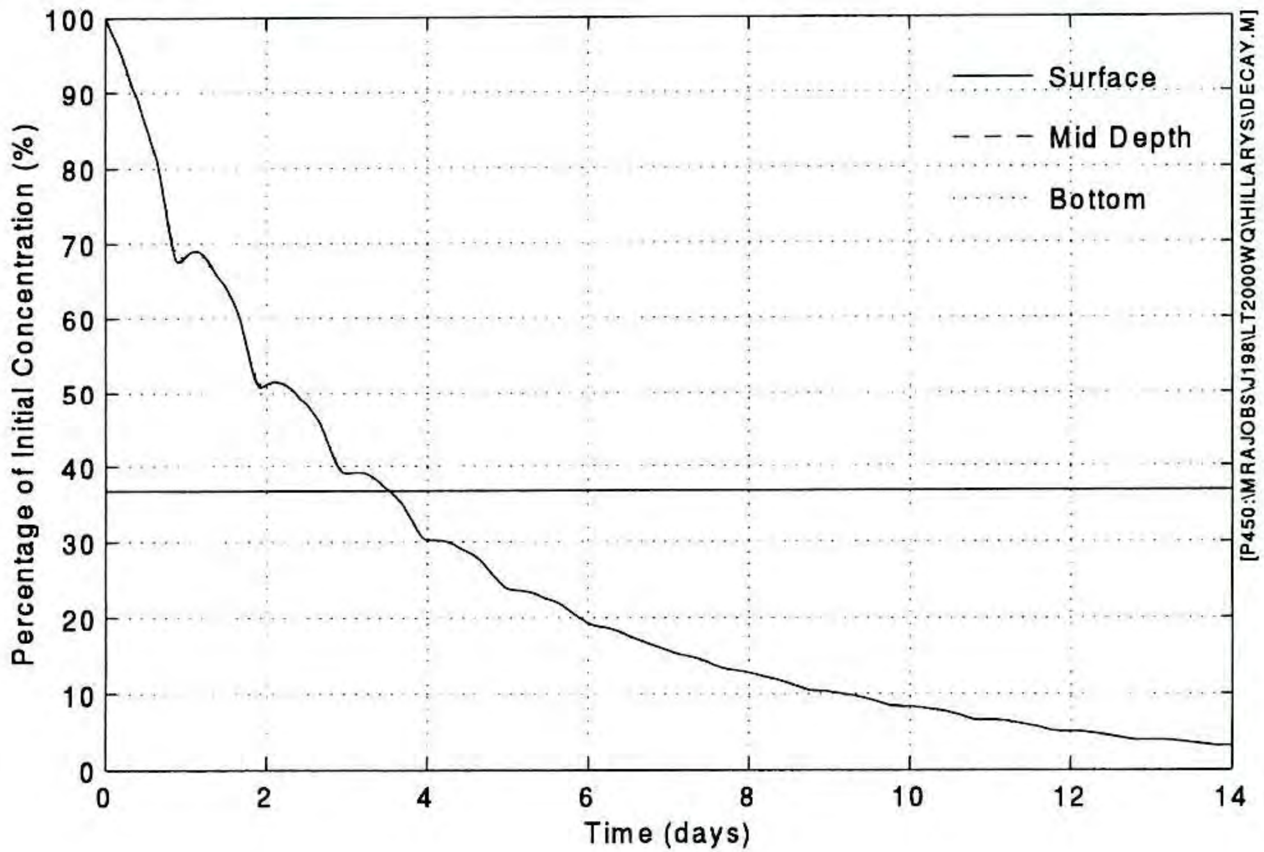
Hillarys Boat Harbour – Decay of Conservative Tracer at Location 1



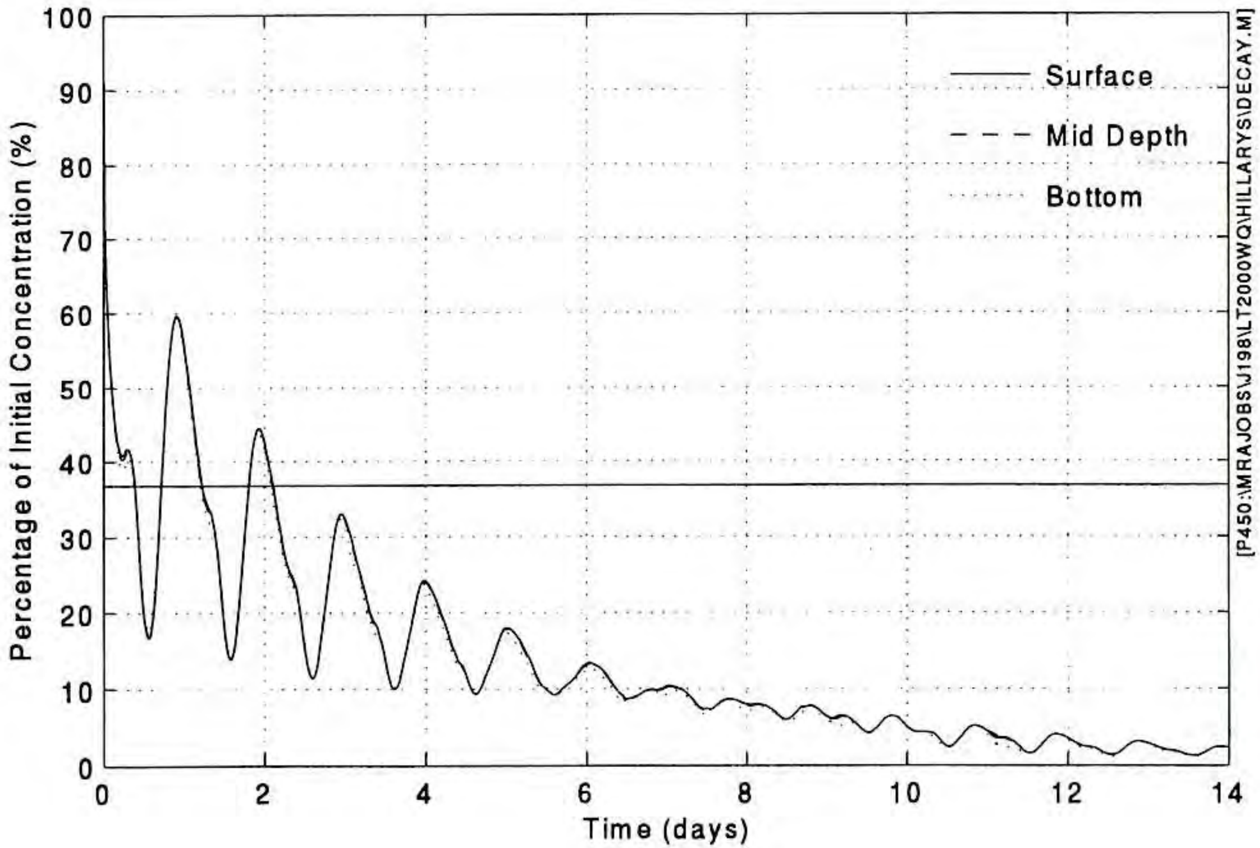
Hillarys Boat Harbour - Decay of Conservative Tracer at Location 3



Hillarys Boat Harbour – Decay of Conservative Tracer at Location 4



Hillarys Boat Harbour - Decay of Conservative Tracer at Location 5



APPENDIX VI
Vegetation and Flora Report
(Dr. A. Weston)

Searches for Rare and otherwise Significant Flora
And Assessment of Vegetation Condition
Port Catherine Project Area, Spearwood and Coogee
City of Cockburn

By Arthur S. Weston, PhD (Botany)
29 July 1997

(word processing errors were corrected, footnotes were added, and the report was retyped on 8-9 May 2001 - ASW)

1.0 INTRODUCTION

This report describes the objectives, methods, results and conclusions of searches for Declared Rare Flora (DRF), Priority Flora and other significant flora of the Perth Metropolitan Area and assessment of vegetation condition in the Port Catherine Project Area. The Port Catherine Project Area encompasses the proposed realignment of Cockburn Road and undeveloped areas west of it between the old power station in the north and Woodman Point Recreation Reserve in the south. In particular, the project area includes the six areas outlined in red on an overlay of the mosaic of two enlarged 1996 aerial photos and designated A, B, C, D, E and F.

1.1 OBJECTIVES

The principal objective of the search project was to locate all plants in the project area of the DRF, Priority and other significant taxa listed in a current table of such plants recorded in the Perth Metropolitan Area (Keighery pers. comm. 1997, Table 16) and in CALM 9 July 1997 printouts of Threatened and Priority Flora of the Coogee area from their three relevant databases: *Threatened Flora, Priority Species List* and *WA Herbarium Specimen.* The CALM printouts list 14 species, of which none is Threatened or DRF. One species listed by CALM is a Priority 1 taxon: *Acacia lasiocarpa* var. *bracteolata* long peduncle variant.

A supplementary objective of the significant flora search was to identify any areas having suitable habitats for any of these plants.

The objectives of the vegetation project were to identify stands of naturally occurring native vegetation in the project area and to assess their condition, particularly in Areas A, B C, D, E and F.

1.2 METHODS

The project was divided into five phases, the first of which was a review of relevant literature, lists, tables, maps and aerial photographs. This phase was done during late June and July 1997.

The second and third phases were in the field, one phase being searches for significant flora and their habitats and the other being recording of types and condition of vegetation. The six-step scale modified from Trudgen by Keighery (1994, p. 27) for floristic community surveys was used to assess vegetation condition.

Phases two and three were done on Tuesday, 8 July and Sunday, 27 July 1997.

The fourth phase was checking of plant identifications in the Western Australian Herbarium, and the fifth was preparation of the report. These phases were done concurrently, between 8 and 10 July and 24 and 29 July 1997.

2.0 RESULTS

2.1 SIGNIFICANT FLORA

No species of significant flora listed by Keighery or CALM was found, nor was any habitat or area in the project area where such flora might occur identified. In fact, very few native herbaceous plants and small shrubs of any type were found in the project area.

The one collection listed by CALM of the Priority 1 taxon Acacia *lasiocarpa* var. *bracteolata* long peduncle variant is from a black sandy swampy area with jarrah, between the Nicholson Road bridge and Bibra Lake. There is no such habitat in the project area.

There may be habitats of the Priority 3 taxon *Hibbertia spicata* subsp. *leptotheca* in the project area, but no plants of this *Hibbertia* were found during the searches. Rottnest Cypress is considered by some, e.g. Powell (1990) and Powell and Emberson (1981), to be significant in the Metropolitan Area, where it has declined markedly in recent times. The species is, however, widespread and locally common on the south coast and its offshore islands.

2.2 VEGETATION

Most of the naturally occurring vegetation in the project area, even shrubby vegetation, is totally weedy and without any native species in the understorey. The most common shrub is Coast Teatree (*Leptospermum laevigatum*), an eastern states import, while Castor Oil Plant (*Ricinus communis*) runs a distant second for commonness. There are also thickets of self-sown pines, mainly along the railway and north of it, i.e. in Area F and east of it, and prickly shrubs of African Boxthorn (*Lycium ferocissimum*), mainly south of the railway and east of the project area.

Other alien species, which are well established in the project area and abundant, include *Pelargoniun capitatun, Euphorbia terracina, Trachyandra divaricata, Lupinus* sp. and several African grasses.

There are concentrations of native shrubs in Areas B, C, D, E and F, and of native graminoids in coastal dune vegetation, particularly in Area A (the vegetation types and conditions of Areas A, B, C, D, E and F and selected other areas in and east of the project area are described in more detail below).

There are scattered individuals and small populations of native shrubs of several species among weedy growth on limestone in the part of the project area south of the railway. The most common and widespread are Parrotbush (*Dryandra sessilis*), *Hakea prostrata, Templetonia retusa, Acacia rostellifer,. Acacia saligna* and *Acacia cyclops,* most of which are mainly in the eastern part of the project area and east of it. *Xanthorrhoea preissii* is common near the railway but uncommon elsewhere, and there are also a few young trees of *Callitris preissii* in the southwestern corner, east of Area A on the eastern side of Cockburn Road. A few small trees of Limestone Marlock (*Eucalyptus decipiens*) are near Ocean Road in the eastern part of the project area.

2.2.1 <u>Area A</u> (at the northern end of System 6 Recommendation M90)

Between the access trail to the beach from the north end of the parking lot, the cycle/pedestrian path and the beach is low mobile dune vegetation of a type described by Powell and Emberson (1981) as seaside community and by Rippey and Rowland (1995) as dune heath. The vegetation is dominated by two established introductions from South Africa, Sea Spinach (*Tetragonia decumbens*) and *Trachyandra divaricata,* with other alien grasses and forbs and Rose Pelargonium (*Pelargonium capitatum*), which is also South African, being common. The perennial grasses *Spinifex hirsutus, Spinifex longifolius* and *Ammophila arenaria,* the saltbush *Atriplex ?isatidea* and Sea Rocket (*Cakile maritima*) are conspicuous on the coastal side of the dunes; there are patches of Coast Sword-sedge (*Lepidosperma gladiatum*) on internal slopes and swales, and there are very few small stands of the shrubs *Acacia cochlearis, Acacia cyclops* and *Scaevola crassifolia* and of Rottnest Cypress (*Callitris preissii*), mainly on the inland side of the dunes.

The vegetation type represented in Area A comes closest to matching Floristic Community Type S14.

Condition of vegetation in Area A is assessed as 4 (=Good), or better. In spite of the intrusion of aliens, the vegetation retains a basic structure upon which rehabilitation is being based and is in better condition than the rest of the seaside vegetation in the project area.

2.2.2 <u>Area B</u> (old Coogee Siding, north of Woodman Point Recreation Reserve)

The vegetation of Area B is currently mainly weedy, particularly comprising annual grasses and forbs, Rose Pelargonium, *Euphorbia terracina* and, to a lesser extent, Bridal Creeper (*Asparagus asparagoides*), but it was probably previously transitional between what Powell and Emberson (1981) describe for Woodman Point as Cypress Belt and Tuart Woodland vegetation, with treeless patches of heath and scrub. This native vegetation is now represented by scattered clumps, small groves and individuals of Rottnest Cypress (*Callitris preissii*), both mature and young, *Acacia saligna, Acacia cyclops, Acacia cochlearis* and *Spyridium globulosum.* South of the area, nearby, there are a few Tuart (*Eucalvptus gomphocephala*) trees. There are also plantings of Coastal Moort (*Eucalyptus platypus* var. *heterophylla*) and other trees and shrubs. According to French (1997), Coastal Moort is cultivated extensively in the Perth area. The Peppermint (*Agonis flexuosa*) in Area B may also be planted; it is not in the Powell and Emberson (1981, p.83) list of native plants in their Woodman Point Study Area. The vegetation type represented in Area B comes closest to matching Floristic Community Types 30a and 30b.

Condition of vegetation in Area B is assessed as >40% 5 (=Degraded) and <60% 4 (=Good) to 5. A large proportion of the native vegetation and its structure have been severely altered and would require intensive rehabilitation and management to improve them to a level of better than Good.

Area B has some value, however, for its Rottnest Cypress trees, which are rare in the Perth Metropolitan Area outside Woodman Point and which appear to be reproducing spontaneously. Powell (1990), in writing about the decline of Rottnest Cypress since European settlement, states that "Although once common along the mainland coast, its major populations in the Perth area are now limited to Garden Island and Woodman Point. It also survives in the Trigg dunes and at Peppermint Grove by the Swan River." Powell (1990) and Powell and Emberson (1981) add that there are still a few naturally occurring cypress trees on Rottnest Island and at south Swanbourne and Coogee north of the caravan park. The relatively dense, Woodman Point population extends north to Coogee Beach and the caravan park.

2.2.3 <u>Area C</u> (native vegetation between Robb Road and the railway)

The native vegetation of Area C is Closed Tall Scrub to Closed Heath of *Acacia rostellifera,* with an understorey of Rose Pelargonium, *Euphorbia terracina,* Bridal Creeper, other weeds and very few, if any, native plants. It, along with the *Acacia rostellifera* in Area E, is the densest naturally occurring native vegetation in the part of the project area south (or west) of the railway.

The vegetation type represented in Area C comes closest to matching Floristic Community Type 29b.

Condition of vegetation in Area C is assessed as 3 (=Very Good) to 4 (=Good), because the structure and composition of the overstorey is largely intact. The rating would be higher if native species constituted a significant part of the understorey and if the three aggressive weeds Rose Pelargonium, *Euphorbia terracina* and Bridal Creeper were absent. The aggressiveness and spread of these weeds in the community appears to be worsening its condition.

2.2.4 Area D (just south of railway, east of Cockburn Road and southeast of Area C)

Between the railway and the former industrial area south of it is a small stand of shrubs, which appears never to have been totally cleared. There are now a few shrubs of *Hakea prostrata* and *Petrophile serruriae* with an almost totally weedy understorey.

Condition of vegetation in Area D is assessed as 5 (=Degraded) to 4 (=Good). The native vegetation and its structure have been altered and would require rehabilitation and management to improve them to a level of Good or better.

2.2.5 Area E (just south of railway in proposed realignment of Cockburn Road)

Area E vegetation is a dense stand of *Acacia rostellifera*, with a few Parrotbush and *Spyridium globulosum* bushes and a weedy understorey. The stand is spreading southward and westward.

The vegetation type represented in Area E comes closest to matching Floristic Community Type 29b.

Condition of vegetation in Area E is assessed as 3 (=Very Good) to 4 (=Good), because the structure and composition of the overstorey is largely intact. The rating would be higher if native species constituted a significant part of the understorey and if aggressive weeds were absent.

Immediately west of Area E, in what was first a quarry and then a flyash dump, is a mosaic of *Acacia rostellifera* and alien trees and shrubs, mainly pines, *Eucalyptus saligna*, Coast Teatree and Castor Oil Plant.

2.2.6 Area F (north of railway and east of Cockburn Road, including proposed Cockburn Road realignment and interchange area)

Area F has a patchy distribution of shrubs with a ground layer, which, for the most part, is almost totally weedy. The principal, most widespread shrubs in the area are Coast Teatree, Parrotbush (*Dryandra sessilis*) and Red-eyed Wattle (*Acacia cyclops*), but there are also other species which are less common and have restricted distributions. These less common, more restricted species include *Hakea prostrata, Petrophile serruriae, Templetonia retusa, Scaevola crassifolia, Spyridium globulosum, Banksia attenuata,* Geraldton Wax, Olive Tree, African Boxthorn, *Nicotiania glauca, Ricinus communis* and *Pinus* sp. There are impenetrable thickets of Bridal Creeper in a few areas.

There are many four-wheel drive and motorcycle tracks and piles of rubbish in the area, especially in its western part. There is also a recently constructed bitumen cycle/foot path along the southern boundary.

The eastern edge of Area F borders an abandoned large quarry and limestone ridges with Floristic Community Type 26a vegetation, which is less modified by disturbance than any native vegetation in the project area[1].

The vegetation type represented in Area F comes closest to matching Floristic Community Type 26a/b.

Condition of vegetation in Area F is assessed as >80% 4 (Good) to 5 (=Degraded), with <20% 3 (=Very Good: mainly thickets of Parrotbush and wattle).

2.2.7 East of the Project Area

Lowland linkage between Market Garden Swamp and Manning Lake

There is no continuous strip of native vegetation between Market Garden Swamp and Manning Lake either through the lowlands or across the ridge, but there are stepping stones of shrubby plants and other perennial vegetation along both routes. The stepping-stones vary in number, size and composition. On the ridge in the project area they are more numerous, smaller, more open and largely of alien shrubs, while along the lowland route, east of the project area, they are fewer, larger, largely of native paperbarks and closer to directly in line between the swamp and the lake.

For instance, the main lowland stepping stone, between Ocean, Cross, Entrance and Hamilton Roads, is, like the swamp and the lake, a wetland with a forest of Swamp or Freshwater Paperbark (*Melaleuca rhaphiophylla*). Another lowland stepping stone, one without paperbarks, is a pond behind the Watsonia plant east of Hamilton Road and south of

[1] This ridge vegetation has been added to the vegetation map area as F'.

the railway; the pond is open water with belts of bulrush (*Typha* sp.) and Castor Bean (*Ricinus communis*) bordering it.

Melaleuca huegelii - M. acerosa[2] Shrublands of Limestone Ridges (Floristic Community Type 26a)

The vegetation near the project area in best condition belongs to Floristic Community Type 26a (see Gibson *et al.* 1994)[3], variations of which probably covered most of the upper slopes and ridges of the project area before they were cleared. Gibson *et al.* (1994) gives the conservation status of this community type as unreserved.

No examples of this community type were found in the project area which are in better condition than a poor 5, very degraded.

Currently, the best representations of this community type near the project area are, south of the railway, near the Rotary Lookout and, north of the railway, east of the abandoned large quarry. Both of these representations are in System Six Recommended area M92.

Immediately northeast of Rotary Lookout there is a limestone crest with shallow and skeletal soils and a weedy remnant of Floristic Community Type 26a. Principal native species in the stand include *Melaleuca huegelii, Grevillea preissii, Hakea prostrata, Templetonia retusa, Xanthorrhoea preissii, Acacia rostellifera, Spyridium globulosum, Dryandra* 'nivea', *Hardenbergia comptoniana, Dianella revoluta, Opercularia vaginata* and *Acanthocarpus preissii.* The condition of the core of this stand is rated 3 (=Very Good).

A larger representation of Floristic Community Type 26a covers the top of the highest ridge east of the abandoned large quarry east of the part of the project area, which is north of the railway[3]. This stand has all of the native species found in the Rotary Lookout stand, all of the shrubs and vines listed for this community type by Gibson *et al.* and most listed for it in a 1997 unpublished study of this community type by Weston and Gibson (Weston pers. comm.). The condition of this stand is rated 2 (=Excellent) to 3 (=Very Good).

A poorer representation of this community type is on the lower ridge north of the quarry and bordering the project area.

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[2] The name '*Melaleuca systena*' is now used instead of '*Melaleuca acerosa*'.

[3] This vegetation is now in the northeastern part of the vegetation map area, as F'. Its condition is assessed as 3 (=Very Good). *Bush Forever Vol. 2* (p. 41) lists Floristic Community Type 26a as Endangered.

3.0 CONCLUSIONS AND DISCUSSION

The likelihood that any species of Declared Rare or Priority Flora occurs in the project area is minimal or less. One locally important species, which is not, however, listed as significant, does occur in Areas A and B: Rottnest Cypress. Its occurrence in Area B, the old Coogee Siding, renders that area more important than it would otherwise be.

All of the project area east of Cockburn Road except the railway reserve and a few trees and shrubs had been cleared by the end of 1953 (see aerial photograph WA 125 Run 14: 276, 7920' 6", 6.11.53). Most of it that was not industrialised or in Lot 50 north of Ocean Road was beginning to regenerate, especially north of the railway, by late 1963 (see aerial photograph WA 838 Run 27: 5341, 7000' 6", 14.10.63). Lot 50 was in agricultural use until after 1973.

Areas A, B, C, D, E and F have importance for stands of vegetation in them, but the stands of vegetation are relatively poor examples of the vegetation types they represent[4]. Furthermore, the types are more extensively and better-represented elsewhere, nearby examples being Woodman Point Reserve (System 6 M92) and south of Manning Lake (System 6 M92 in part).

4.0 REFERENCES

French, M.E. (1997). *The Special Eucalypts of Perth and the Southwest.* F&N Publications, Perth (?).

Gibson, N., Keighery, B.J., Keighery, G.J., Burbidge, A.H. and Lyons, M.N. (1994). *A Floristic Survey of the Southern Swan Coastal Plain.* Unpublished report for the Australian Heritage Commission prepared by Department of Conservation and Land Management and the Conservation Council of Western Australia (Inc.), Perth.

Keighery, B. (1994). *Bushland Plant Survey: A Guide to Plant Community Survey for the Community.* Wildflower Society of WA (Inc.), Nedlands.

[4] However, the stands of *Melaleuca huegelii - M systena* shrublands of Area F', in the northeastern part of the Vegetation Map, are very good examples of the vegetation types they represent (also see Footnote 3).

Powell, R. (1990). *Leaf and Branch: Trees and Tall Shrubs of Perth.* Department of Conservation and Land Management, Perth.

Powell, R. and Emberson, J. (1981). *Woodman Point: A Relic of Perth's Coastal Vegetation.* Artlook, Perth.

Rippey, E. and Rowland, B. (1995). *Plants of the Perth Coast and Islands.* University of Western Australia Press, Nedlands.

Vegetation Map

Source : Dr. Arthur S. Weston, 2001

BOWMAN BISHAW GORHAM
ENVIRONMENTAL MANAGEMENT CONSULTANTS

ATTACHMENT

DEPARTMENT OF CONSERVATION AND LAND MANAGEMENT

RARE FLORA INFORMATION

CONDITIONS IN RESPECT OF SUPPLY OF INFORMATION

1. All requests for data to be made in writing to the Executive Director, Department of Conservation and Land Management, Attention: Administrative Officer Flora, Wildlife Branch.

2. The data supplied may not be supplied to other organisations, nor be used for any purpose other than for the project for which they have been provided, without the prior written consent of the Executive Director, Department of Conservation and Land Management.

3. Specific locality information for Declared Rare Flora is regarded as confidential, and should be treated as such by receiving organisations. Specific locality information for DRF may not be used in reports without the written permission of the Executive Director, Department of Conservation and Land Management. Reports may only show generalised locations or, where necessary, show specific locations without identifying species. The Administrative Officer Flora is to be contacted for guidance on the presentation of rare flora information.

4. Note that the Department of Conservation and Land Management respects the privacy of private landowners who may have rare flora on their property. Rare flora locations identified in the data as being on private property should be treated in confidence, and contact with property owners made through the Department of Conservation and Land Management.

5. Receiving organisations should note that while every effort has been made to prevent errors and omissions in the data provided, they may be present. The Department of Conservation and Land Management accepts no responsibility for this.

6. Receiving organisations must also recognise that the database is subject to continual updating and amendment, and such considerations should be taken into account by the user.

7. It should be noted that the supplied data do not necessarily represent a comprehensive listing of the rare flora of the area in question. Its comprehensiveness is dependant on the amount of survey carried out within the specified area. The receiving organisation should employ a botanist, if required, to undertake a survey of the area under consideration.

8. Acknowledgment of the Department of Conservation and Land Management as source of the data is to be made in any published material. Copies of all such publications are to be forwarded to the Department of Conservation and Land Management, Attention: Principal Botanist, Wildlife Branch.

WAHERB SPECIMEN DATABASE
GENERAL ENQUIRY
Grevillea olivacea A.S.George (Proteaceae)
CONSERVATION STATUS: P4
Coll.: G.J. Keighery 13063 Date: 13 07 1993 (PERTH 03358232)
LOCALITY Woodman Point; Rockingham WA
Lat.: 32^ 08' 11" S Long.: 115^ 44' 23" E
Open erect shrub 1-2 m, style red; perianth green-red. Coastal dunes. .
Abundance: self seeding from plantings.

Taxon Name	Cons.	Pop ID	Latitude	Longitude	Purpose	V
Dodonaea hackettiana	4	16	32^08'00"	115^45'50"	REC	S

A total of 1 records were printed.

3

Species: Dodonaea hackettiana

Common Name: ______________________ Flowering Period: ______________________

Photos: ______________________ Description: ______________________ Line Drawing: ______________________

Pop ID	District	Location	Vesting	Purpose	No. Plants	Last Inspect	Noti
16	Perth	Clarence Townsite, 377 Cockburn Rd. 0.25 km W of Cockburn Rd and 0.5 km E of The D.Y.S.R. camp.	SHI	REC		15-JUN-87	

4

APPENDIX VII
Fauna Reports
(Bamford Consulting Ecologists)

PORT CATHERINE PROJECT

Report on Fauna Values

Bamford CONSULTING ECOLOGISTS
23 Plover Way, Kingsley, WA, 6026

18/07/'97

Background

The Port Catherine Project involves the re-alignment of Cockburn Road and the development of land within this re-alignment. The re-alignment and part of the development would take place in two areas recognised under System Six: the northern tip of M90 (Woodman Point area) and the western side of M92 (which is continuous with the Manning Lake Reserve).

We inspected the site briefly on 25th June and were asked to consider four main issues in relation to the impact of these proposals upon fauna conservation.

- The value of the high limestone ridge within M92 for conservation linkage between Market Garden Swamp and Manning Lake, and the location of alternative links between these two wetland areas.
- The value of the area just north of the railway line.
- The value of a small area of native vegetation on the northern edge of the proposal, bounded by Robb Road and the railway.
- The value of the northern tip of M90 compared with an area of railway reserve, adjacent to the Woodman Point Recreation Reserve, with which it could be exchanged.

Linkage between Market Garden Swamp and Manning Lake

The high limestone ridge between Market Garden Swamp and Manning Lake supports very degraded vegetation which is different in character to that found around the two wetlands. The most conspicuous elements of the vegetation are introduced pine trees *Pinus ?radiata* and the introduced Coast Teatree *Leptospermum laevigatum*. There are some pockets of native vegetation, such as around the Rotary Lookout, although this is typical of coastal limestone soils (eg. *Dryandra sessilis*, *Rhagodia* sp., *Acacia rostellifera* and *Melaleuca huegelii*) rather than wetlands. The vegetation is in particularly poor condition on the western side of the ridge, which is proposed for development. More details on the vegetation are provided in Dr Arthur Weston's botanical report.

Given that the proposed linkage is between two wetland areas, the high limestone ridge with degraded vegetation would seem to be of little relevance and remnant wetlands in the intervening space would be more appropriate. There is a substantial sumpland with more or less intact cover of *Melaleuca rhaphiophylla* alongside Ocean Road, between Cross and Hamilton Roads, which could form a "stepping stone" for mobile wetland species such as waterbirds. Former swamps, directly north of Market Garden Swamp and between Hamilton and Mell Roads, have been developed for agriculture. The northernmost end of this area, close to the railway and surrounded by the Watsonia operations, may retain some native vegetation but could not be inspected. These former swamps, although cleared, are probably still flooded in winter and support dense vegetation which consists almost entirely of weeds. Such habitat is utilised by species such as the Quenda *Isoodon obesulus* (Southern Brown Bandicoot, classed as Schedule 1 under the Wildlife Protection Act), but would be very difficult to manage. Both the sumpland and the former swamps appear to be on privately-owned land.

The high limestone ridge has some value for fauna in its own right, particularly where it supports remnant native vegetation. Bird species observed around the Rotary Lookout included: Brown Honeyeater *Lichmera indistincta*, White-cheeked Honeyeater *Phylidonyris nigra*, Singing Honeyeater *Lichenostomus virescens*, Silvereye *Zosterops lateralis* and Short-billed Black-Cockatoo *Calyptorhynchus latirostris*. Small groups of this last species, which is of conservation significance (Schedule 4 under the Wildlife Protection Act), were actually travelling south from trees near Manning Lake, visiting pine trees and thickets of *D.sessilis* on the limestone ridge and then flying south-east towards Market Garden Swamp; they were therefore using the ridge as a link between the two areas! All the vegetation they were visiting was located on the eastern side of the ridge, which will not be affected by the proposed development.

This observation of the Black-Cockatoos indicates that there is some conservation value even in very degraded vegetation, although overall the limestone ridge south of the railway provides poor habitat for fauna. The area to the east of the proposed realignment has more remnant vegetation than that to the west, so retention of land east of the proposed realignment of Cockburn Road as Parks and Recreation Reserve should retain much of the value of the ridge for fauna.

Area just north of the railway line

This area supports a mixture of native and introduced plant species and is interspersed with tracks used by "recreational" vehicles; it also includes a limestone quarry. There are some quite extensive thickets of *D.sessilis* and *Acacia rostellifera* and a brief visit (45 minutes) yielded a list of 16 species of birds. These were: Nankeen Kestrel *Falco cenchroides*, Black-shouldered Kite *Elanus axillaris*, Short-billed Black Cockatoo, Laughing Turtle-Dove *Streptopelia senegalensis* (introduced), Feral Pigeon *Columba livia* (introduced), Silver Gull *Larus novaehollandiae*, Striated Pardalote *Pardalotus striatus*, Western Gerygone *Gerygone fusca*, Mistletoebird *Dicaeum hirundinaceum*, Singing Honeyeater, White-cheeked Honeyeater, Willie Wagtail *Rhipidura fuliginosa*, Welcome Swallow *Hirundo neoxena*, Richard's Pipit *Anthus novaeseelandiae*, Black-faced Cuckoo-shrike *Coracina novaehollandiae* and Australian Magpie *Gymnorhina tibicen*. This is a good list for such a short visit, which may be the result of the site being directly linked to good areas of vegetation within the Manning Lake Reserve. These species are all typical of the urban area, and species such as the Western Gerygone and the Striated Pardalote reflect the presence of some remnant vegetation. Species which are indicators of especially good sites in the urban area, such as thornbills, scrubwrens and fairy-wrens, were not observed. The site could be expected to support a rich reptile fauna, including the skink lizard *Lerista lineata* which is of conservation significance (listed as Priority 4 by the Department of Conservation and Land Management).

The area examined just north of the railway line is essentially the degraded corner of the Manning Lake Reserve. It is therefore of some value in acting as a buffer to the rest of the reserve and contributing to the overall size of the reserve. As such, the area resumed for the road re-alignment should be kept to a minimum.

Native vegetation between Robb Road and the railway

This small remnant of native vegetation consists of very dense *Acacia rostellifera*. While it undoubtedly supports some fauna, its small size and isolation compromise its value. It does indicate, however, how dense vegetation will grow in sheltered locations close to the coast, and it could serve as a model for future planting of road verges and median strips. Such dense vegetation, if continuous, could be useful corridors for the movement of wildlife through the area.

Potential exchange of land at the northern end of M90

The two areas which may be under consideration for exchange are different in vegetation type. The northern end of M90 is fore-dune vegetation in moderately good condition, while the alternative area near the recreation reserve is degraded woodland. It supports a few specimens of the Rottnest Island Pine *Callitris preissii* as well as some specimens of the Peppermint *Agonis flexuosa*; these latter may have been planted. In terms of fauna, this alternative area, although degraded, has the advantage of consolidating an existing reserve area and providing a more diverse array of habitats than that present on the fore-dune. Given the nature of the proposed development, it may be possible to re-establish fore-dune vegetation on the new shoreline, possibly using material from the existing site.

PORT CATHERINE PROJECT

Supplementary Report on Fauna Values

Bamford CONSULTING ECOLOGISTS
23 Plover Way, Kingsley, WA, 6026

05/12/'97

BACKGROUND

The Port Catherine Project involves the re-alignment of Cockburn Road and the development of land within this re-alignment. The re-alignment and part of the development would take place in two areas recognised under System Six: the northern tip of M90 (Woodman Point area) and the western side of M92 (which is continuous with the Manning Lake Reserve). These areas were examined by us in June 1997 to determine the impact of these proposals upon the conservation value of fauna in the area. As a result of this examination, further information has been requested concerning the importance for fauna conservation of land between the railway and Manning Reserve. Cockburn Road would pass through this area if it was re-aligned. In particular, we were asked to provide further information on the Perth Lined Lerista *Lerista lineata*, a species of conservation significance which could occur on the site.

The site was visited on the 1st of December 1997 by Mr R. Davis and Dr M. Bamford of Bamford Consulting Ecologists, at the request of Bowman Bishaw Gorham. Opportunistic records on all fauna were made and intensive searching for reptiles was carried out. In addition, the site which would be affected by the road re-alignment and adjacent areas of Manning Reserve were examined and compared.

GENERAL OBSERVATIONS ON VEGETATION AND LANDSCAPE

The area north of the railway line which would be affected by the re-alignment of Cockburn Road is a west-facing slope with shallow soils over limestone. The vegetation consists of extensive thickets of Parrotbush *Dryandra sessilis*, one of the coastal wattles *Acacia ?rostellifera* and the introduced Coastal Teatree *Leptospermum laevigatum*. There are scattered specimens of some other native plants, including a clump of the Candlestick Banksia *Banksia attenuata* which may be directly on the proposed road re-alignment. There are also scattered and stunted specimens of introduced pine trees *Pinus* sp.. The understorey of what is essentially a tall shrubland is dominated by weeds.

The thickets of Parrotbush in particular are not well represented within Manning Reserve except for an area in the south-east corner of the Reserve. We recommend that the reserve boundary in this region be checked. Those parts of Manning Reserve closest to the proposed road re-alignment have been recently burnt but include

Melaleuca huegelii as a major component, whereas Parrotbush is poorly represented. This difference may reflect past land-uses in the area, as the Parrotbush may represent regenerating vegetation, but the adjacent Manning Reserve does differ in that it consists mainly of east facing slopes. The soils throughout are shallow with much exposed limestone.

OBSERVATIONS ON FAUNA

Species of fauna recorded on the two inspections of the area are listed on Table 1. The only species of conservation significance recorded was the Short-billed Black-Cockatoo, which is classed as Schedule 1 (Rare and Likely to Become Extinct) under the Wildlife Conservation Act, and as Vulnerable by Garnett (1992). It is threatened by loss of breeding habitat in the Wheatbelt and utilises remnant bushland around Perth when not breeding. It was seen feeding from introduced pine trees in June, and probably also feeds from the Parrotbush. The plants in the area visited are therefore of seasonal and very local importance to the Black-Cockatoo.

The other species of fauna observed are widespread in the Perth region. The bird species did not include sedentary species, such as fairy-wrens, scrubwrens and thornbills, which are indicators of especially good urban bushland. The Rufous Whistler *Pachycephala rufiventris* and the Weebill *Smicrornis brevirostris*, which tend to occur in large, good quality remnants in the Perth area, were present in Manning Reserve within eucalypt woodland, but were not observed in the low vegetation in the area of the road re-alignment. The bird species recorded did include several honeyeaters which may make seasonal use of the Parrotbush thickets. The plants had just finished flowering but probably support high densities of Brown and White-cheeked Honeyeaters in late spring. In the local area, the Parrotbush thickets may be significant for these honeyeaters.

The reptile species recorded were all expected to be present. The Perth Lined Lerista *L. lineata* was not found despite several hours of searching through leaf-litter, but it is probably present. It can be very difficult to locate and catch, especially on a warm day. This species is found only on the coastal plain between the Swan River and near Mandurah, including Rottnest and Garden Islands (Bush *et al.* 1995), and therefore much of its range has been or will be developed. Despite this, it is classed as Priority 4 only by the Department of Conservation and Land Management, which indicates that the species is currently secure and is represented on conservation land, but that its status could change if circumstances were altered. Cogger *et al.* (1993) classify the species as Rare or Insufficiently Known. The Perth Lined Lerista is a small species, with a total length of about 10 cm, and it probably occurs at high densities in suitable habitats. Therefore, small areas such as Manning Reserve can support large populations.

The mammal species recorded were all introduced and the only native species which are likely to have survived in the area are several species of bats, such as the White-striped Bat *Tadarida australis*, the Lesser Long-eared Bat *Nyctophilus geoffroyi* and

Gould's Wattled Bat *Chalinolobus gouldii*. These probably shelter under bark and in hollows of trees in Manning Reserve but may forage over the study area.

CONCLUSION

The area north of the railway line which would be affected by the re-alignment of Cockburn Road may be of local importance for some bird species, because it supports thickets of vegetation (primarily Parrotbush *Dryandra sessilis*) which are not well-represented in adjacent parts of the nearby Manning Reserve. It almost certainly supports the Perth Lined Lerista, but a viable population of this species is probably also present within Manning Reserve. These values are very local and to some degree, rehabilitation of the verges of the re-aligned road could re-create the vegetation of the site.

TABLE 1. Fauna observed in the area north of the railway which would be affected by the re-alignment of Cockburn Road. (I) indicates introduced species.

Species		25th June	1st December
REPTILES			
Varanidae (goannas or monitor lizards)			
Gould's Sand Goanna	*Varanus gouldii*		+
Scincidae (skinks)			
Fence Skink	*Cryptoblepharus plagiocephalus*		+
	Ctenotus ?lesueurii		+
	Morethia lineoocellata		+
Bluetongue	*Tiliqua occipitalis*		+
Bobtail	*Tiliqua rugosa*		+
Elapidae (elapid snakes)			
Dugite	*Pseudonaja affinis*		+
BIRDS			
Accipitridae (hawks and eagles)			
Black-shouldered Kite	*Elanus axillaris*	+	
Collared Sparrowhawk	*Accipiter cirrhocephalus*		+
Falconidae (falcons)			
Nankeen Kestrel	*Falco cenchroides*	+	
Laridae (gulls and terns)			
Silver Gull	*Larus novaehollandiae*	+	
Columbidae (pigeons and doves)			
Rock Dove (feral pigeon)	*Columba livia* (I)	+	
Laughing Turtle Dove	*Streptopelia senegalensis*	+	+
Cacatuidae (cockatoos)			
Short-billed Black Cockatoo	*Calyptorhynchus latirostris*	+	
Psittacidae (parrots)			
Australian Ringneck	*Barnardius zonarius*		+
Meropidae (bee-eaters)			
Rainbow Bee-eater	*Merops ornatus*		+
Pardalotidae (pardalotes and allies)			
Striated Pardalote	*Pardalotus striatus*	+	
Western Gerygone	*Gerygone fusca*	+	

Table 1 (cont.)

Species		25th June	1st December
Meliphagidae (honeyeaters)			
Singing Honeyeater	*Lichenostomus virescens*	+	+
Brown Honeyeater	*Lichmera indistincta*		+
White-cheeked Honeyeater	*Phylidonyris nigra*	+	
Dicruridae (flycatchers and allies)			
Willie Wagtail	*Rhipidura leucophrys*	+	
Campephagidae (cuckoo-shrikes)			
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*	+	
Artamidae (woodswallows and butcherbirds)			
Australian Magpie	*Gymnorhina tibicen*	+	
Motacillidae (pipits and true wagtails)			
Richard's Pipit	*Anthus novaeseelandiae*	+	
Dicaeidae (mistletoebirds)			
Mistletoebird	*Dicaeum hirundinaceum*	+	
Hirundinidae (swallows)			
Welcome Swallow	*Hirundo neoxena*	+	+
Zosteropidae (silvereyes)			
Silvereye	*Zosterops lateralis*	+	
MAMMALS			
Leporidae (rabbits and hares)			
Rabbit	*Oryctolagus cuniculus* (I)	+	+
Canidae (foxes and dogs)			
European Red Fox	*Vulpes vulpes* (I)	+	+
Felidae (cats)			
Feral Cat	*Felis catus* (I)		+

REFERENCES

Bush, B., Maryan, B., Browne-Cooper, R. and Robinson, D. (1995). A Guide to the Reptiles and Frogs of the Perth Region. University of WA Press, Perth.

Cogger, H.G., Cameron, E.E., Sadlier, R.A. and Eggler, P. (1993). The Action Plan for Australian Reptiles. Australian Nature Conservation Agency Project Number 124.

Garnett, S. (1992). Threatened and Extinct Birds of Australia. Royal Australasian Ornithologists Union and Australian National Parks and Wildlife Service; RAOU Report 82.

Attachment

DEPARTMENT OF CONSERVATION AND LAND MANAGEMENT

THREATENED FAUNA INFORMATION

Conditions In Respect Of Supply Of Information

* All requests for data to be made in writing to the Executive Director, Department of Conservation and Land Management, Attention: Senior Zoologist, Wildlife Branch.

* The data supplied may not be supplied to other organisations, nor be used for any purpose other than for the project for which they have been provided without the prior consent of the Executive Director, Department of Conservation and Land Management.

* Specific locality information for Threatened Fauna is regarded as confidential, and should be treated as such by receiving organisations. Specific locality information for Threatened Fauna may not be used in reports without the written permission of the Executive Director, Department of Conservation and Land Management. Reports may only show generalised locations or, where necessary, show specific locations without identifying species. The Senior Zoologist is to be contacted for guidance on the presentation of Threatened Fauna information.

* Receiving organisations should note that while every effort has been made to prevent errors and omissions in the data, they may be present. The Department of Conservation and land Management accepts no responsibility for this.

* Receiving organisations must also recognise that the database is subject to continual updating and amendment, and such considerations should be taken into account by the user.

* It should be noted that the supplied data do not necessarily represent a comprehensive listing of the Threatened Fauna of the area in question. Its comprehensiveness is dependent of the amount of survey carried out within a specified area. The receiving organisation should employ a biologist/zoologist, if required, to undertake a survey of the area under consideration.

* Acknowledgment of the Department of Conservation and Land Management as the source of data is to be made in any published material. Copies of all such publications are to be forwarded to the Department of Conservation and Land Management, Attention; Senior Zoologist, Wildlife Branch.

The search of the database indicated that the following threatened and priority fauna occur in the area in question.

Schedule 1 (Fauna which is Rare or likely to become Extinct)

Leathery Turtle (*Dermochelys coriacea*) This species has been recorded from inshore waters of Cockburn Sound on a number of occasions.

Loggerhead Turtle (*Caretta caretta*) This species has been recorded from inshore waters of Cockburn Sound on a number of occasions.

Schedule 4 Fauna which is "Otherwise Specially Protected"

Peregrine Falcon (*Falco peregrinus*) This species is known to inhabit the area around the Power Station where it hunts for feral pigeons. It has also been recorded from further south along the Coogee industrial strip.

Priority Taxa

Fairy Tern (*Sternus nereis*) P4 This has been recorded from undisturbed sandy beaches north and south of the area in quesiton. It is most commonly seen during the summer months when it breeds on flat sandy beaches and areas around limestone groynes.

Lined Burrowing Skink (*Lerista lineata*) P4 This species occurs in coastal dune systems along the Swan Coastal Plain, particularly those areas south of the Swan River.

Black-striped Snake(*Vermicella calanotus*) This species inhabits coastal and near-coastal dunes supporting heathlands and *Banksia*/eucalypt woodlands.

APPENDIX VIII
Acoustic Assessment
(Herring Storer Acoustics)

Rochdale Holdings Pty Ltd A.C.N. 009 049 067 trading as:
HERRING STORER ACOUSTICS
Suite 34, 11 Preston Street, Como, W.A. 6152
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ALLAN HERRING M.I.E. AUST. M.A.A.S.
LYNTON STORER M.A.I.E.A., M.A.A.S.

PORT CATHERINE DEVELOPMENT

ACOUSTIC ASSESSMENT

FOR

PORT CATHERINE DEVELOPMENTS

MAY 2001

REFERENCE: 9117-2-97109

CONTENTS

APPENDICES

1.0 INTRODUCTION

A study has been made of the noise and vibration levels that would be received at residential premises within the Port Catherine Development due to:

- train movements on the existing railway to the north of the development; and
- road traffic on the proposed Primary Regional Road to the east of the development.

This report presents the applicable criteria for the assessment, methods of determining noise propagation and where applicable, recommends methods of managing the noise.

There are no regulatory criteria in Western Australia applicable to noise and vibration received from transport systems such as road and rail traffic. The following are used for guidance as to the acceptability of such noise:

- Westrail "Railway Noise Criteria".
- Main Roads Western Australia "Noise Level Objectives".
- EPA Draft Guidance "Road and Rail Transportation Noise (Draft Version 3.0, 10/05/00)".

2.0 CONCLUSION

2.1 TRAINS

Vibration

The vibration emitted from a train travelling at 40km/hr would be minimal and therefore, acceptable.

Noise

Train noise received at all residences within the Port Catherine Development comply with Version 3 of the EPA's draft guidance for road and rail transportation noise and Westrail's L_{Aeq} of 60 dB(A) criteria.

Noise from trains exceeds Westrail's L_{Amax} of 80 dB(A) criteria at residences located within 50 metres of a track and where the cutting is less than 3 metres. There are approximately 12 residential lots located at the northern end of the development where this criteria would be exceeded (see Figure C1 in Appendix C for locations). To comply with the Department of Environmental Protections Preliminary Draft Guidelines, we recommend:

- the construction of a 1metre high earth landscaping bund located adjacent to the tracks, and

- the use of 'quiet house' designs, to ensure acceptable internal noise levels.

2.2 ROAD TRAFFIC

To comply with the Main Roads Western Australia's criteria by applying separation as the management measure, residences would need to be at least 70 metres from the road. However, the 'noise objective' at residential locations significantly closer can be achieved with a small 1 metre high bund or the construction of a standard 1.8 metre high fence depending on the location.

Noise received at residences located adjacent to the Primary Regional Road would exceed the EPA's draft guidance for acceptable noise by up to 11 dB(A) during the day period and 12 dB(A) during the night period in the year 2021. To comply with the EPA's draft guidance, the following noise control options are recommended:

- The construction of either a 1.5 metre high earth landscaping bund or standard 1.8 metre high fence (locations are shown on Figure C1 in Appendix C); and
- the use of 'Quiet House' designs along the row of residences located adjacent to the Primary Regional Road. (Locations are shown on Figure C1 in Appendix C).

Note: *The height of the bund can vary, provided the relative height between the top of the bund and the ground level of the residence is maintained.*

3.0 CRITERIA

The Environmental Protection (Noise) Regulations 1997, which are administered under the Environmental Protection Act 1986, exclude assessment of the noise emissions from trains and vehicles on roads. The following summarises the various criteria for rail and / or vehicle noise which can be used for guidance. For further information see Appendix D - Criteria.

3.1 VIBRATION (TRAINS)

The criteria used for assessment is taken from AS 2670 - Part 2 1990.

3.2 NOISE (TRAINS)

Westrail's criteria are contained in their "Environmental Management Manual", and can be summarised as:-

Day Period	L_{Aeq} of 65 dB(A) L_{Amax} of 80 dB(A)
Night Period	L_{Aeq} of 60 dB(A) L_{Amax} of 80 dB(A)

3.3 NOISE (ROADS)

Main Roads Western Australia noise level objectives can be summarised as:

1) a base objective of an $L_{A10,(18hour)}$ of 63 dB(A) where the existing road traffic noise is less than an $L_{A10,(18hour)}$ of 60 dB(A).
2) a maximum increase of 3 dB(A) where the existing road traffic noise is greater than an $L_{A10,(18hour)}$ of 60 dB(A).

3.4 DEPARTMENT OF ENVIRONMENTAL PROTECTION - DRAFT EPA GUIDANCE FOR ROAD AND RAIL TRANSPORTATION NOISE

The Department of Environmental Protection (DEP), under preliminary drat EPA Statements for EIA No. 14 (Version 3) Road and Rail Transportation Noise. Statement for EIA No. 14 (Version 3); Road and Rail Transportation Noise, has provided draft guidelines for the acceptability of road and rail noise on noise sensitive premises. The approach taken is similar to Australian Standard 2021 - 1994 which relates to aircraft noise received at a noise sensitive premise. The draft guidance determine zones which, depending on the noise level, classify an area as acceptable, conditionally acceptable and unacceptable.

Under the acceptable zone, no noise amelioration is required.

Under conditionally acceptable, noise amelioration is required, either in terms of attenuating the noise before it reaches the premises or providing an increased noise reduction through the building structure to achieve acceptable internal noise levels.

Within the unacceptable zone, noise sensitive premises would not be recommended.

The range of noise levels are summarised below in Table 1.

TABLE 1 - ACCEPTABILITY OF LAND USE

Rating	Day Noise Level dB(A)	Night Noise Level dB(A)	Zoning		
			Acceptable	Conditionally Acceptable	Unacceptable
N0	50	40	Residential		
N1	51 - 55	41 - 45	Residential		
N2	56 - 60	46 - 50	Open Space	Residential	
N3	61 - 65	51 - 55		Residential Units, Open Space	Residence+yard
N4	66 - 70	56 - 60		Residential Units, Open Space	
N5	70	60		Residential Units, Open Space	Open Space

A copy of EPA Statement for EIA No. 14 (Version 3); Road and Rail Transportation Noise is attached in Appendix D.

4.0 CALCULATIONS

Calculations were carried out, as outlined below, to determine the noise that would be received at the first row of residence to either the railway tracks or the Primary Regional Road.

The analysis undertaken only considers the first row of residences (i.e. closest to the railway line or the proposed Primary Regional Road) as these residences provide a substantial barrier to the other residences within the development. Therefore, noise received at the other residential lots would comply with all the stated criteria.

4.1 TRAINS

Noise level emission of trains has been based on file data of a freight train travelling in notch 3; as follows:-

L_{Amax} (15 metres)	88 dB(A)
$L_{Aeq\ 1\ min}$ (15 metres)	73 dB(A)
$L_{Aeq\ 24\ hour}$ (15 metres) 1 train	40 dB(A)

The corrections as listed in Table 2, would be made for trains pulled by different classes of locomotives.

TABLE 2 - ADJUSTMENT FOR CLASSES OF LOCOMOTIVE COMPARED TO A Q CLASS LOCOMOTIVE

Loco Class	Noise Reduction dB(A)	
	L_{Aeq} (1 min)	L_{Amax}
D	0	0
P	-4	-4
S	-6	-7

From information received from Westrail and the Fremantle Port Authority, we understand that on this section of track there are 4 to 6 train movements per week. The speed of trains along this section of track is approximately 40km/hr. Based on this information, we believe that the maximum movements per day along the section of track of concern is 2. We also believe that 40km/hr relates to a notch setting of 3.

Based on the above information, we calculated the noise level received at the closest residence (over the ground) from a passing train with a D class locomotive, and the results are listed in Table 3.

TABLE 3 - REDUCTION IN NOISE LEVEL VS DISTANCE

Condition	Distance (m)/Calculated Noise Level dB(A)			
	15m	30m	60m	90m
Single Pass (L_{Aeq} 1min)	71	65	59	55
L_{Aeq} (Day period 0700 - 2200 hrs)*	44	38	32	28
L_{Aeq} (Night Period 2200 - 0700 hrs)*	47	41	35	31

* For two trains within one period.

Using the above sound power levels, the computer program (ENM) was employed to predict the reduction of a train within a cutting and the results are listed in Table 4.

TABLE 4 - REDUCTION IN NOISE LEVEL FOR TRAIN WITHIN A CUTTING

Depth* of Cutting (m)	Reduction in Noise Level dB(A)
0 (ie : No Barrier)	0
2	2
3	7
3.5	9
4	11

4.2 ROAD TRAFFIC

Calculations were carried out using the computer programme TNoise (TNoise is a computer program developed by the Main Roads Western Australia, based on the Welsh or CRTN Method) to determine the noise level that would be received at the residences adjacent to the Primary Regional Road. Calculations were carried out for residences located at various distances from the Primary Regional Road, and for various barrier heights using the existing flow rates and those predicted for the year 2021. The input data listed is in Table 5. The location of the barrier was taken to be 10m from the edge of the nearest carriageway.

Calculations were carried out at locations B - G as shown on Sketch A1 attached in Appendix A. Data relating to relative ground levels were determined from sections supplied by Sinclair Knight Merz.

TABLE 5 - 'TNOISE' INPUT DATA

Input Variable	Existing	2021
Total Flow / 18 hours	19669	33000
Heavy Vehicles %	7.2	7.2
Speed km/h	70	70
Surface	Dense Graded Asphalt	Dense Graded Asphalt

Note:- Although the EPA draft guidance states that calculations should be for predicted traffic flows at least 25 years in the future, we believe that the flow rate stated for the year 2021 is the ultimate traffic volume.

Calculations were not required at location A, as the closest residences are protected from road traffic noise by a row of commercial premises.

The results are listed in Table 6 - 9. Table 6 shows the results for the current design ground contours, where as Tables 7 - 9 show noise levels received at the closest residences with either 1.0, 1.5 or 2.0 metre high earth landscaping bunds.

TABLE 6 - CALCULATED NOISE LEVELS WITHOUT A BUND [dB(A)]

Location	Noise Level (dB(A))					
	L_{Aeq} (Day)		L_{Aeq} (Night)		$L_{A10,(18hour)}$	
	Existing	2021	Existing	2021	Existing	2021
B & C	64	66	58	60	66	68
D & E	69	71	61	62	66	68
F & G	64	67	59	61	66	69

TABLE 7 - CALCULATED NOISE LEVELS WITH 1.0 METRE BUND [dB(A)]

Location	Noise Level (dB(A))					
	L_{Aeq} (Day)		L_{Aeq} (Night)		$L_{A10,(18hour)}$	
	Existing	2021	Existing	2021	Existing	2021
B & C	58	61	53	55	60	62
D & E	N/A	N/A	N/A	N/A	N/A	N/A
F & G	57	60	52	54	59	62

TABLE 8 - CALCULATED NOISE LEVELS WITH 1.5 METRE BUND [dB(A)]

Loction	Noise Level (dB(A))					
	L_{Aeq} (Day)		L_{Aeq} (Night)		$L_{A10,(18hour)}$	
	Existing	2021	Existing	2021	Existing	2021
B & C	57	59	51	53	58	61
D & E	58*	60*	50*	51*	55*	58*
F & G	56	60	50	52	58	60

* Noise levels for standard 1.8 metre high fence

TABLE 9 - CALCULATED NOISE LEVELS WITH 2.0 METRE BUND [dB(A)]

Location	Noise Level (dB(A))					
	L_{Aeq} (Day)		L_{Aeq} (Night)		$L_{A10,(18hour)}$	
	Existing	2021	Existing	2021	Existing	2021
B & C	55	57	49	51	57	59
D & E	N/A	N/A	N/A	N/A	N/A	N/A
F & G	54	56	48	50	56	58

5.0 DISCUSSION

5.1 TRAINS

Vibration

Recorded vibration levels for a freight train travelling at 70 km/hr and at 15 metres from the track are shown in graphical form in Figure B1, attached in Appendix B. This data is compared to building damage and perception criteria. The vibration emitted from a train travelling at 40km/hr and at a distance of 30m would be less than those shown, therefore, the impact from vibration is a non issue.

Noise

For the current usage, noise emissions from trains when received at a residence located within the Port Catherine development complies with the EPA preliminary draft guidance and Westrail's L_{Aeq} of 60 dB(A) criteria.

To exceed the proposed EPA guidelines, the number of train movements in any one day would need to increase to approximately 60 during the day period and 8 during the night period. Given the current usage, we believe that this increase in train movements is highly unlikely.

For residences located within 50 metres (over flat ground) of the railway line, the maximum noise level would exceed Westrail's L_{Amax} of 80 dB(A) criteria. Therefore, for these residences, we recommend:-

1) the construction of a 1 metre high earth landscaping bund located adjacent to the tracks; and

2) the use of 'quiet house' design, with bedrooms located on the far side of the house from the railway lines.

Note: Bund only required over flat ground or where the cutting is less than 1 metre.

For locations where the tracks are in a cutting of 3 metres or more, the maximum noise level at a residence would comply with Westrail's L_{Amax} criteria of 80 dB(A).

It should also be noted that the analysis of train noise has been based on the 'loudest' locomotive (D class) used and in future years, we would expect noise emissions from locomotives to be reduced to that of an S class locomotive.

5.2 ROAD TRAFFIC

To comply with the Main Roads Western Australia's criteria without provision of noise attenuation techniques, residences would be required to be at least 70 metres from the road. However, the 'noise objective' at residential locations significantly closer can be achieved with a small 1 metre high bund or the construction of a standard 1.8 metre high fence depending on the location.

Noise received at the residence located adjacent to the Primary Regional Road would exceed the EPA draft guidance for acceptable by up to 11 dB(A) during the day period and 12 dB(A) during the night period in the year 2021.

Various noise amelioration options are outlined in Appendix E. However, to comply with the EPA draft guidance, we recommend:-

1) The construction of either a 1.5 metre high earth landscaping bund or standard 1.8 metre high fence (locations are shown on Figure C1 in Appendix C); and

2) the use of 'Quiet House' designs along the row of residences located adjacent to the Primary Regional Road. (Locations are shown on Figure C1 in Appendix C).

Note: The height of the bund can vary, provided the relative height barrier between the road, the top of the bund and the ground level of the residence are maintained.

For: **HERRING STORER ACOUSTICS**

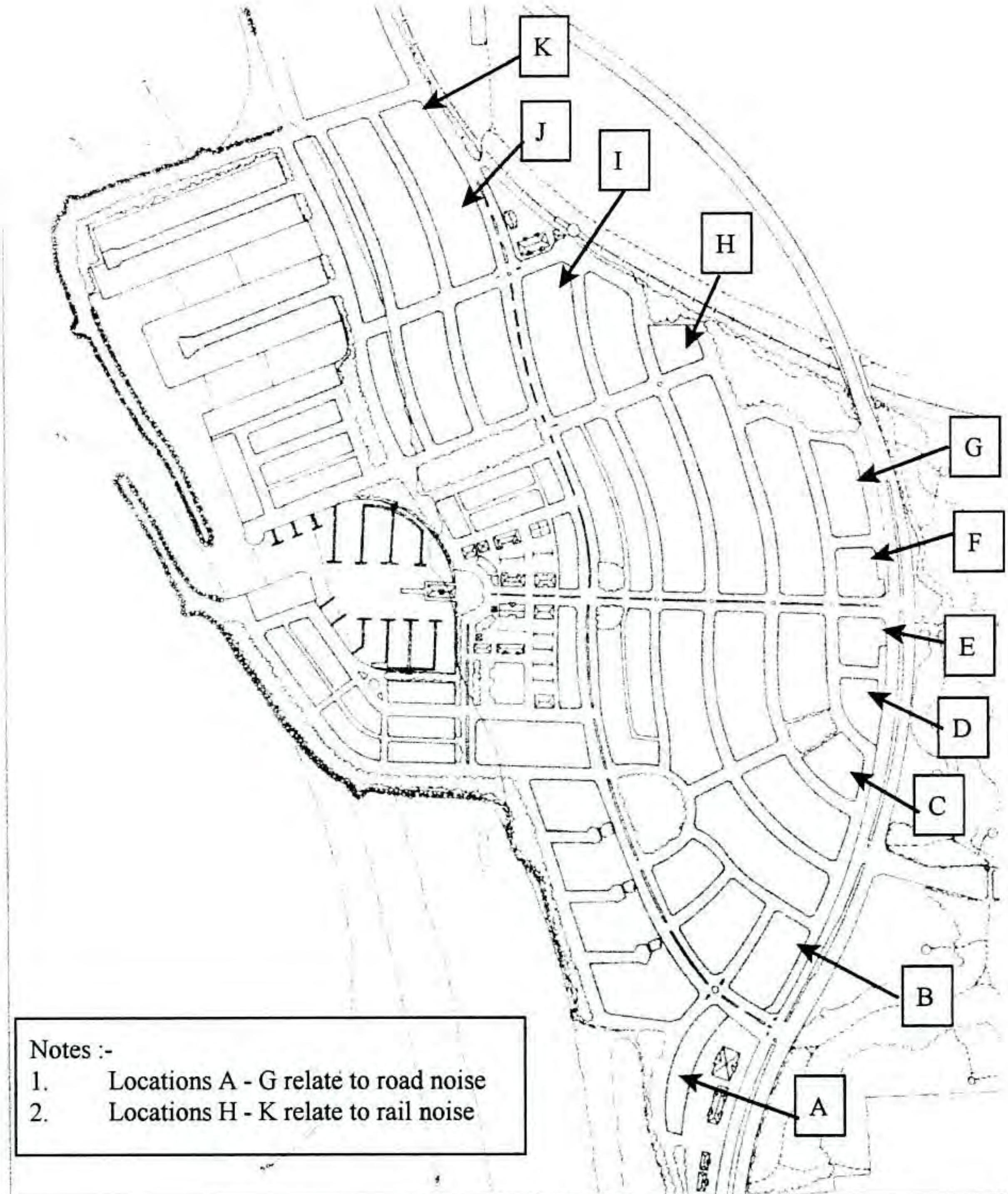
T.C. Reynolds.

Tim Reynolds

4 May 2001

APPENDIX A

FIGURE A1 -CALCULATION LOCATIONS



Notes :-

1. Locations A - G relate to road noise
2. Locations H - K relate to rail noise

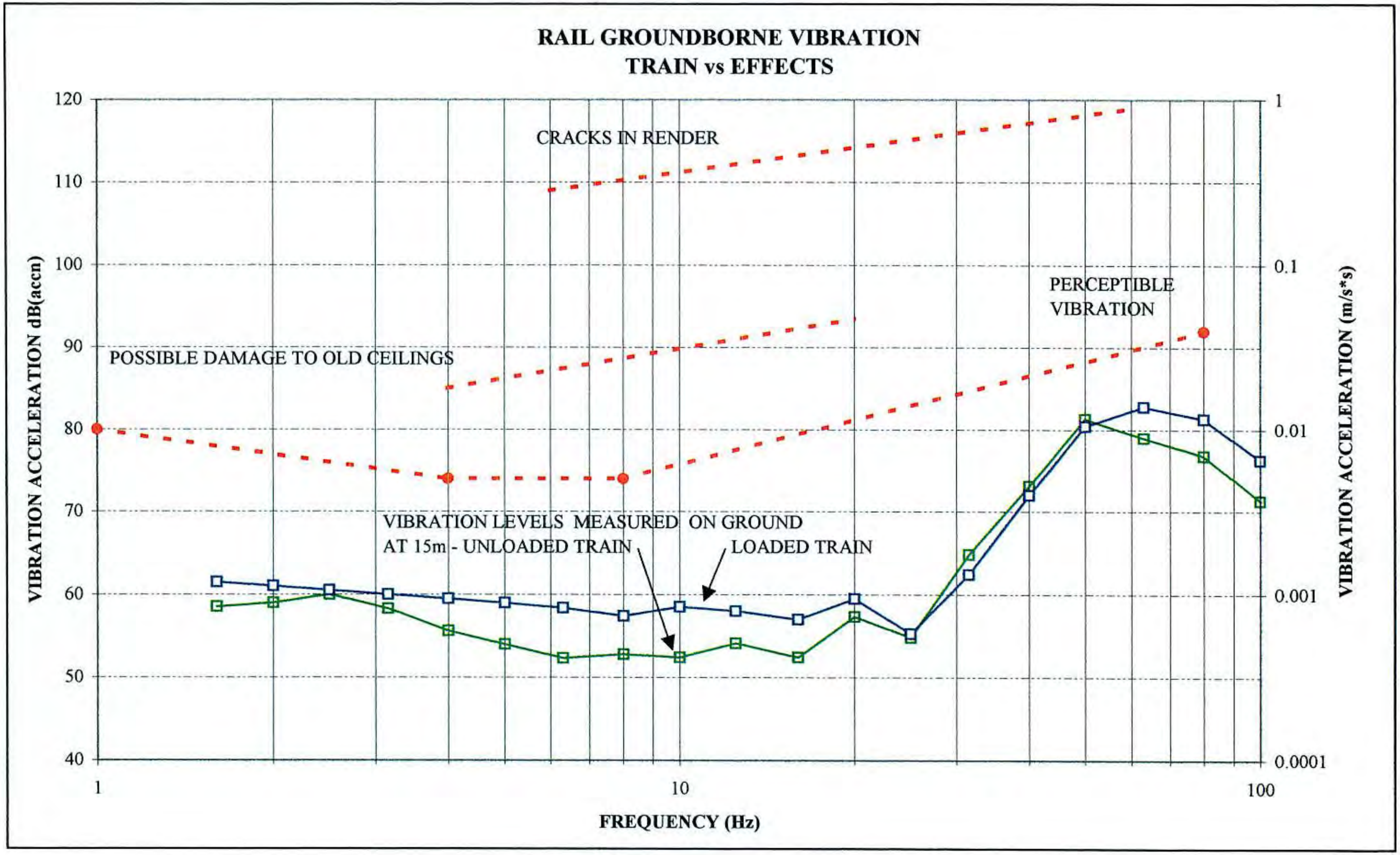
PORT CATHERINE DEVELOPMENT
CALCULATIONS LOCATIONS A - K

Herring Storer Acoustic

Figure A1

APPENDIX B

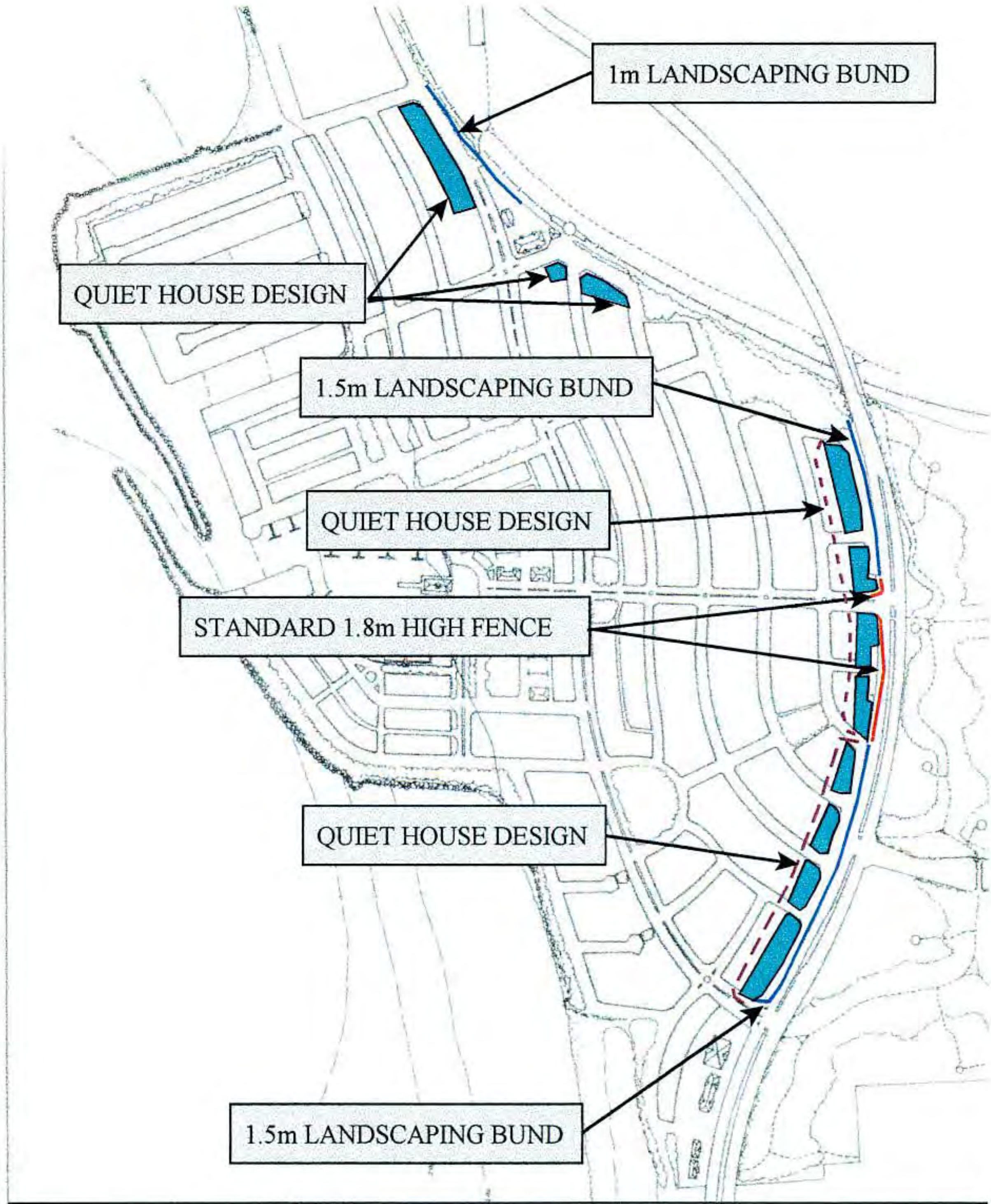
FIGURE B1 - VIBRATION LEVELS



MEASURED VIBRATION vs CRITERIA RELATING BUILDING DAMAGE

APPENDIX C

FIGURE C1 - AREAS REQUIRING AMELIORATION



PORT CATHERINE DEVELOPMENT
NOISE AMELIORATION FOR RAIL AND ROAD NOISE

Herring Storer Acoustic

Figure C1

APPENDIX D

CRITERIA

APPENDIX D - CRITERIA

D.1 TRAINS

Vibration

Vibration levels from trains is relatively low, in fact often imperceptible at 20 metres from the line. The exception can occur from a locomotive sitting idling for any length of time and if there is reasonable connecting medium such as rock. Also travelling trains can cause perceptible vibrations if there are imperfections in rail joints or crossing points.

The criteria used for assessment is taken from AS2670 - Part 2 1990, the most critical of which is 'perception criteria'. Also used is the criteria for possible structural damage.

The Environmental Protection (Noise) Regulations 1997, which are administered under the Environmental Protection Act 1986, exclude assessment of the noise emissions from trains and vehicles on roads. The following have stated criteria for rail and / or vehicle noise which can be used for guidance.

D.2 WESTRAIL - ENVIRONMENTAL MANAGEMENT MANUAL

The Westrail "Environmental Management Manual" cites the following as acceptable criteria for urban passenger railway services, but not specifically for freight services:

WESTRAIL OUTDOOR NOISE CRITERIA FOR URBAN PASSENGER SERVICES

Period		L_{Aeq} * dB(A)	L_{AMax} * dB(A)
Daytime	(0600-2000hrs)	65	80
Nighttime	(2000-0600hrs)	60	80

* These would be:
- the arithmetic average of the LAeq (1 hour) for the period stated; and
- when received at residential premises and at a minimum distance of 25 metres from the centre line of the track.

The above levels give guidance on the noise that should be received at a noise sensitive premises due to freight trains. The standards exclude the use of safety warning devices fitted to trains and rail crossings where they are a specific requirement for operation.

D.3 MAIN ROADS WESTERN AUSTRALIA - NOISE LEVEL OBJECTIVES

Main Roads current practice for assessment of traffic noise level impact is based around 'noise level objectives' described as follows:

"Noise level criteria to be used in the assessment are the Noise Level Objectives specified in Table 1 below. Objectives are specified upper limits of traffic noise which it is intended should not be exceeded. Objectives apply outside residential buildings, and they may also be applied outside public buildings such as hospitals, schools and libraries. In the case of public buildings there is a scope to relax the objectives if affected rooms are air-conditioned, and therefore normally used with windows closed.

TABLE 1 Noise Level Objectives

Base Objective	*Objective for High Ambient Areas*
63 dB(A)	*Ambient + 3 dB(A)*

Notes

(1) *Noise levels are $L_{10\,(18hour)}$ values, from 6am to midnight*

(2) *Ambient noise is the level of noise before the road project commences*

(3) *A high ambient area is where ambient noise is more than 60 dB(A)*

(4) *Due to the impracticality of controlling noise at the upper floors of multi-storey buildings, noise assessment is restricted to the ground floor level.*

(5) *Noise is assessed at a position 1 metre from a building facade, and 1.2 to 1.5 metres above the ground floor level.*

(6) *The objectives apply to the expected 15 to 20 years after opening of the road project.*

(7) *Noise level objectives relate to the total traffic noise expected at a building facade, i.e. noise from the new road and any other roads."*

Noise levels stated above and throughout this report are $L_{10\,(18hour)}$ values. The $L_{10\,(18hours)}$ value is the arithmetic average of the hourly L_{10} percentile levels (the level exceeded for 10% of the time) between 0600 and 2400 hours.

Based on the above 'noise level objectives', we believe that the noise received at a noise sensitive premises within the development approximately 10 years (ie year 2021) after completion of the Primary Regional Road should be limited to 63 dB(A).

EPA Statements for EIA No. 14 (Version 3)

Road and Rail Transportation Noise

(Draft 10/5/00)

Key words: Noise, transportation, developments, trucks, trains, heavy vehicles, traffic

1 Purpose

1.1 The purpose of this statement is to minimise noise from road or rail transportation resulting from or impacting upon proposals submitted for environmental impact assessment.

1.2 This statement is specifically intended to influence land use planning in areas which may be affected by road and rail transportation noise, in order that an acceptable level of amenity may be achieved.

2 Objective

2.1 The objective of this statement is:

(a) to protect the environment as defined by the *Environmental Protection Act 1986* (EP Act 1986) with focus on road and rail transportation noise;

(b) to address the factor of uncertainty of outcome of the EIA process as raised in 1992 during the review of the EP Act 1986;

(c) to address the factor of road and rail transportation noise in a quantitative manner which deals with both modes equally; and

(d) to present to developers, proponents who have proposals subject to environmental impact assessment (EIA) and the general public, the Environmental Protection Authority (EPA) position on road and rail transportation noise to ensure adverse impacts are prevented.

3 Introduction/Preamble

3.1 The EPA recognises that noise associated with road and rail transportation is one of the most pervasive sources of noise in our community. The mobile and distributed nature of the source means that it is difficult to control through regulations. The *Environmental Protection (Noise) Regulations 1997* specifically exclude road and rail transportation noise. As a result, there is a need for consistent noise criteria for transportation noise which can be used as the basis for planning decisions and environmental impact assessments.

3.2 In this statement, there are three contexts in which road and rail transportation noise are considered -

- proposed noise-sensitive developments (residences, hospitals and the like) near existing road or railway transportation routes;
- new transportation infrastructure (road or railway) near existing noise-sensitive premises;
- traffic expansion on existing road or railway infrastructure;

3.3 The noise criteria which are developed and the availability of control measures are different in each of the above contexts. In all cases, the "as low as reasonably practicable" principle should apply.

3.4 Related issues such as noise from air transport and ground vibration from road and rail transport may be included in this statement at a later stage or incorporated in a separate statement.

4 Definitions

4.1 **Effects of transportation noise**

(Include reduced summary of ICBEN research papers).

4.2 **Definitions**

A series of Noise Amenity Ratings are defined in terms of L_{Aeq}, or average, noise level ranges as follows:

Noise Amenity Rating NX:

Rating	$L_{Aeq,T}$ (Day)	$L_{Aeq,T}$ (Night)
N0	50	40
N1	51 - 55	41 - 45
N2	56 - 60	46 - 50
N3	61 - 65	51 - 55
N4	66 - 70	56 - 60
N5	70	60

Notes: (i) The NAR for a location is the higher of the day and night ratings.
(ii) Noise levels refer to external locations at 1m from a building façade.
(iii) "Day" means 7am – 10pm and "Night" means 10pm – 7am.

The impact of transportation noise levels in these ranges would depend on a number of factors, including the characteristics of the transportation, the nature of the receiving area (rural, urban or commercial) and the use and construction of the receiving premises. With this in mind, for noise-sensitive premises, the impact may be said to increase with rating number, from "acceptable" at N0 to "substantial" at N3 and above, with the impact becoming "noticeable" to "significant" over N1 and N2.

Noise Reduction: NR

NR is defined as the difference in the noise level from outside at 1m from the building façade to the interior space. For example, an NR of 15 provides a noise reduction of 15 dB(A), reducing an external level of 60 dB(A) to an internal level of 45 dB(A).

A typical building where the room faces the road provides a NR of 10 with windows open and 15 with windows closed. If windows are to be kept closed, mechanical ventilation or airconditioning would be required.

5 Policy

5.1 Proposed urban developments near pre-existing major transportation routes

5.1.1 Environmental Objective

(a) The achievement of acceptable noise levels inside new residences and other noise sensitive premises constructed adjacent to major road or rail transportation routes.

(b) To influence the land use planning process such that road and rail transportation noise is taken into account in the planning, design and construction of new developments.

5.1.2 Rezoning land to permit noise-sensitive uses

This section applies where land that is within an area of influence, that is, within 200 metres of a road carrying at least 2000 vehicles per day or any railway, is proposed to be rezoned to permit any noise-sensitive use. This section also applies to land which is within an area of influence of a road or rail reserve, where there is a reasonable prospect of construction of the road/railway within the next 25 years. The definition of "Noise-sensitive premises" should be as per the *Environmental Protection (Noise) Regulations 1997*.

Land which is within an area of influence and is to be rezoned to allow noise-sensitive uses, including residential, schools, hospitals and the like, should be mapped to determine road and rail noise amenity ratings across the site. This mapping may be carried out by -

(a) direct measurement of noise levels at selected locations and interpolation between measured levels; and/or

(b) prediction of noise levels using an accepted model.

All measurements should be adjusted to take into account likely maximum traffic flows for a year at least 25 years from the date of the assessment.

The rezoning should comply with the following table of land uses:

TABLE 1: ACCEPTABLE LAND USES FOR REZONING

Rating	Acceptable	Conditionally Acceptable	Unacceptable
N0	Residential		
N1	Residential		
N2	Open space	Residential	
N3		Residential units, open space	Residence + yard
N4		Residential units, open space	
N5		Residential units	Open space

"Conditionally acceptable" means the development will require acoustic measures in order to achieve acceptable rating levels, both for internal and external noise. The external noise levels may be achieved through barriers, while internal levels may be achieved through orientation and screening of sensitive rooms and facade design, as outlined in Section 5.1.3. The reference to "residential units" means residential apartments where there is no external space facing the road or railway, and acceptable internal levels can be achieved through acoustic treatment of the facade.

With regard to "open space", the level of acceptability will depend on the intended use envisaged for the open space and the type of noise reduction measures which may be available.

Rezoning proposals which are referred to the EPA should be noise mapped and should not contain land use zonings in "unacceptable" areas. Land uses in "conditionally acceptable" areas should comply with Table 1 and the mechanism for implementation of the relevant treatments at subdivision stage should be indicated.

5.1.3 Subdivision proposals and land use changes

This section applies to any areas within a planning scheme which have been identified under Section 5.1.2 above as being "conditionally acceptable". Where a residential subdivision is proposed or a change of use to a noise-sensitive one is proposed, for example a city site is converted to unit dwellings, the following guidance should be complied with, even if the proposal is not referred to the EPA for advice.

Residential premises should be designed such that the external spaces comply with N2 rating, or preferably N1. If located in an N3 area, this may require provision of a barrier wall or fence. It should be noted that the second row of houses back from a road or railway will be screened by the first row, and this may be taken into account in the design of the second row.

The internal spaces of residences should be designed to comply with the internal equivalent of N1. The internal noise levels, with windows open, would be typically 10 dB(A) lower than the corresponding external levels. Where the N1 rating is achieved externally, the internal equivalent of N1 would be achieved without specific treatment. Where the external noise level is N2, however, the achievement of the equivalent internal level to N1 would require some form of treatment. This may take the form of "quiet house" design, where noise-sensitive spaces such as bedrooms are screened by the remainder of the house. Where such rooms must face the road or railway, treatment of the facade will be needed. This will comprise substantial treatment in the case of residential apartments in high noise areas.

Australian Standard 3671-1989[1] provides guidance in the treatment of building facades for road traffic noise.

Where the external noise levels comply with the table, but the internal levels do not, a construction category offering the appropriate Noise Reduction should be applied to achieve an internal noise level which is 10 dB(A) below the specified external level.

Example: A new subdivision proposal has noise levels in the N3 range for a proposed block of units near a major road. In order to achieve the equivalent internal levels to N1, the appropriate Noise Reduction is

$$\begin{aligned} NR &= N3 - N1 + 10 \\ &= 65 - 55 + 10 \\ &= 20 \end{aligned}$$

Therefore, according to AS 3671, Category 2 construction would be required.

The exterior spaces of non-residential premises which may be occupied for recreational purposes should be designed so as to achieve N2 rating.

The interior spaces of non-residential premises should be designed and constructed such that the noise levels from road and rail transportation comply with the maximum sound levels given in Table 1 of Australian Standard 2107 - 1987[2], according to the following methodology:

Step 1 - Determine the maximum sound level for the type of internal space from Table 1 of AS 2107 - call this $L_{A\ Design}$.

Step 2 - Determine the NX value for the existing noise environment

Step 3 - Design the building envelope to achieve a noise reduction (NR) of -

$$NR = NX - L_{A\ Design}$$

Any subdivision which is referred to the EPA should identify those lots which will require some form of treatment, either in the form of barrier walls/fences or in the form of facade treatment, and should indicate the mechanism by which this will be achieved.

5.2 Criteria for proposed road or rail infrastructure development adjacent to existing noise-sensitive premises

5.2.1 Environmental Objective

The objectives are -

(i) that the noise emissions from the road or rail reserve are minimised as far as is practicable through appropriate design; and

(ii) that the noise levels inside and outside existing noise-sensitive premises do not exceed acceptable levels.

5.2.2 Noise-sensitive premises planned prior to gazettal of road/rail corridor

This section applies where a road or railway is to be constructed within an area of influence, and where the road or railway reserve was not gazetted prior to the planning and construction of the existing noise-sensitive use. In this case, the noise receivers would not have had the expectation that a transportation corridor was to be constructed in the vicinity.

The first step is to determine the ambient noise levels in the area of influence. Where ambient levels are low, that is, N0 then this section should be applied. If ambient levels due to transportation noise sources are N1 or higher, then Section 5.3 below should be used.

Predictions of noise emission levels from the proposed corridor should be carried out according to an accepted method for all noise receivers of relevance, and for typical maximum traffic flows for a year at least 25 years from the time of the proposal.

The design of the road/railway should be carried out so as to minimise noise emissions as far as is practicable, but in any case so as to achieve the following criteria in Table 2.

TABLE 2: ACCEPTABLE NOISE LEVELS FOR EXISTING NOISE-SENSITIVE PREMISES NEAR NEW ROAD/RAIL CORRIDORS

Rating	Acceptable	Conditionally Acceptable	Unacceptable
N0	Rural res		
N1	Urban/Unit res	Rural res	
N2	Open space	Rural/Urban res	
N3		Residential units	
N4			Rural/Urban res
N5			Residential units

The noise emissions should be reduced as far as is practicable by means of corridor alignment, use of cuttings and noise barriers to achieve the "acceptable" levels in Table 2. Where these levels cannot be practicably achieved, the equivalent internal level to N1 in the "conditionally acceptable" cases should be achieved by means of acoustic treatment to the building envelope and provision of mechanical ventilation/airconditioning. In the "unacceptable" cases, provision should be made for the purchase of the noise-sensitive premises.

5.2.3 Noise-sensitive premises constructed after gazettal of road/rail corridor

This section applies where a road or railway is to be constructed within an area of influence, and where the road or railway reserve was gazetted prior to the construction of the existing noise-sensitive use. In this case, the noise receivers would have had some expectation that a transportation corridor was to be constructed in the vicinity. If the residential area had been planned after the commencement of this Guidance Statement, then the planning process should have ensured that noise-sensitive premises within the area of influence had been constructed so that the noise levels in Table 1 would be achieved when the corridor was eventually constructed.

As in Section 5.2.2, ambient noise levels should be determined and predictions of future noise emissions from the corridor carried out.

The design of the road/railway should be carried out so as to minimise noise emissions as far as is practicable, but in any case so as to achieve rating N2.

Where it is not practicable to achieve N2, or where the predicted level is 15 dB(A) or more above the ambient noise level, the proponent should undertake one of the following -

(i) acoustic treatment of the building envelope to achieve the internal equivalent of N1;

(ii) where the building already incorporates such treatment, compensation at the rate of 1.2% of the current market value of the property for each dB(A) increase in noise level above N2;

(iii) where the predicted level exceeds N3, purchase of the property, unless the property comprises residential units with no open space facing the road/railway, in which case (iv) below applies; or

(iv) in the case of residential units where the predicted level at the planning stage was N3, N4 or N5, compensation to each title holder at the rate of 1.2% of the current market value of the property for each dB(A) increase in noise level above that used at the planning stage for design purposes.

The information provided to the EPA should include the ambient noise level data, predicted noise levels, description of measures to be used to achieve N2 or better, numbers of noise-sensitive premises in each NX range, and proposed treatment/compensation mechanism.

5.3 Criteria for proposed increase in road or rail traffic

5.3.1 Environmental objective

This section applies where an increase in traffic flow is proposed such that the total flow along the corridor exceeds that on which planning decisions were made under Section 5.1 above, and where a significant traffic flow, either temporary or permanent, would result from a specific industrial or transportation proposal. This section would not apply to incremental increases which were associated with the normal traffic growth along the corridor and were within the bounds of planning decisions under Section 5.1 above.

The objectives are -

(i) that the noise levels inside noise-sensitive premises associated with the proposed traffic should meet acceptable levels, or that the degree of increase in noise levels should be of low significance; and

(ii) that the noise emissions of the vehicles associated with a specific proposal should comply with "best practice".

5.3.2 Traffic increases not associated with a specific industrial/transportation proposal

This section applies where an increase in traffic flow is proposed such that the total flow along the corridor exceeds that on which planning decisions were made under Section 5.1 above. The acceptable increases are as follows:

Rating before Increase	Acceptable Increase in $L_{Aeq,T}$ noise level

N0	4 dB, or to top of N0, whichever is greater
N1	3 dB
N2	1.5 dB
N3	0.5 dB
N4	0 dB

6 Procedure for Proponents

7 Application

8 Responsibilities

9 Technical terms

The following technical terms are used in this document -

A-weighted	an A-weighted sound level includes the "A" frequency weighting in the measurement of a sound, to approximate the frequency response of the normal human ear
dB(A)	the level of a sound, measured in decibels, A-weighted
$L_{Aeq,T}$ time	the constant A-weighted sound level which has the same energy as the fluctuating sound of the traffic, averaged over T
Noise-sensitive premises	are defined as in regulation 2 (1) of the *Environmental Protection (Noise) Regulations* 1997

10 References

1 Australian Standard 3671-1989: "Acoustics - Road traffic noise intrusion - Building siting and construction", Standards Australia, 1987

2 Australian Standard 2107-1987: "Acoustics - Recommended Design Sound Levels and Reverberation Times for Building Interiors", Standards Australia, 1987

Index: Draft

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Appendices: (to be drafted)

APPENDIX E

NOISE AMELIORATION TECHNIQUES

APPENDIX E - NOISE AMELIORATION TECHNIQUES

Options available to reduce exposure of residential occupants due to road traffic include:

Reduction of the source by:

- Reducing vehicle noise emission.
- 'Quiet' road surface such as open graded asphalt.
- Reduce the speed limits along areas of significance.

Reduction be treatment of the propagation path:

- Barriers.
- Choosing the road route to take advantage of natural barriers and maintain maximum distance to residents.

Treatment at the receiver location:

- Barriers close to house.
- Increase the transmission loss of the house facade.
- 'Quiet House' design i.e. bedrooms on the opposite side of residence from the road
- Relocation of the premises.

Using an open graded asphalt can result in reductions of up to 2.5 dB(A) compared with the current surface. In practice, partly due to the height of the noise source of trucks, reductions of around 2 dB(A) are likely to be achieved.

Treatment to houses in the form of double glazing, door seals and roof / ceiling treatment can give reductions of up to 10 dB(A) over and above that of closed windows. However, this requires that one is inside with the windows shut and often necessitates the use of mechanical ventilation or air conditioning. Also, such reductions tend to reduce mid to high frequency noise leaving the sometimes more annoying low frequency noise.

Bund locations and areas requiring 'quiet house' design are shown on Figure C1, attached in Appendix C.

The following provides some techniques that can be incorporated in 'Quiet House' designs:-

- Locating bedrooms on opposite side of residence from road.
- Locating of laundries / bathrooms on same side of road.
- Protecting main entrance from road noise.
- Enclosing eaves.
- Roof insulation.
- Double brick construction.

Australian Standard AS 2021-1994 "Acoustics - Aircraft noise intrusion - Building siting and construction", can also provide guidance on construction requirements for various maximum noise levels.

The barriers should be solid in nature, with no gaps. However, their construction can range from a close timber or compressed cement sheet fence to a masonry wall. Landscaped earth bunds could also be used in this instance.