FINAL REPORT ON BEHALF OF

accessUTS LIMITED

GROUNDWATER ASSESSMENT FOR THE PROPOSED PORT BOTANY EXPANSION

FOR

SYDNEY PORTS CORPORATION

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EXECUTIVE SUMMARY

Sydney Ports Corporation is committed to providing an additional capacity for increased trade through Botany Bay. Part of the strategy includes reclamation of a portion of Botany Bay between the Patrick Container Terminal and the Parallel Runway of Sydney Airport.

When land adjoining a foreshore is reclaimed, there is potential for a rise in groundwater levels on the landward side of the foreshore. The expected rise in groundwater levels can be nullified by providing a channel between the reclaimed area and the foreshore, or by installing drainage along the existing shoreline. The groundwater in parts of the Botany Sands aquifer is known to be contaminated. Hence, any reclamation for port development that has an impact on groundwater levels, if not adequately mitigated, could also cause mobilisation, acceleration or redirection of dissolved contaminants.

The main purpose of this study is to evaluate by means of numerical modelling the likely groundwater impacts of the proposed reclamation for a new container terminal and foreshore works that will cause a re-alignment of the present shoreline. This study follows earlier modelling studies that investigated alternative reclamation plans.

The present study focuses on the long-term equilibrium behaviour of the groundwater system under normal conditions, but also considers extreme climatic conditions and transient forces. This study also provides comment on any consequences that reclamation could have on groundwater quality issues, particularly the known contaminant plumes heading from the Botany Industrial Park to Penrhyn Estuary. A high-concentration plume of ethylene dichloride (EDC) is expected to discharge into Penrhyn Estuary in 5-7 years from now. The Penrhyn Estuary habitat enhancement works will have the effect of bringing forward the arrival time by 6 to 12 months.

The numerical modelling demonstrates that the proposed reclamation for the new container terminal (without the foreshore works) will have no effect on groundwater levels on the landward side of the present shoreline, nor will there be any change to groundwater flow directions. Hence there cannot be any interference with the natural migration of contaminants.

There is some effect from the foreshore works, due to the enhancement of Foreshore Beach to address the erosion of the present shoreline that has occurred over the last two decades. The edge of the proposed tidal channel will be 20 m at most on the seaward side of the existing shoreline. The foreshore works cause extensions in the distance that groundwater must flow to reach the Bay and will result in water table rises of between 0.01 m and 0.04 m in residential areas and up to 0.06 m at the ponds in Sir Joseph Banks Park.

The Penrhyn Estuary habitat enhancement works will move the shoreline closer to Foreshore Road by up to 200 m. This will lead to falls in groundwater level that are

expected to be generally 0.01-0.03 m beneath Botany Golf Course, and 0.04-0.06 m south of Foreshore Road.

The small anticipated rises and falls in groundwater levels must be placed in context with the variations that can be expected due to rainfall variability, changes in abstraction, and tidal effects. It is estimated that the magnitude of fluctuations from these influences is about 1 m at Foreshore Road and Dent Street, 1.5 m at Botany Road, and up to 5 m at the northern boundary of the Botany Industrial Park. Hence, the anticipated rises from the foreshore works are extremely small with respect to the natural dynamic variations in water level.

Overall, there will be no change in the total discharge of groundwater to the Bay. Without shoreline drainage, due to lower hydraulic gradients along the new beach, about 20 percent of natural groundwater discharge to the Bay, in this area, will be diverted to the Mill Stream Diversion Channel and the tidal channel. One of the consequences of this is that the groundwater flux carrying the Northern Plume could increase by up to 5 percent. This is caused by a slight increase in groundwater levels, with associated reduction in hydraulic gradient, to the immediate west of the exit swathe where the tidal channel is to be about 20 m on the seaward side of the present shoreline. Although the contaminants in the Northern Plume will be diluted there should be no change in contaminant mass that will enter the channel.

The water table rises attributed to the foreshore works are really a restoration of groundwater levels to what they were before the erosion of the existing foreshore. The foreshore has eroded up to 40 m since 1980.

It is recommended that the foreshore works be constructed initially without drainage, provided that an adequate monitoring system is put in place to assess whether there is a perceptible change in groundwater levels. There is really no need to install a drain, as the predicted impacts are very small in relation to natural variations in groundwater levels. As a precaution, groundwater levels should be monitored during construction, and for one year after construction, to check that there is no discernible change in the pattern of groundwater level variations. It is most unlikely that it will be possible to extract a “port effect” from groundwater level measurements. If this proves to be the case, then that will provide confirmation that the port development is not having any real impact on groundwater conditions.

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1.0 INTRODUCTION

Sydney Ports Corporation is preparing to expand the container terminal facility at Port Botany to accommodate forecast trade growth. Figure 1 shows the existing port in Botany Bay. The area proposed to be reclaimed is in Botany Bay, between the Patrick Container Terminal and the Parallel Runway of Sydney Airport (Figure 1).

When land adjoining a foreshore is reclaimed, there is potential for a rise in groundwater levels on the landward side of the foreshore. The reason for this is that the groundwater has to follow a longer flow path with a reduced hydraulic gradient. The basic principles are illustrated in Figure 2. The expected rise in groundwater levels can be nullified by providing a channel between the reclaimed area and the foreshore, or by installing drainage along the existing shoreline (Figure 2).

accessUTS Pty Ltd, through its agent the National Centre for Groundwater Management (NCGM) at the University of Technology, Sydney has undertaken modelling of the groundwater impacts of the proposed development, as a contribution to the Environmental Impact Statement (EIS) for this project. Modelling can predict the magnitude and extent of groundwater rises and can assess whether groundwater flow directions and fluxes will be altered. This modelling exercise follows similar modelling for two earlier port designs (Merrick, 1998a).

Figure 3 shows the extent of the proposed expansion of Port Botany. Reclamation will create:

- A new container terminal attached to the western end of the Patrick Container Terminal;
- An enhanced beach to the west of the new container terminal and improved public access ; and
- A new boat ramp and car park at the northern end of the new container terminal.

Penrhyn Estuary will remain as an open water body, linked to Botany Bay by an open tidal channel at the northern end of the new container terminal.

The present study investigates the long-term steady state behaviour of the groundwater system under normal climatic regimes. This study also provides comment on any consequences that reclamation could have on groundwater quality issues, particularly the known groundwater contamination heading from the Botany Industrial Park (former Orica Botany Plant site) to Penrhyn Estuary and Botany Bay (Figure 3).

2.0 GROUNDWATER CONDITIONS

The Botany Basin is designated by the Department of Land and Water Conservation (DLWC) as Groundwater Management Area (GWMA) 018. It is divided into northern, southern and western zones. Only the northern zone is relevant to this study. The aquifer is classified as a “high risk resource” in terms of groundwater quality (Bish *et al*., 2000), due to the presence of a large number of contaminated sites. A groundwater protection zone

(Figure 3) has been declared in the projected path of the Orica contaminant plume. In this zone, bore licences will be issued only for cleanup and control activities. A buffer zone 500-700 m wide around the main zone has also been declared. In this zone, existing users may continue to pump groundwater, but no new licences will be issued.

2.1 HYDROGEOLOGY

Groundwater in the Botany Bay district occurs in unconsolidated sediments of Quaternary age which overlie a bedrock surface consisting of Hawkesbury Sandstone. These sediments comprise the Botany Sands aquifer and are made up of river, beach and dune sands interbedded with clay and peat lenses. This sequence can be separated into two subdivisions :

- an upper, predominantly sandy section of variable thickness;
- a lower section of interbedded clays, peats and sands above the bedrock.

Discontinuous peat beds and indurated sand-rock layers, termed “Waterloo Rock” which may be up to a few metres thick, can occur in the upper section. An extensive area of saline peat (Veterans Swamp) underlies Banksmeadow to the north of the Botany Foreshore and west of the Botany Industrial Park.

2.2 GROUNDWATER LEVELS

In the past, many bores have been drilled close to the northern shoreline of Botany Bay for the purpose of monitoring groundwater levels, or for abstracting groundwater for industrial or irrigation use. The locations of all known bores are shown in Figure 4. However, not many of these bores have survived. For those that remain, there has not been a routine monitoring program in place. In part this is due to ownership, as the bores were drilled by a number of independent groups.

The bores with the longest period of record are those of the Department of Land and Water Conservation (DLWC), dating back to 1974 for a few. Despite the addition to the network of nine new bores in 1998 with automatic data loggers, monitoring of the rest of the network has been interrupted in recent years. Although regular data are not available since 1994, a census was undertaken in April 2000 to establish which bores in the network were still accessible, and to record water depths at that time. The status of the network is reported in Bish *et al*. (2000).

Orica (through URS Australia) has been monitoring groundwater levels and chemistry since 1994 on the Orica Botany Plant site and in the general vicinity of Southlands (Figure 4). Comprehensive water level data are available for June/July 1994, August 1996, March 1998 and May 2000.

In April 2002, Sydney Ports Corporation re-commenced monthly monitoring of water levels at 13 sites: 4 DLWC, 4 MSB (Maritime Services Board), 4 industrial, and 1 pond in Sir Joseph Banks Park[1]. Monitoring had been conducted over many years at a number of sites by the MSB and later SPC after the initial development of the port.

In order to gain an appreciation of current groundwater conditions, given the spasmodic sampling of water levels, the best that can be done is to combine water level measurements over a 2-year period from April 2000 to April 2002. This gives the composite groundwater level pattern shown in Figure 5. *(Lake and bay levels have been used to constrain the contouring. Some older values near the airport define the edges.)* Groundwater flows in a general south-westerly direction towards Botany Bay. The pattern has changed considerably over the last decade, with much higher water levels west of the Botany Industrial Park. This is believed to be due to a substantial reduction in groundwater pumping in that area, in association with higher rainfall.

In places, a distinction is made between *shallow* and *deep* aquifers. The shallow aquifer generally has about 5 m of saturated thickness. In most places, particularly to the north, there is very good hydraulic connection between shallow and deep aquifers. Where piezometers have been placed at multiple depths in older bores (as in Figure 6), there is rarely any record of the depths being sampled. Where records exist, the average screen depths for shallow and deep bores are 8 m and 24 m below ground.

An illustration of the dynamic variations in groundwater levels is provided in Figure 6 for two representative bores: (a) Bore 42170 (due east of Penrhyn Estuary and south of the Orica site); (b) Bore 42176 (on the eastern boundary of the Orica site). Historical groundwater levels have fluctuated by about 1.5 m at 42170, and 3 m at 42176, in response to rainfall variability and groundwater abstraction.

2.3 VERTICAL HEAD PATTERN

The hydrographs in Figure 6 show that the groundwater levels in the shallow and deep parts of the Botany Sands Aquifer are not identical, but in general they are similar to each other. This suggests that the aquifer can be regarded as behaving as a single aquifer, and that it would be appropriate to model the groundwater system in this way.

The magnitude of the vertical head difference has been investigated at sites where bores are screened at multiple depths. There are 30 sites in the northern Botany Basin with information on shallow and deep groundwater heads. Most sites have information at two levels, but some have three. The historical levels at all sites have been examined, and a representative head difference estimated for each, as displayed in Figure 7.

[1] There is concurrent pumping of water from the easternmost pond by the City of Botany Bay. This water is used to irrigate the greens of Botany Golf Course in times of drought.

If the shallow head exceeds the deep head, there is a potential for downwards flow. Conversely, upwards flow is indicated if the deep head exceeds the shallow head. Of the 30 sites, 12 suggest upwards flow, 14 suggest downwards flow, and 4 sites have no head difference.

At the sites where downwards flow is likely, the median head difference is 0.18 m and the maximum is 1.0 m. At the sites where upwards flow is likely, the median head difference is 0.22 m and the maximum is 0.8 m.

Figure 7 shows that the propensity for upwards flow is confined to a zone trending northeast from Penrhyn Estuary through Southlands to a distance of 1.4 km from the shoreline. Elsewhere, downwards flow is indicated, even very close to the shoreline. A possible reason for this zone of upwards flow is the impact that Springvale Drain and Floodvale Drain have on capturing groundwater from the shallow aquifer. Woodward-Clyde (1995) found that Springvale Drain had a capture zone extending to about 7 m depth. *(Springvale Drain passes through the centre of Southlands, heading due south to the Bay; Floodvale Drain runs along the western boundary of Southlands towards the Bay.)*

Figure 8 shows a cross-sectional view of the groundwater flow regime along transect A-A' (see Figure 7 for location). Although the March 1998 heads are lower in general, the head pattern is similar for the two dates. A near-vertical contour at 1600 m distance shows the point at which downwards flow (to the right of 1600 m) converts to upwards flow (to the left of 1600 m). The groundwater flow direction is approximately perpendicular to the head contours. Both sections indicate strong upwards flow of groundwater into Penrhyn Estuary. There is not enough data between Botany Bay and Penrhyn Estuary (beneath the Patrick Container Terminal) to give a reliable pattern in this area. One would expect downwards flow close to ground surface due to a small groundwater mound that would be built up from rainfall infiltration.

Beneath Penrhyn Estuary, the deep aquifer head is about 0.5 mAHD. It is not known what the deep aquifer head is beneath the Bay, but the section data suggests 0.3 mAHD at the most. Sampling of electrical conductivity by Woodward-Clyde (1995) has shown very saline conditions beneath the existing port (near A on the transect) and a zone of diffusion beneath Penrhyn Estuary. On this evidence it is likely that the saltwater interface is close to the shoreline rather than far out into the Bay. The saltwater wedge will drive groundwater upwards into the Estuary and the waters close to the shore. There is expected to be very little groundwater flow at depth beneath the Bay. Along this transect, most groundwater discharge is captured by Penrhyn Estuary.

2.4 HYDRAULIC STRESSES

The most important dynamic stresses on the Botany Sand aquifer are rainfall and groundwater abstraction. The main recharge area is in Centennial Park at the northern end of the catchment. Substantial recharge also occurs in green space areas (parks and golf courses).

Groundwater levels are controlled by Alexandra Canal, the Lachlan Lakes and Swamps, Cooks River and Botany Bay.

2.4.1 Rainfall

Long term median rainfall is 1073 mm per annum at Sydney Airport (Mascot). There is a strong correlation between rainfall and groundwater fluctuations. Merrick (1994), based on calibration of an earlier groundwater model, estimated that rainfall infiltration varies from 6 percent on estuarine sediments to 37 percent on sand.

An illustration of the effect of rainfall on groundwater levels is given in Figure 9. There is a close correlation between long-term groundwater fluctuations and rainfall residual mass (the cumulative deviation from monthly mean rainfall). Rainfall residual mass is a measure of the cumulative excess of water added to an aquifer by rainfall recharge. An aquifer that is responsive to rainfall can be expected to have groundwater level fluctuations that are in sympathy with changes in residual mass. The procedure for calculating residual mass effectively filters out the rapid variations in raw rainfall, and presents the rainfall data at a time scale that matches the much slower aquifer response. At sites where there is little impact from groundwater abstraction, one would expect a groundwater hydrograph to be similar in appearance to the rainfall residual mass curve.

Figure 9 shows that there was a substantial rise in the 1980s in groundwater levels in the industrial area near Botany Bay. Part of this rise is due to reduction or cessation of groundwater pumping, particularly near Bore 42167. However, some of the rise is due to natural climatic variations. The residual mass curve demonstrates that there was a drought up to 1981, normal conditions to 1987, and a wet period to 1990. The groundwater levels respond in a similar fashion to the residual mass curve.

At Bore 42167, the water level rose from –1.5 mAHD to +4.7 mAHD during the 1980s, due partly to lower abstraction, but mostly to higher rainfall during the late 1980s. Bore 42176, which is less affected by groundwater pumping, has a natural range of nearly 3 m.

2.4.2 Abstraction

The Botany Sands aquifer has been an important source of water for more than a century. The history of groundwater abstraction in the area is recorded by Merrick (1998b).

Estimates of groundwater abstraction have varied from about 20 ML/day to about 55 ML/day in the last 50 years. In 1992, usage was reported as 30 ML/day. Since then, there has been no official check on usage. In some instances, installed meters have been vandalised and rendered inoperative. It is likely that usage has declined significantly over the last decade, as industrial users close to the Bay have shut down pumping operations (due to pollution) or have moved their businesses elsewhere. The likely current distribution of production is presented in Figure 10, with an estimate of the relative abstraction at each bore. The distribution is based on licensed allocations, historical usage up to 1991, and local knowledge of active users (D. McKibbin, DLWC, pers. comm.).

There are about 90 bores with current licences, but only about 60 percent would be in use. About 70 percent of bores are used for irrigating parks and golf courses; the remainder are used by industry. However, the industrial users account for about 60 percent of usage. Most of the groundwater abstraction is due to three industrial users:

- AMCOR (about 34% of total usage)
- Solvay Interox (about 12% of total usage)
- Orica (about 11% of total usage)

The largest user is AMCOR Packaging (Australia). AMCOR withdraws about 6 ML/day from a borefield at Snape Park (Figure 10), 3 km north of the Botany Mill site (Sinclair Knight Merz, 2000). The water is discharged into a stormwater canal for transit to a dam adjacent to the Mill site.

The Environmental Impact Statement for AMCOR's proposed new Botany Paper Mill (Sinclair Knight Merz, 2000) reports that Solvay Interox withdraws 3.1 ML/day from their borefield close to the Lachlan Swamps (Figure 10). Five bores are in use in Myrtle, Begonia, Ocean and Bay Streets. Usage is likely to range from 2 ML/day to 2.9 ML/day on average (C. Koch, pers. comm., 2002). Water is piped to the company's premises in McPherson Street, due west of Southlands (Figure 10), for use as a coolant after which it is transmitted to the dam at the AMCOR site.

The Orica borefield (Figure 10) is comprised of four bores that produce about 2 ML/day in winter, and 3 ML/day in summer (J. Stening, pers. comm., 2002).

The City of Botany Council is the largest groundwater user close to the Bay. The Council relies on a bore at Banksmeadow (Figure 10) to service Botany Golf Course. The water is aerated and piped to a lined dam on the golf course. Supplementary water for irrigating greens during dry times is drawn from the easternmost pond in Sir Joseph Banks Park. During the drought of 2002, pond water was pumped for 3 hours per day every day. It is estimated that this withdrawal would cause a transient change in local pond water level of 1-3 cm, with rapid recovery.

Total current usage of groundwater in the northern part of the Botany Basin is estimated to be about 7,000 ML/year (about 20 ML/day). There is not expected to be any significant change in this abstraction rate in the foreseeable future.

3.0 METHODOLOGY

3.1 NUMERICAL MODEL

Two separate modelling approaches have been followed for this study: (1) two detailed cross sections (A-A' and B-B' in Figure 7) have been simulated with a finite difference method using MODFLOW software (McDonald and Harbaugh, 1988); (2) the areal behaviour of the aquifer has been simulated with a finite element method using AQUIFEM-1software (Townley and Wilson, 1980). Each method computes groundwater levels for a large number of cells or elements by solving simultaneous groundwater flow equations. Each model simulates groundwater flow and does not specifically simulate the transport of contaminants.

The regional finite element model has been used for a number of management applications in the Botany Basin, including industrial borefield reliability, the environmental impact of the Parallel Runway at Sydney Airport (Merrick, 1994), and the environmental impacts of the New Southern Railway (Merrick, 1998c) and the Eastern Distributor. Feedback from the two latter applications has demonstrated that the model has performed very well as a predictor of groundwater level impacts (Merrick, 1998c; C. Jewell, pers. comm., 2001).

This model can track the response of the sand aquifer as recharge stresses (rain, irrigation) and discharge stresses (abstraction, drainage) vary from month to month. The finite element technique requires that the study area be sub-divided into a number of triangular elements. In each element, the transmission and storage properties of the aquifer are taken to be uniform. AQUIFEM-1 is limited to a single aquifer, which in this study is predominantly sand but also incorporates fill, residual clay, and sedimentary peat and clay. Impermeable bedrock is taken as the top of either Ashfield Shale or Hawkesbury Sandstone. The model does not explicitly consider water flow within the underlying sandstone formation as the permeability and porosity of the sandstone are much lower than for sand. The finite element grid consists of 460 nodes and 815 elements (see Appendix A, Figure A1 for the portion of the grid near the Bay). The entire northern zone of the Botany Sands aquifer is modelled, so that rainfall inputs at the northern end of the basin are properly taken into account.

Each cross section model consists of 23 layers, with layers generally 2 m thick. Line A-A’ has 51 columns, each 50 m wide, and Line B-B’ has 45 columns, each 50 m wide. The slices are nominally 100 m wide in the directions perpendicular to the sections.

Similar aquifer properties are allocated to finite difference cells and finite element nodes, namely: aquifer top/bottom elevations or aquifer thickness, hydraulic conductivity, and storage coefficient (for transient simulations only). Multi-layer models also require the leakage coefficient between layers. In the models, reclamation material is not identified by lithology but by values for hydraulic conductivity (and storage coefficient). Each surficial cell or element has been allocated land use and rainfall infiltration characteristics.

Cells and elements that are defined in open water (particularly Penrhyn Estuary and Mill Stream) are treated as “lake” features[2]. At lake nodes, the model will calculate a groundwater level for the aquifer beneath the lake. If the groundwater level is higher

[2] Use of the “lake” feature is more accurate than use of the “ocean” feature. Modelling shows that simulated groundwater levels close to the Bay are slightly higher using the “lake” feature.

than the lake level, groundwater will discharge to the lake. Cells and elements in contact with Botany Bay are treated as "ocean" features. This means that groundwater levels at the boundary nodes are set equal to sea level. In the models, lake features extend from Penrhyn Estuary out to the far edge of the new container terminal, so that the model runs "before" and "after" reclamation have the same model boundary along the southern and western edges of the new container terminal.

3.2 STEADY STATE

Modelling simulations are focused on the equilibrium (or steady state) response of the aquifer to constant stresses set at current levels for pumping and irrigation, using long-term median rainfall. This approach simplifies the modelling, captures the essential long-term response of the system, and isolates the impact of the reclamation activity from water level variations due to natural climatic variations. Previous modelling (Merrick, 1998a) showed that the anticipated rises in groundwater level under steady state conditions were comparable with the short-term rises under transient conditions.

In order to establish baseline water levels, the model is run first for the existing situation with the present shoreline. Then the model is run assuming that the only reclamation that is to take place is for the new container terminal. Finally, the full reclamation (terminal plus foreshore works) is examined, with and without shoreline drainage.

Groundwater discharge rates to Penrhyn Estuary are compared for each simulation to check whether the reclamation might focus or accelerate the groundwater contaminants from the plumes when they reach the shoreline.

3.3 CALIBRATION

The regional finite element model used in this study has been calibrated against transient groundwater fluctuations (Merrick, 1994) and has been progressively refined over a period of 17 years. Given that groundwater abstraction has reduced in the last decade, some additional calibration was done against the spatial distribution of water levels presented in Figure 5. The contours in Figure 5 present a "snapshot" of what is really a dynamic system; at different times, the contours will move back and forth a substantial distance in response to climatic variations.

An important calibration parameter for this study is the unit conductance[3] of the Mill Stream and its Diversion Channel. A reliable value for this is important, as it provides a guide for the selection of unit conductance for Penrhyn Estuary and for

[3] Unit conductance is defined as the product of the width of a stream and the stream leakage coefficient (hydraulic conductivity divided by bed thickness). The volume of groundwater entering or leaving each lineal metre of a stream is the product of unit conductance and the difference between groundwater level and surface water level.

any drainage channels that might be necessary in the design of the port facility. The calibrated values are 100 m/d for the Mill Pond and 200 m/d for the Mill Stream Diversion Channel.

In addition, the MODFLOW cross section models had to be calibrated against the observed responses of Figure 8. The simulated cross section shown in Figure 11 indicates good calibration with the observed cross section for March 1998 shown in Figure 8 (b).

3.4 BENCHMARK SCENARIO

The simulated water table pattern for existing conditions is shown in Figure 12. Comparison with Figure 5, the “snapshot” observed contours, shows excellent agreement in pattern. Both Orica and Solvay Interox borefields are assumed to operate at 2.0 ML/day each over the long-term[4]. This pattern serves as a base condition for examining the incremental impact of reclamation.

4.0 RECLAMATION CONDITIONS

4.1 TERMINALS ONLY

The simulated groundwater levels after reclamation of the new container terminal, without any modification to the shoreline, are shown in Figure 13. As it is difficult to discern any differences from the base map (Figure 12), it is essential to compose a map of the residuals, as shown in Figure 14.

In the model, there is no perceptible[5] change in groundwater level on the landward side of the present shoreline. There is a small groundwater mound under the new container terminal, with slight rises[5] in the water table at the western end of the Patrick container terminal.

The main body of reclamation for the new container terminal has no effect on landward groundwater levels.

4.2 TERMINAL AND FORESHORE WORKS

When the proposed foreshore works (beach, car park and boat ramp) are added to the terminal reclamation, the simulated groundwater levels do show some change from the benchmark response. The groundwater contours are displayed in Figure 15, and

[4] 2.0 ML/day is the lower limit advised in Section 2.4.2; this is more consistent with the observed effects in Figure 5.

[5] Less than 0.01 m.

the incremental effect is shown in Figure 16. The enhanced beach is at most 40 m wide, and the tidal channel alignment is at most 20 m to the seaward side of the existing shoreline (at 0 mAHD). According to the groundwater principles illustrated in Figure 2 (b), some rise in the water table is to be expected.

It should be noted that the present shoreline has been eroded from the foreshore in place around 1980, at the time of initial port development. The shoreline has eroded a maximum of about 30 m at the northern end of the proposed tidal channel (Figure 3). As the foreshore eroded, landward groundwater levels would have fallen.

The response in Figure 16 shows that there is a rise of between 0.01 m and 0.04 m over a large residential area. This is at the limit of resolution of the model. The expected rise in the residential area is insignificant when compared with the range of natural water level variations that are up to 100 times greater. There is a smaller area with a rise of about 0.06m. This does not intersect the residential area and is confined to the ponds at the western end of Sir Joseph Banks Park. Measurements of pond level at the easternmost pond from April 2002 to January 2003 show a natural variation (over 10 months) of 0.54 m, which is more than 10 times the predicted rise in that area. Pumping from this pond for irrigation of Botany Golf Course would cause only a transient drop in water level estimated at about 0.01-0.03 m. This is unlikely to influence the groundwater readings. Transient modelling of a king tide suggests a rise in pond level of about 0.15 m during such an event. A rise of 0.06 m in the ponds would not have any adverse impact on ecosystem health, as this is well within the normal range of fluctuation.

Appendix A presents alternative responses for the situation where a drain is installed along the present shoreline from the tidal channel to 100m east of the Mill Stream (Figure A2), and for drains with half (Figure A3) and double (Figure A4) the assumed conductance. This mitigation measure is in accord with Figure 2 (d). The unit conductance for this drain is taken to be the lower of the two values that were found by calibration for the Mill Stream. With drainage, there is an area of rise extending to Botany Road of only 0.01m and a rise of about 0.02 m in the ponds at the eastern end of Sir Joseph Banks Park.

There is a mild sensitivity to the conductance of the drain. The expected rises stay within the 0.01 – 0.02 m range.

The model estimates a groundwater discharge of about 3,800 m^3/day (0.044 m^3/s) along the present shoreline extending from the Mill Stream outlet to Penrhyn Estuary. In addition, there is expected to be a discharge of about 2,100 m^3/day to the Springvale Drain outlet and about 1,000 m^3/day to the Floodvale Drain outlet between Foreshore Road and the Estuary.

Following reclamation and shoreline re-alignment, there will be a reduction in discharge along the new beach of about 20 percent due to the reduction in hydraulic gradient. This deficit still gets to the Bay via increased discharge to the tidal channel and the Mill Stream. There would be negligible change in groundwater discharge along the new beach if a drain were installed along the present shoreline for the length of the beach. No change is expected for Springvale and Floodvale Drains. There is no change in groundwater discharge to Penrhyn Estuary. Therefore, the reclamation will not cause any change in concentration of the groundwater contaminants destined for the estuary via the Central Plume or the Southern Plume (see Section 5). Where the Northern Plume enters the tidal channel (see Section 5), groundwater discharge will increase by about 5 percent with no beach drainage, or about 3 percent with beach drainage. This means that contaminant concentrations should reduce a little, but the contaminant mass per unit of time that will enter the channel should remain the same. In the regional model, drains are represented by links between nodes that have a specified invert level and a unit conductance (an indicator of the capacity of a drain to capture groundwater flowing towards the Bay). Unit conductance cannot be measured directly. It is a complex function of the dimensions of the drain (width, and depth below mean sea level), the permeability (hydraulic conductivity) of the drainage medium, and the saturated thickness of the aquifer. The efficiency of a drain, taken to be a buried rubble drain, can be controlled by the size of the gravel (or boulders) used in its construction.

As a check on whether the single layer regional model gives an adequate representation of the groundwater impacts, a cross section model was prepared for conditions before and after reclamation along Line B-B' (see Figure 7 for location). The resulting groundwater heads and flow directions are shown in Figure 17. Prior to reclamation, most groundwater discharge occurs to Botany Bay close to the shoreline. After reclamation and foreshore re-alignment, the modelling confirms that most groundwater discharge is still captured by the channel between the new terminal and the shore. The model's water budget indicates that 90 percent of groundwater is captured by the channel. In reality, the capture rate is likely to be higher than this, as the groundwater salinity interface (not modelled here) would provide an additional force for driving groundwater upwards for discharge to the channel.

The expected rise in water table elevation is shown in Figure 18. The peak rise is about 0.03 m adjacent to the present shoreline. The predicted rises are slightly higher than suggested by the regional model, but the general magnitude of rise is in agreement, namely 0.01 – 0.02 m rise out to about 600 m on the landward side of the present shoreline.

4.3 PENRHYN ESTUARY WORKS

As part of the proposed Penrhyn Estuary habitat enhancement works, SPC will be removing some of the sand dune immediately west of Floodvale Drain. This will be replaced by a strip of saltmarsh along the shore at an elevation of about 0.9 mAHD, and intertidal sand/mud flats (at about 0 mAHD).

This effectively will move the present shoreline in that area back towards Foreshore Road by a maximum of 200 m. In accordance with the principle in Figure 2 (b), the landward groundwater level should drop as the groundwater flow path is reduced in length.

The expected groundwater contours are displayed in Figure 19, with the likely drop in water table elevation shown in Figure 20. Between Foreshore Road and the new shoreline, the water table should drop by 0.04-0.06 m. Between Foreshore Road and Botany Road, beneath Botany Golf Course, the drop in level should be 0.01-0.03 m.

This is a small change that will not be noticed within the context of much larger natural variations.

The extent of the predicted rise in the water table due to the foreshore works does not overlap with the extent of the predicted fall due to habitat enhancement works.

4.4 SENSITIVITY ANALYSIS

The aquifer parameters of the calibrated regional model have been used as a guide in selecting parameters for the fill material for the new container terminal. For hydraulic conductivity, the chosen values are 30 m/d for reclaimed areas and 28 m/d for the aquifer material under Penrhyn Estuary, in accordance with calibrated values. For storage coefficient (for transient simulations), the chosen values are 0.2 for the new beach, and 0.075 for the new terminal, the car park, the boat ramp and the aquifer beneath Penrhyn Estuary (in accordance with calibrated values). The unit conductance in Penrhyn Estuary is taken to be 200 m/day, as calibrated in the cross-section model along Line A-A’.

In order to account for uncertainty in the chosen aquifer parameters, a sensitivity analysis has been performed by perturbing hydraulic conductivity and unit conductance by ±50 percent. (Varying storage coefficient has no effect in a steady-state model.)

The sensitivities to fill hydraulic conductivity and lake conductance are both very mild. As the differences between the incremental rise plots for extreme values are marginal, any error in the assumed values will not affect the findings of the model.

The preceding steady-state modelling shows that very small changes in groundwater levels can be expected from the proposed foreshore works. It is instructive to place these anticipated rises within the context of variations that can be expected due to rainfall variability, change in abstraction, and tidal effects.

Steady-state model simulations have been run for extreme rainfall conditions that are assumed to prevail continuously. While this cannot happen in practice, the results indicate upper and lower limits for dynamic groundwater level fluctuations. When rainfall moves from an extremely low to an extremely high value, the natural fluctuations in groundwater level are expected to be about 0.5 m at Botany Road due north of the new container terminal, and 1.7 m at the northern boundary of the Botany Industrial Park.

If groundwater pumping reduces in the future, as has happened in the past, groundwater levels will rise. It is instructive to see the extent of the rise for the extreme case of zero pumping. While this is unlikely in the long-term, it could occur over a short period of time and would lead to a transient rise in groundwater levels. The rise increases monotonically away from the constraining surface water bodies to a maximum of about 3 m at the northern boundary of the Botany Industrial Park. Along Botany Road due north of the new container terminal, the rise is expected to be about 1 m. At Dent Street, the rise should be about 0.6 m, while at Foreshore

Road, a rise of about 0.1 m can be expected. Of course, these changes are independent of the proposed terminal development.

The regional model has been run also in transient mode by varying sea level in steps of 6.215 hours in order to simulate the response to actual tidal variations observed in May 1997. This particular month included a king tide of 2.18 mLAT (Lowest Astronomical Tide), or 1.255 mAHD (Australian Height Datum), and occurred at 10:50 pm on 10th May. The maximum effect is a rise of about 0.5 m close to the shoreline. In the vicinity of Dent Street, the king tide is responsible for a rise in groundwater level of about 0.15 m. Near Botany Road, the rise reduces to about 0.06 m.

The sensitivity of transient responses to the assumed storage coefficients of fill material has been assessed for a king tide event. Variation of the base values by ±50 percent had no discernible effect on groundwater responses.

5.0 OTHER GROUNDWATER ISSUES

The Director General of PlanningNSW has requested comments and advice from various government agencies and other interested parties as to the Director General's requirements of the Environmental Impact Statement for this project.

5.1 AGENCY REQUIREMENTS

Issues relevant to groundwater, raised by respondents to the Director General, are summarised here.

- **PlanningNSW**

Key issue is groundwater quality. [Addressed in Section 5.2]

- **NSW Fisheries**

a) "Impacts on groundwater." [Addressed]

b) Study area to extend upstream "to take all potential impacts into account." [Addressed]

- **Environment Protection Authority (EPA)**

a) Assessment of potential impacts on the Bay from disturbance of potentially contaminated groundwater/soil/sediment during dredging and land reclamation. [Addressed in Section 5.3]

b) Outline of baseline groundwater information on depth to water table, flow direction and gradient, groundwater quality, and reliance on groundwater by surrounding users and the environment. [Addressed in Section 2 and Section 5.2]

c) Identification of any potential impacts on quality, quantity and flow patterns of groundwater, with a description of their source and significance. [Addressed in Section 4 and Section 5.2]

d) Description of groundwater impact mitigation measures. [Addressed in Section 1 and Section 4.2]

- **Kogarah Council**

The impact of dredging on groundwater. [Addressed in Section 5.3]

- **Randwick City Council**

"Impact on groundwater levels and quality including the Botany Aquifer." [Addressed in Section 4 and Section 5.2]

- **Healthy Rivers Commission**

a) "Changes to the levels and flow patterns of groundwater in the vicinity of the proposed site, and the resultant impacts on stormwater flows, flooding and the potential for contaminated groundwater to reach the surface …" [Addressed in Section 4]

b) "Should dredging breach the groundwater table, contaminants may reach the Bay and have further impacts on Bay ecology." [Addressed in Section 5.3]

- **City of Botany Bay**

a) "The effects on the groundwater contamination plumes at Orica and other relevant areas in Banksmeadow…" [Addressed in Section 5.2]

b) "The effects of the proposal on groundwater levels and the level of water in the ponds in the adjacent Sir Joseph Banks Park." [Addressed in Section 4.2]

- **Department of Land and Water Conservation (DLWC)**

a) "The proposal's site is in an area of known shallow ground water, which may also be contaminated." [Addressed in Section 2 and Section 5.2]

b) Fill could “cause rising of the groundwater off-site…” [Addressed in Section 4.2]

c) “Dredging of the Bay is likely to intersect with potentially contaminated groundwater. This may expose the Bay to different and more contamination.” [Addressed in Section 5.3]

d) A hydrogeological report showing the impacts on the groundwater and the other users of the water. [Addressed in Sections 2, 4.2 and 5.4]

e) The EIS must demonstrate compliance with the NSW Groundwater Policy Framework Document, and guarantee that the development will not degrade the sustainability of the groundwater resource. [Addressed in Section 5.4]

f) The EIS must demonstrate the commercial, environmental benefits and sustainability of the proposal as it relates to the groundwater resource of the area. [Addressed in Section 5.4]

5.2 CONTAMINANT PLUME

Several chlorinated hydrocarbon plumes occur in groundwater flowing from the Botany Industrial Park. This was originally the site of substantial chemical manufacture by ICI (now Orica). Chemical manufacture is much reduced now, and remediation of the contaminants is underway (Orica, 2001; Orica, 2002; Woodward-Clyde, 1999).

The southern-most plume (the Southern Plume) that is mostly 1, 2-dichloroethane (ethylene dichloride or EDC) and trichloroethene (TCE) has reached Penrhyn Estuary in a zone between Floodvale and Springvale Drains at the eastern end of the Estuary (Figure 21). The representative concentration of EDC and TCE is about 10 mg/L at the coast. Substantial dilutions occur within the Estuary when the groundwater, that discharges slowly, mixes with the seawater in the Estuary. Contaminant concentrations in groundwater at this location are expected to reduce over time. This is due to a number of factors that include: stopping of chemical production; removal of previous manufacturing locations; remediation strategies on Orica land and natural attenuation.

Another plume known as the Northern Plume with core concentrations in the range 100 – 200 mg/L of EDC is known to extend in a southwest direction from the Orica site. Its 10 mg/L front could be about 850 m from Botany Bay and is about 300 m wide at the present time. On a current estimate of 120 m/year movement, it is projected to arrive at the Bay by 2006 (see Figure 21).

Another plume of EDC know as the Central Plume has been identified as moving towards the Bay and more specifically will probably enter Penrhyn Estuary (Orica, 2001; Orica, 2002). The locations of the Central Plume in October 2000 and July 2001 are shown in Appendix B. Also shown in Appendix B are the sections through the Plume along its axis.

As the Central Plume approaches McPherson Street at the southwest corner of Southlands Block 2 (Orica land) (see Figure B3) its core is at a depth of about 15 m and the plume extends back upgradient to the site of former EDC storage tanks on Orica land. The core of the Plume has a concentration of >5000 mg/L but is viewed as a limited zone that has a long axis length of about 300 m. Surrounding the core there are concentration zones (100 – 1000 mg/L) that extend over about 13.5 m in the vertical direction over the length of the plume. In plan the Plume was inferred to be about 190 m wide in July 2001. As it progresses it may widen to some degree due to dispersion and other factors. Repeated measurements of the Plume indicate that its leading edge is travelling southwest at an average speed of 95 m/year, for the >5000 mg/L core and 120 m/year for the 100 – 1000 mg/L part surrounding the core zone. This suggests that the Plume will probably reach the coast in four years (2007) and the core will reach the coast in about six years (2009) and will pass through this coastline over a period of about three years (from 2009 to 2012). When it does it will intersect the saltwater wedge and move upwards to the seawater column of Penrhyn Estuary. Concentrations of EDC in Penrhyn Estuary will be strongly influenced by tidal movements and circulating currents. The plume direction in plan is controlled partly by the hydraulic gradient of the groundwater (flow at right angles to the head contours) and partly by density. Pure EDC has a density of 1.235 t/m^3 compared with freshwater of 1.0 t/m^3. The core of the Plume is less dense than pure EDC (about 1.005 t/m^3).

A possible projection of the central axis of the Plume to the coast shows that it will intersect the northern side of Penrhyn Estuary (as it is now) between Floodvale Drain and the present Botany Bay (Figure 21). The Penrhyn Estuary habitat enhancement works will reduce the length of the flow path of the plume, so that the Plume will travel a distance of 50 m to 100 m less to the modified shoreline. This translates to an arrival time some 6 to 12 months earlier. The drop in groundwater level due to the habitat enhancement works will cause a negligible acceleration of the core of the Plume, as the flow path clips the edge of the zone of increased hydraulic gradient. The western flank of the plume could accelerate marginally. The exit point of the Central Plume will occur close to the boundary between the saltmarsh strip and the sand/mud flats.

The terminal and foreshore works of the port development, as distinct from the habitat enhancement works, will not affect the progress of the plumes nor will they affect the exit points to open water , as the groundwater salinity interface will still occur at the intertidal zone. There will be no change in plume concentrations with time for the Central Plume and the Southern Plume, but there is likely to be some dilution of the Northern Plume. Other on-land factors will potentially cause changes in concentrations towards an eventual decline in chemical levels.

5.3 DREDGING

It has been established from the contaminant plume investigations by Orica, using multi-level piezometers, that the transition from groundwater to seawater occurs right at the coast and probably in the intertidal zone. Very little (if any) groundwater would flow out under the Bay seabed to the zone of dredging. Thus there is no need for concern over breaching of the groundwater system beneath the Bay, and allowing ingress of contaminants.

5.4 GROUNDWATER RESOURCE

Management of the groundwater resource resides with the Department of Land and Water Conservation, under the authority of the Water Management Act 2000. The NSW State Groundwater Policy is stipulated in the NSW Groundwater Policy Framework Document and three component policy documents for Groundwater Quantity, Groundwater Quality and Groundwater Dependent Ecosystems.

Modelling shows that the throughflow of groundwater to the Bay will not be impaired, access to groundwater by existing users will not be affected, and there will be no change to the beneficial use of the aquifer. There will be no effect of the proposed works on the quality of groundwater, other than a dilution of the Northern Plume as it approaches the Bay.

The pond habitats in Sir Joseph Banks Park are likely to form a groundwater dependent ecosystem. The ponds will experience rises in water level of 0.06m without installation of a drain and 0.02 m with installation of a drain, but the rises will be much lower than the natural range of variation, and will be no more than the groundwater level prior to the gradual erosion of the foreshore which has been occurring since the 1980s.

All of the aquifer adjoining and within 1 km of the present shoreline (as far west as the enhanced beach) is classified as a Protection Zone in which no new bore licences will be issued. Existing licence holders will not be disadvantaged in any way by the proposed Port Botany Expansion.

6.0 CONCLUSION

The numerical modelling demonstrates that landward groundwater levels are affected only if beach alignment is changed. There is no effect from the reclamation activity to create a new container terminal.

The planned foreshore works will have a minimal impact on the Botany Sands aquifer. Rises in groundwater level will be small and will be localised to three areas:

- The enhanced beach;
- The new boat ramp area; and
- Adjacent to the tidal channel where the channel alignment is seaward of the present shoreline (by up to 20 m).

Falls in groundwater level will be small and will be localised to the land adjacent to the saltmarsh strip and sand/mud flats to be constructed as part of the Penrhyn Estuary habitat enhancement works. The falls are expected to be generally 0.01-0.03 m beneath Botany Golf Course, and 0.04-0.06 m south of Foreshore Road.

Overall, there is expected to be an area of rise extending beyond Botany Road, but the predicted rise without a drain is between 0.01 m and 0.04m. This is at the limit of resolution of the model. This area has mostly residential land use. A rise of less than 0.04 m is considered insignificant against a background of natural water level variations that are up to 100 times greater. There is a smaller area with a rise of about 0.06 m. This does not intersect the residential area, and is confined to the ponds at the western end of Sir Joseph Banks Park. Measurements of pond level at the eastern end of Sir Joseph Banks Park over 10 months during 2002 show a natural variation of about 0.5 m, which is more than 10 times the predicted rise in that area. The City of Botany Bay uses the easternmost pond as a backup water supply for Botany Golf Course. Transient changes in water level of 0.01-0.03 m are estimated when pumping takes place. A rise of 0.06 m in the ponds would not have any adverse impact on ecosystem health, as this is well within the normal range of fluctuation.

With drainage, there is expected to be a general rise of about 0.01 m extending to Botany Road and a rise of about 0.02 m at the ponds at the eastern end of Sir Joseph Banks Park.

Any groundwater level changes caused by the proposed re-alignment of the shoreline will occur within the context of much larger natural variations from rainfall variability and tidal influence, and variations due to changes in groundwater abstraction for irrigation and industrial uses.

The likely range in groundwater levels at a few key locations due to these external influences is summarised in Table 1.

Table 1. Range in Groundwater Levels Due to Influences Other than Reclamation (metres)

LOCATION	RAIN	TIDE	ABSTRACTION	TOTAL
Foreshore Road (north of new container terminal)	0.04	0.8	0.1	0.94
Dent Street	0.3	0.15	0.6	1.05
Botany Road (north of new container terminal)	0.5	0.1	0.9	1.5
Orica (northern boundary)	1.7	0	3.2	4.9

It is estimated that the magnitude of fluctuations from external influences is about 1 m at Foreshore Road and Dent Street, 1.5 m at Botany Road, and up to 5 m at the northern boundary of the Botany Industrial Park. Predicted rises of much less than 0.1 m are insignificant with respect to natural dynamic fluctuations.

The model estimates a discharge of about 3,800 m^3/day (0.044 m^3/s) along the present shoreline extending from the Mill Stream Diversion outlet to Penrhyn Estuary. In addition, there is expected to be a discharge of about 2,100 m^3/day to Springvale Drain and about 1,000 m^3/day to Floodvale Drain between Foreshore Road and the Estuary.

Following reclamation and shoreline re-alignment, there will be negligible change in groundwater discharge to the Bay if a drain is installed along the present shoreline for the length of the beach. However, if no drain is installed, there will be a reduction in discharge along the beach of about 20 percent due to the reduction in hydraulic gradient. This deficit still gets to the Bay via increased discharge to the tidal channel and the Mill Stream. No change is expected for Springvale and Floodvale Drains, and there will be no change in groundwater discharge to Penrhyn Estuary. Therefore, the reclamation will not cause any change in concentration of the groundwater contaminants destined for the Estuary via the Central Plume or the Southern Plume. Where the Northern Plume enters the tidal channel, groundwater discharge will increase by about 5 percent with no beach drainage, or about 3 percent with beach drainage. This means that the plume will be diluted but there should be no change in the contaminant mass that will enter the channel.

There are three contaminant plumes progressing from the Botany Industrial Park towards Penrhyn Estuary. One, of low concentration, has already arrived. The plume of highest concentration (about 5,000 mg/L EDC) is expected to discharge into Penrhyn Estuary in 4-6 years time. However, this plume should now arrive 6-12 months earlier due to the planned Penrhyn Estuary habitat enhancement works, which will reduce the distance between the Bay and the plume. At present, this plume has a width of about 190 m, is centred at about 15 m depth, and extends in the vertical direction over more than 10 m. The core of the plume has an axial length of about 300 m. With the present configuration of Penrhyn Estuary, the plume is expected to discharge to the Bay to the immediate west of the Floodvale Drain outlet. When it does so, the concentrations of EDC in the Estuary will be strongly influenced by tidal movements and circulating currents. With the habitat enhancement works in place, the plume will discharge to the Bay close to the boundary between the constructed saltmarsh strip and the sand/mud flats. The third plume is expected to discharge into the planned tidal channel at the northern end of the new container terminal. At the present time, its front is about 850 m from Botany Bay with a width of about 300 m.

The modelling sensitivity analysis conducted on the transmissive, leakage and storage properties of the dredged material to be used in forming the new container terminal shows that there is negligible error in predicted groundwater levels due to assumptions made about the fill material.

There is no deleterious effect on the groundwater resource as a result of the proposed Port Botany Expansion.

Although drainage can mitigate against water table rises resulting from a re-alignment of the shoreline, the predicted rises are near the limit of resolution of the model. There is no need to install a drain, as the predicted impacts are very small in relation to natural variations in groundwater levels. As a precaution, it is recommended that groundwater levels continue to be monitored during construction, and for one year after construction, to check that there is no discernible change in the pattern of groundwater level variations. Given the predicted small rises and falls in the water table, due to port development, it is most unlikely that it will be possible to extract a “port effect” from groundwater level measurements. If this proves to be the case, then that will provide confirmation that the port development is not having any real impact on groundwater conditions.

The present SPC groundwater monitoring network, shown in Figure 22 in relation to the predicted groundwater level rises, would benefit from the addition of three piezometers. The preferred locations are either side of Foreshore Road at Sir Joseph Banks Park to assess the impacts of the new beach (bore NEW3) and the tidal channel (bore NEW2), and at Botany Golf Course to monitor the impact of the Penrhyn Estuary habitat enhancement works (bore NEW1).

The water table rises attributed to the foreshore works are really a restoration of groundwater levels to what they were before the erosion of the existing foreshore. The foreshore has eroded up to 40 m since 1980.

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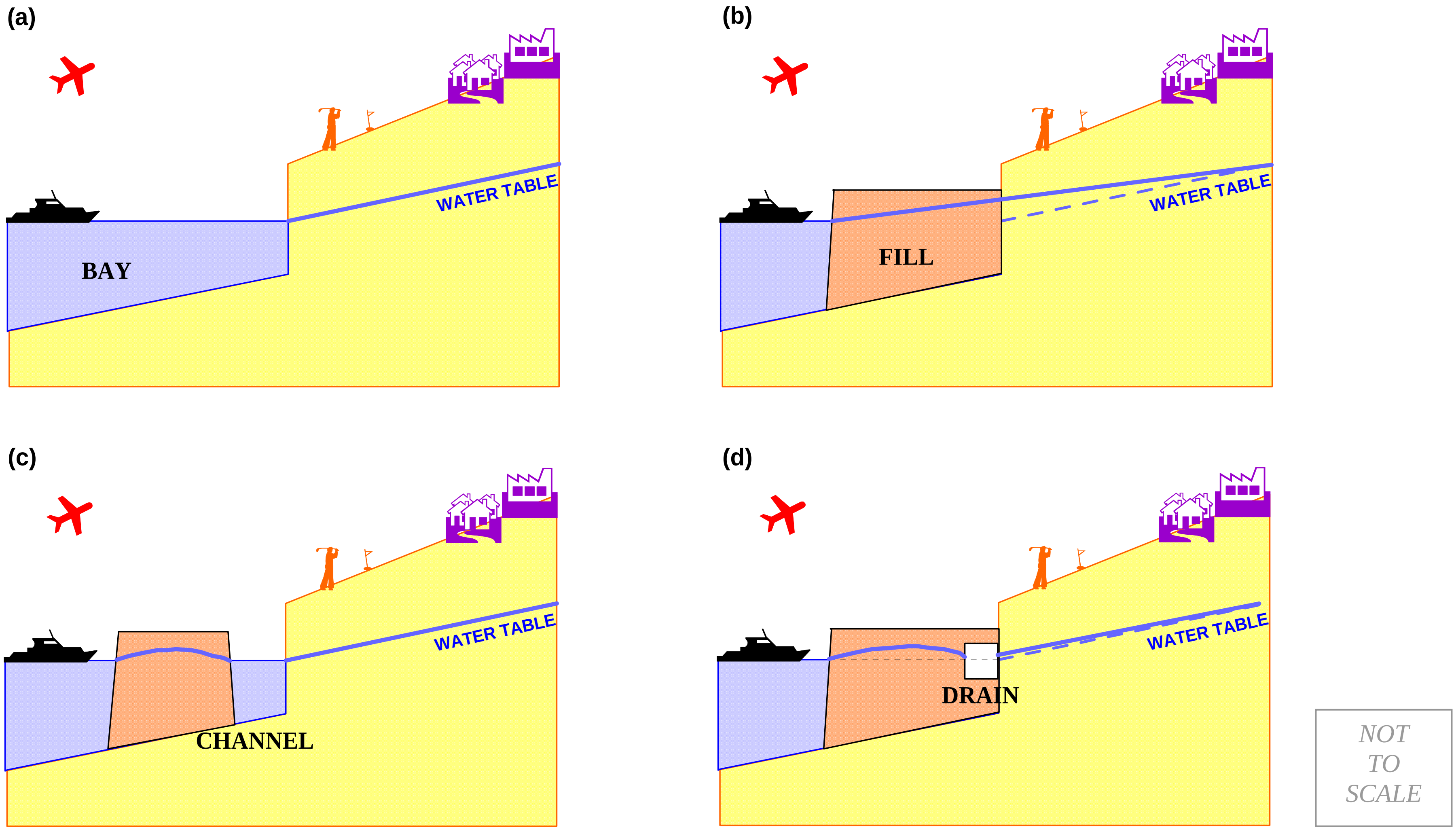
ILLUSTRATIONS -
FIGURES 1 TO 21

Figure 1. Location map



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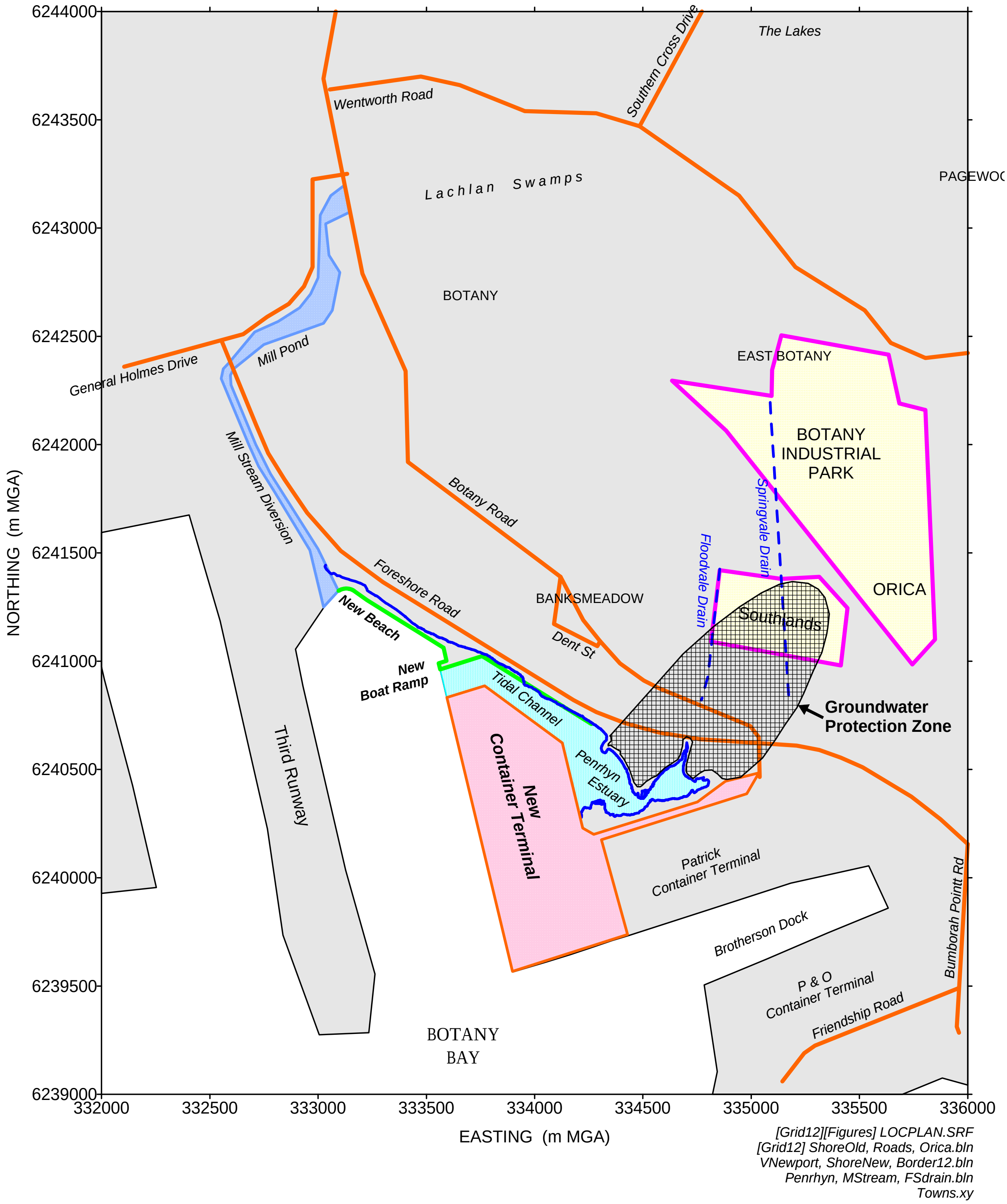


Figure 3. Location plan showing reclamation areas and a designated groundwater protection zone

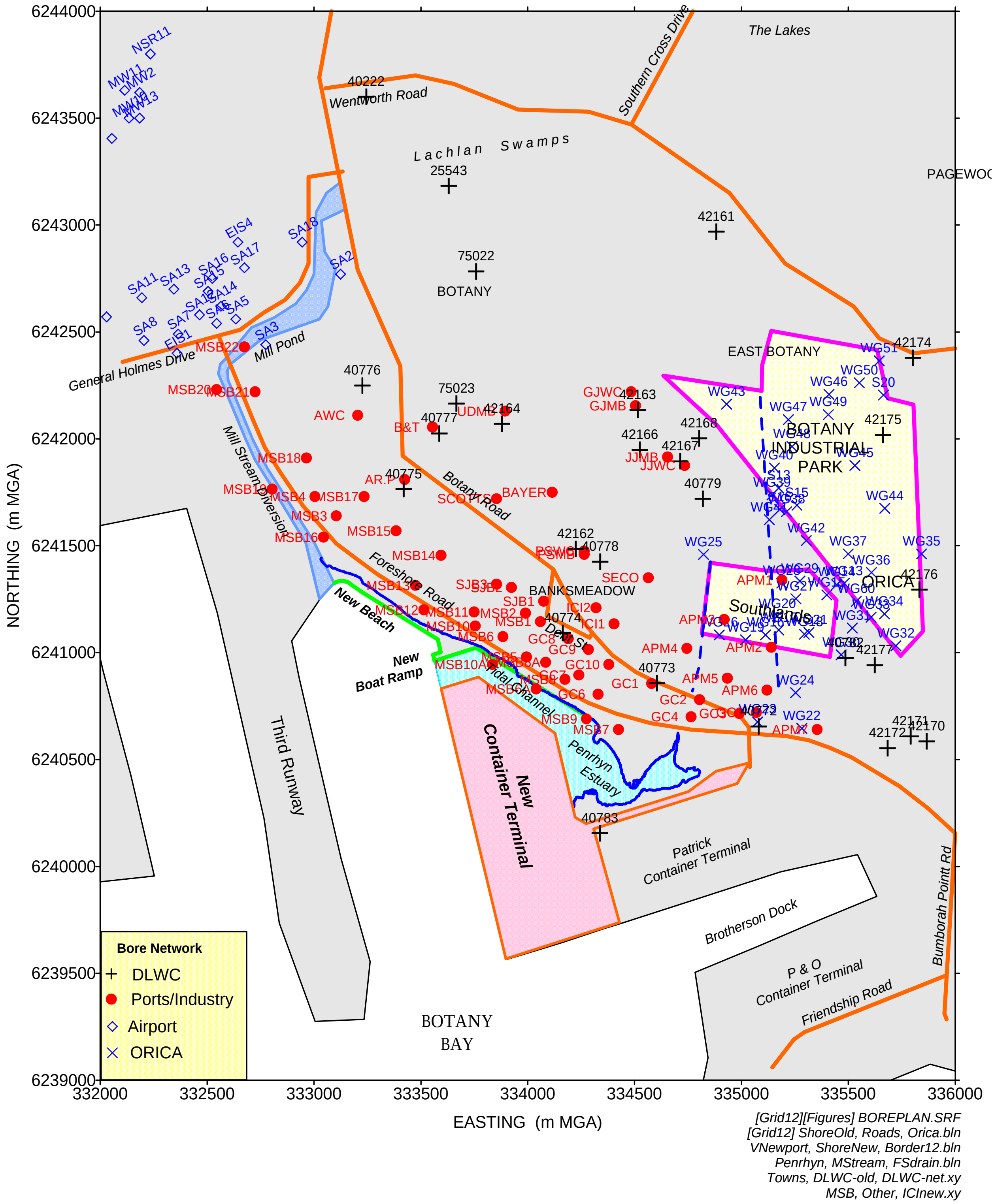


Figure 4. Locations of all known groundwater bores

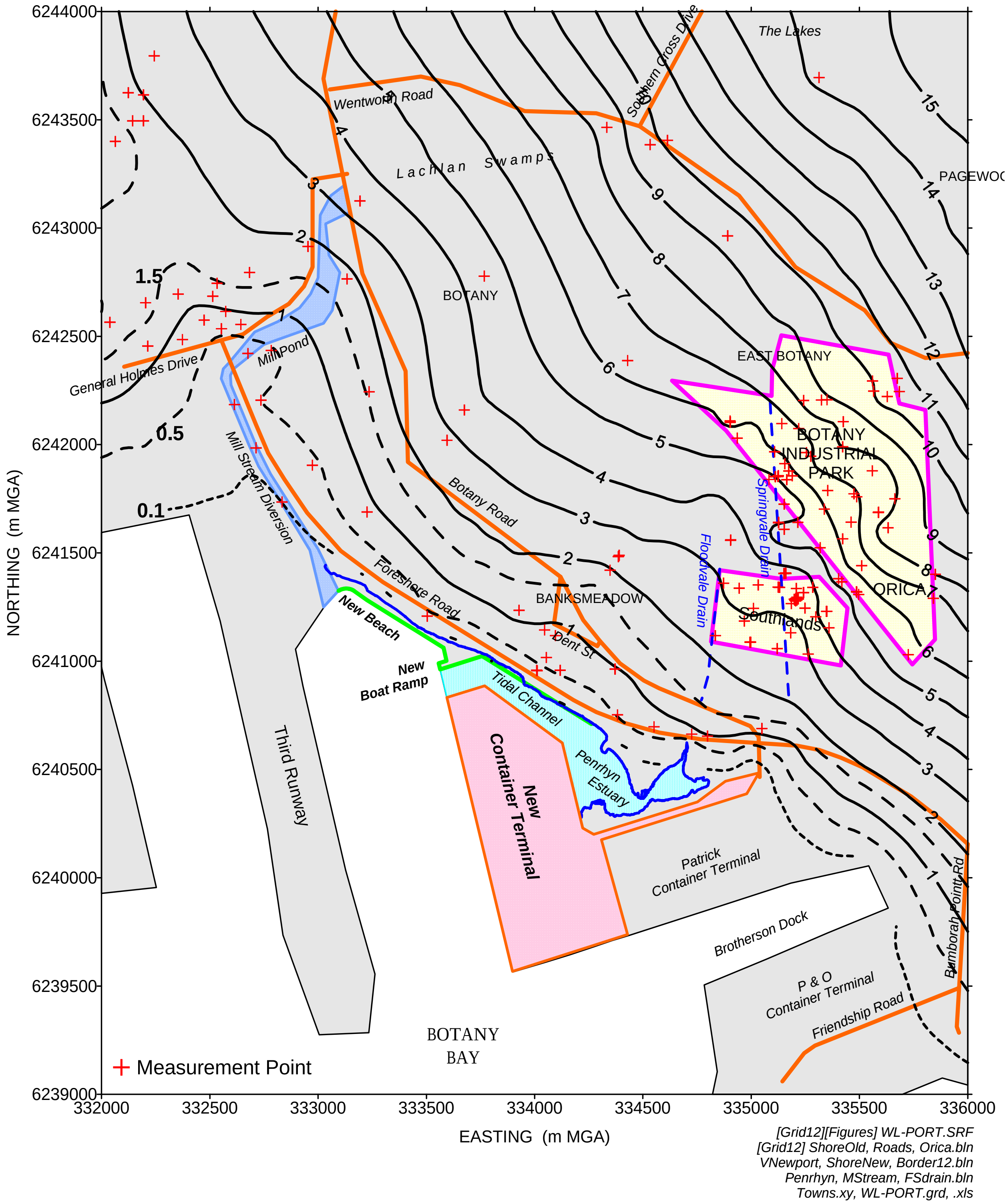
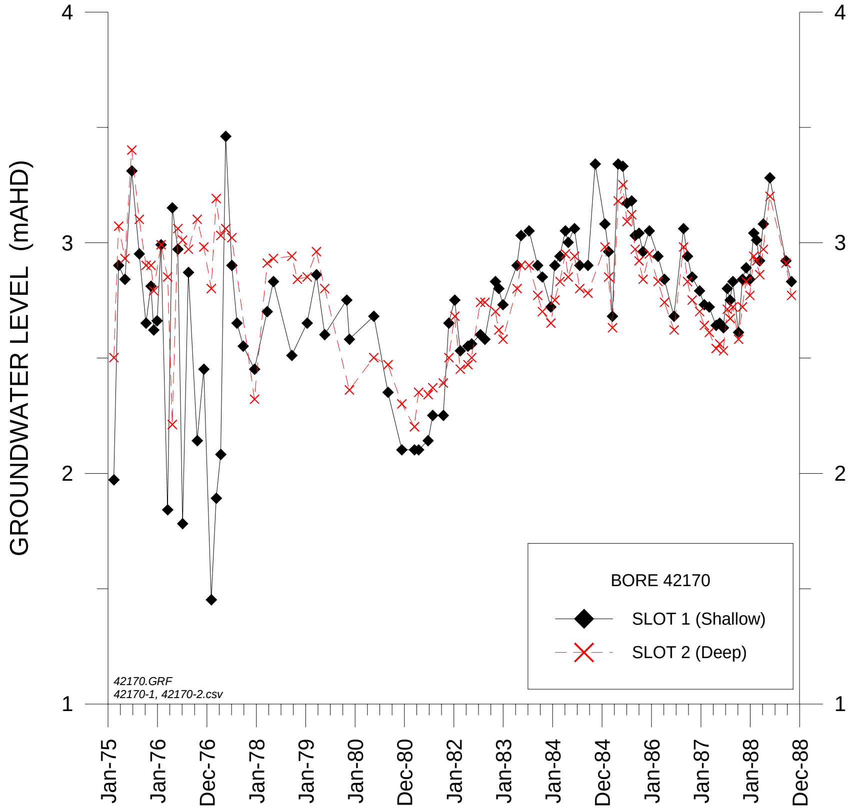


Figure 5. Composite 2000-2002 observed groundwater levels (mAHD)

(a)



(b)

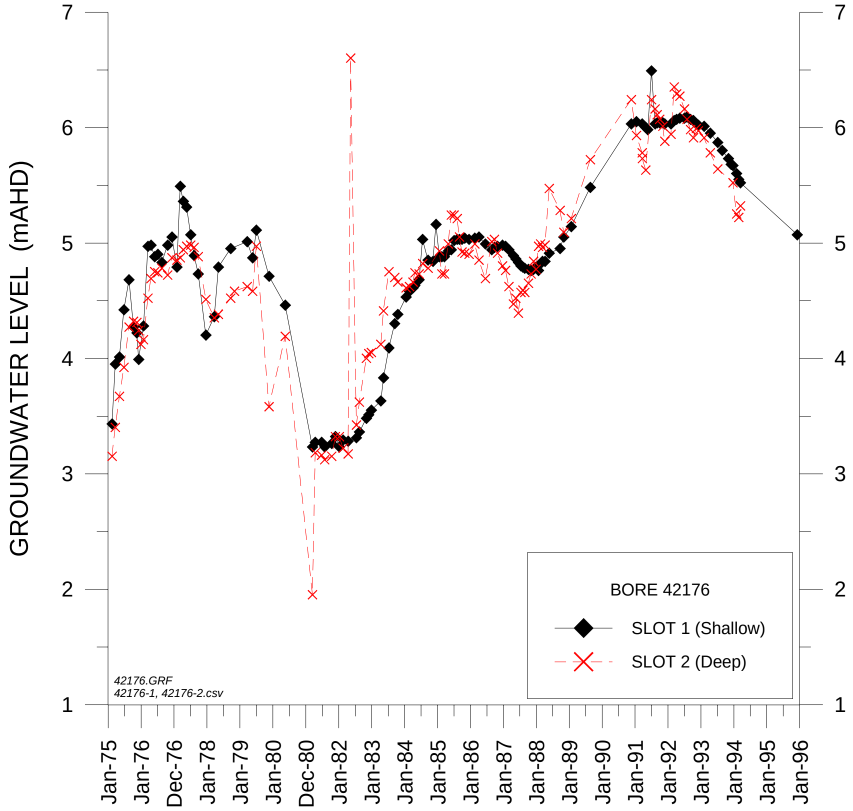


Figure 6. Long-term groundwater hydrographs:
(a) Bore 42170; (b) Bore 42176
[The screen depths are unknown, but the hole depths at Bore 42176 are 15.8 m and 20.3 m.]

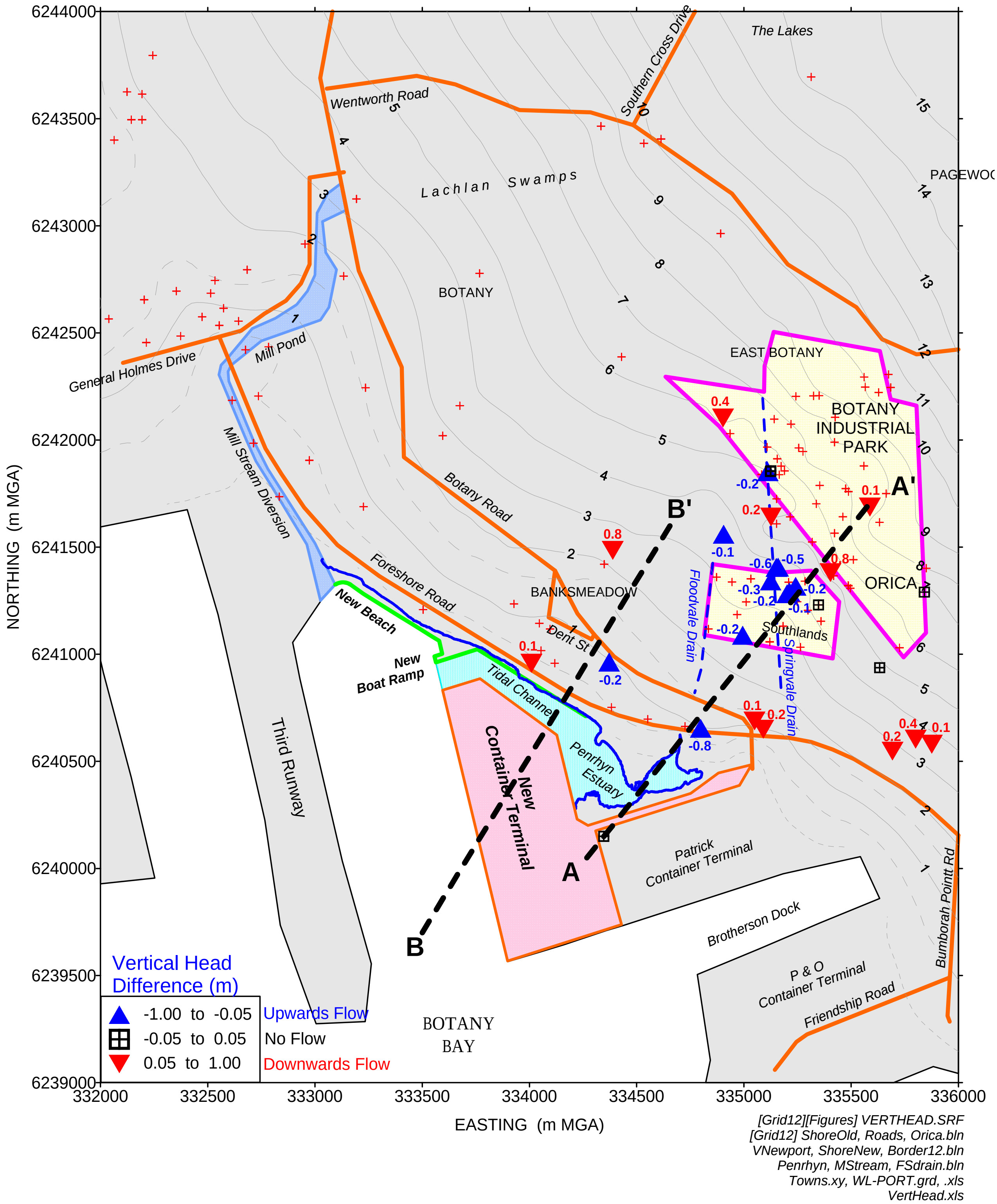


Figure 7. Vertical head differences (m) and vertical flow directions, superimposed on composite 2000-2002 observed groundwater levels (mAHD)

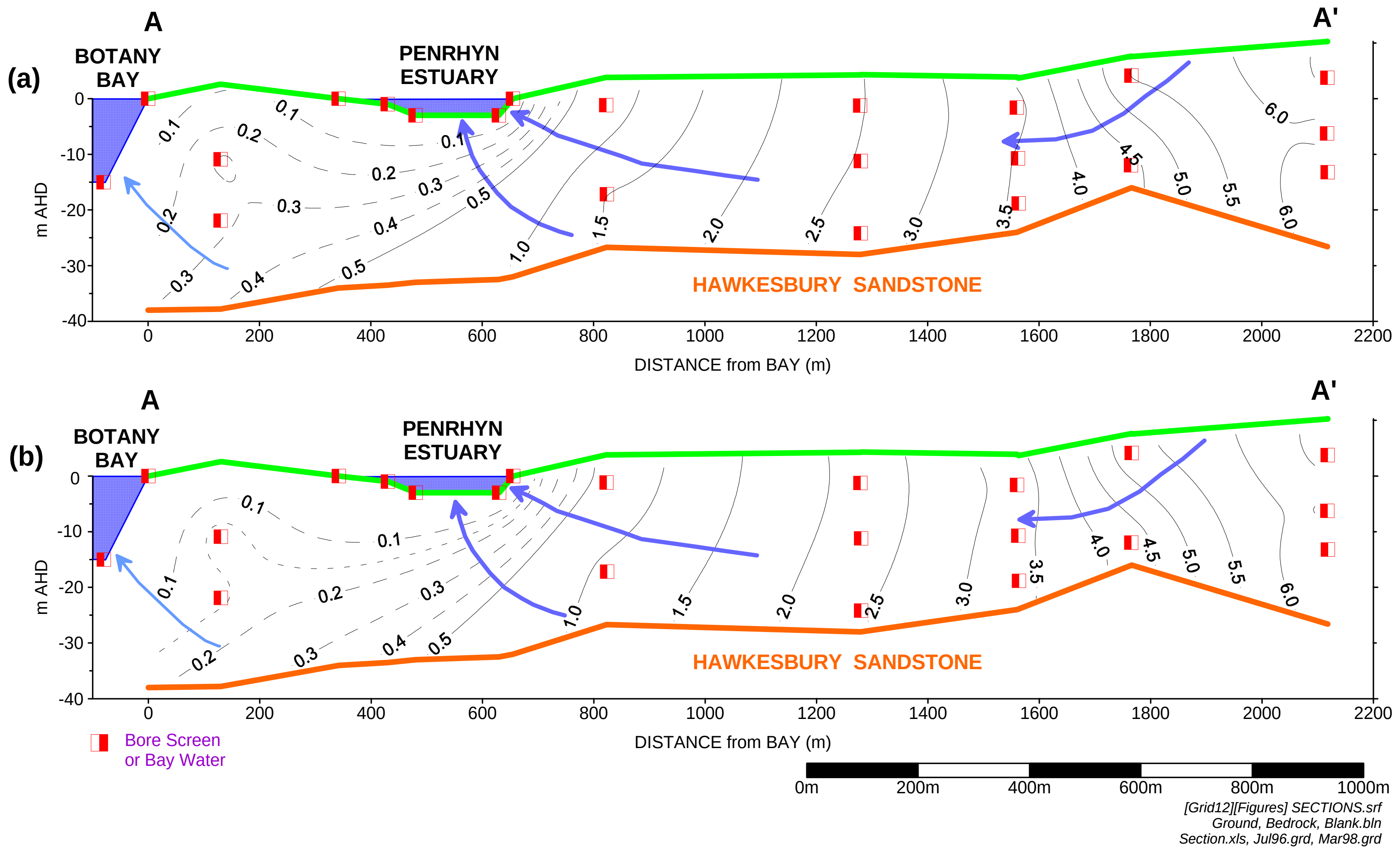


Figure 8. Groundwater head sections and flow directions:
(a) July 1996; (b) March 1998

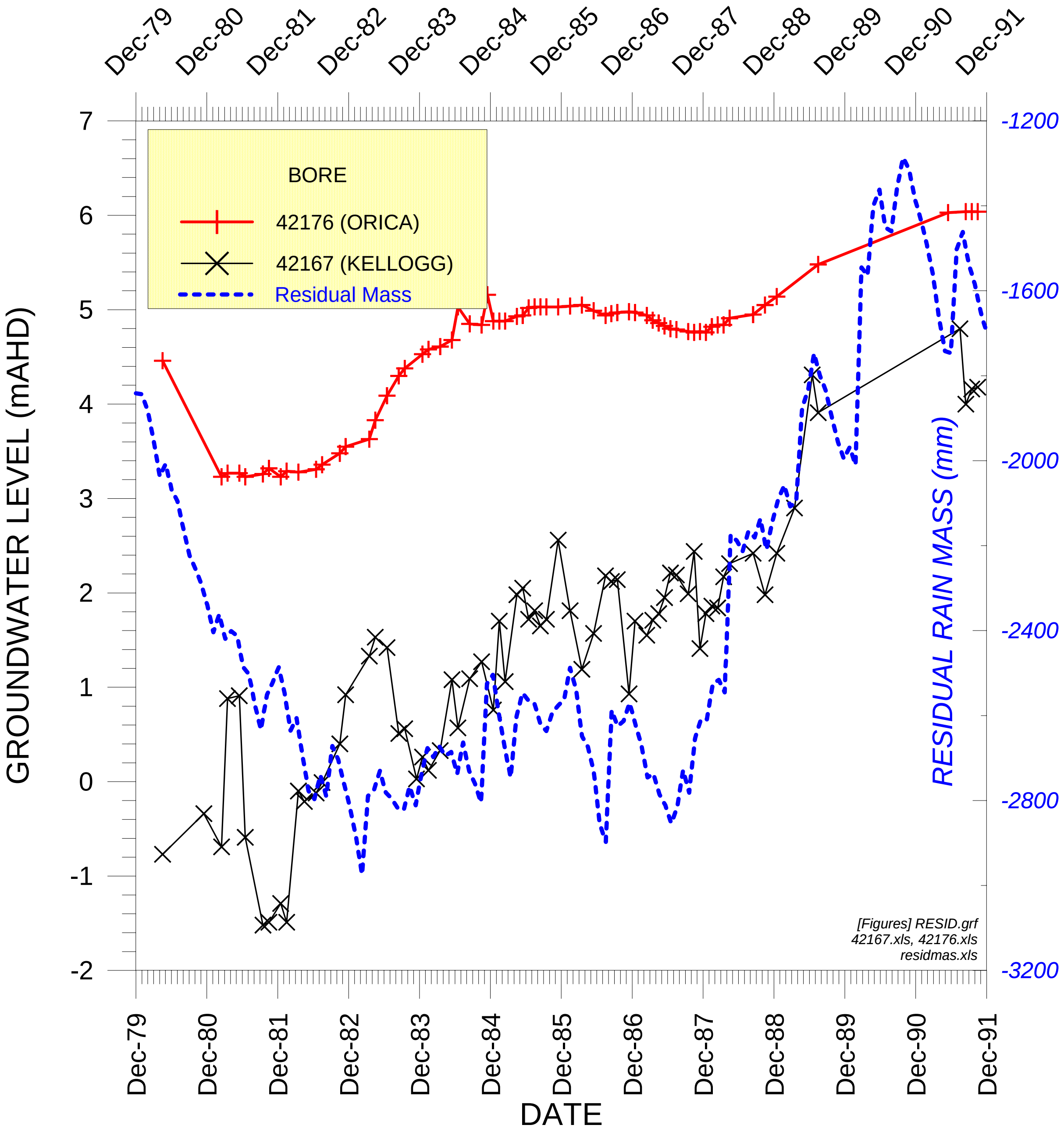


Figure 9. Rising groundwater levels during the 1980s, correlated with rising rainfall residual mass

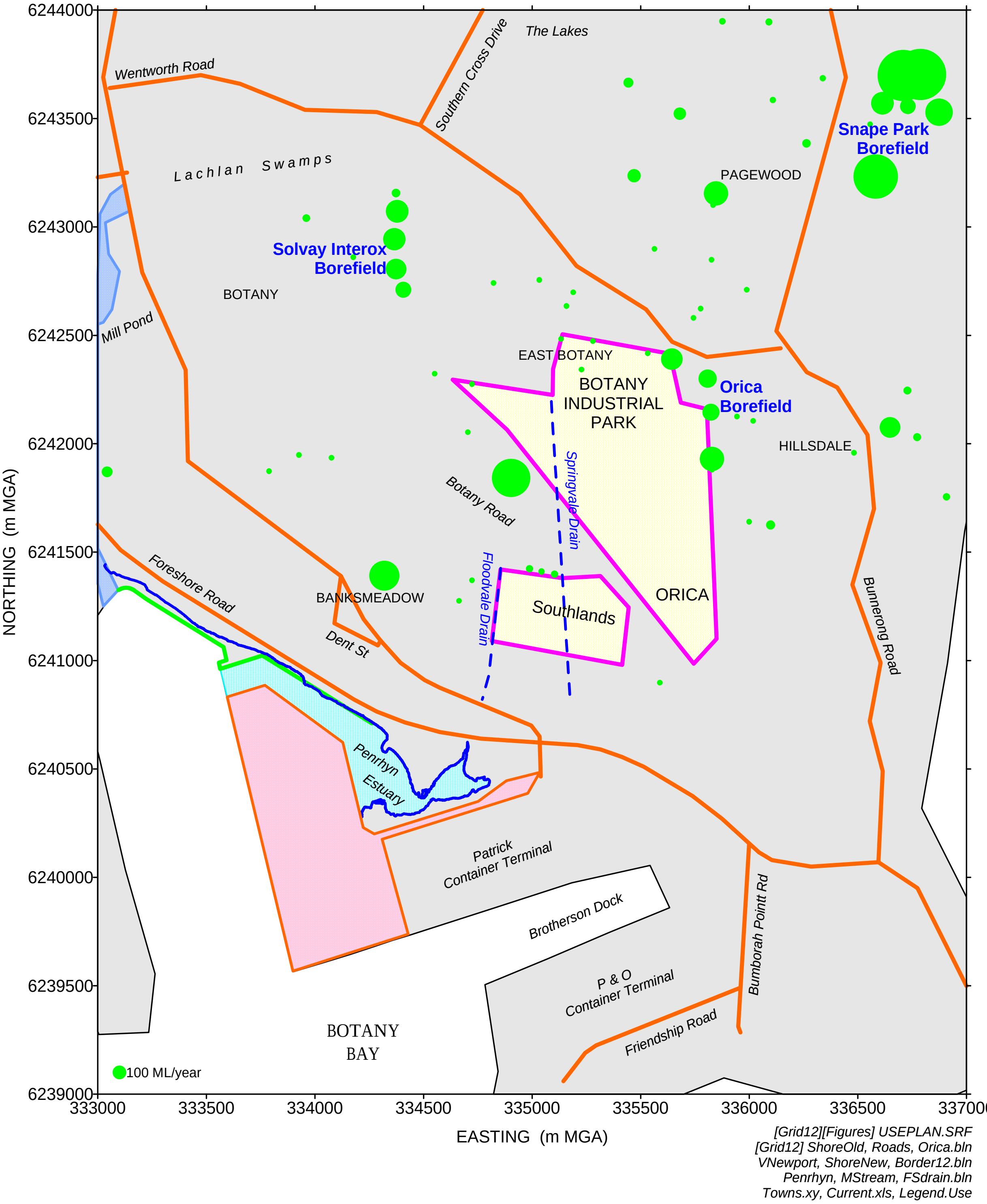


Figure 10. Distribution of active groundwater production bores
(symbol size is proportional to production)

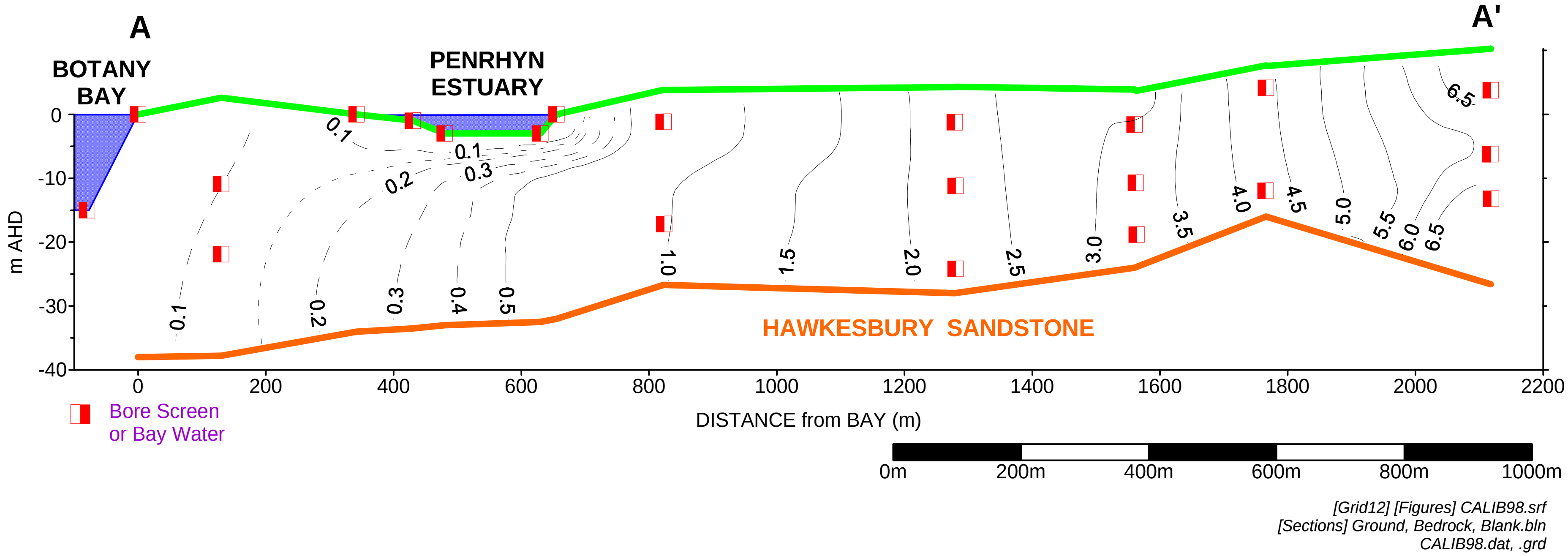


Figure 11. Simulated groundwater heads (mAHD) along Line A-A' at March 1998

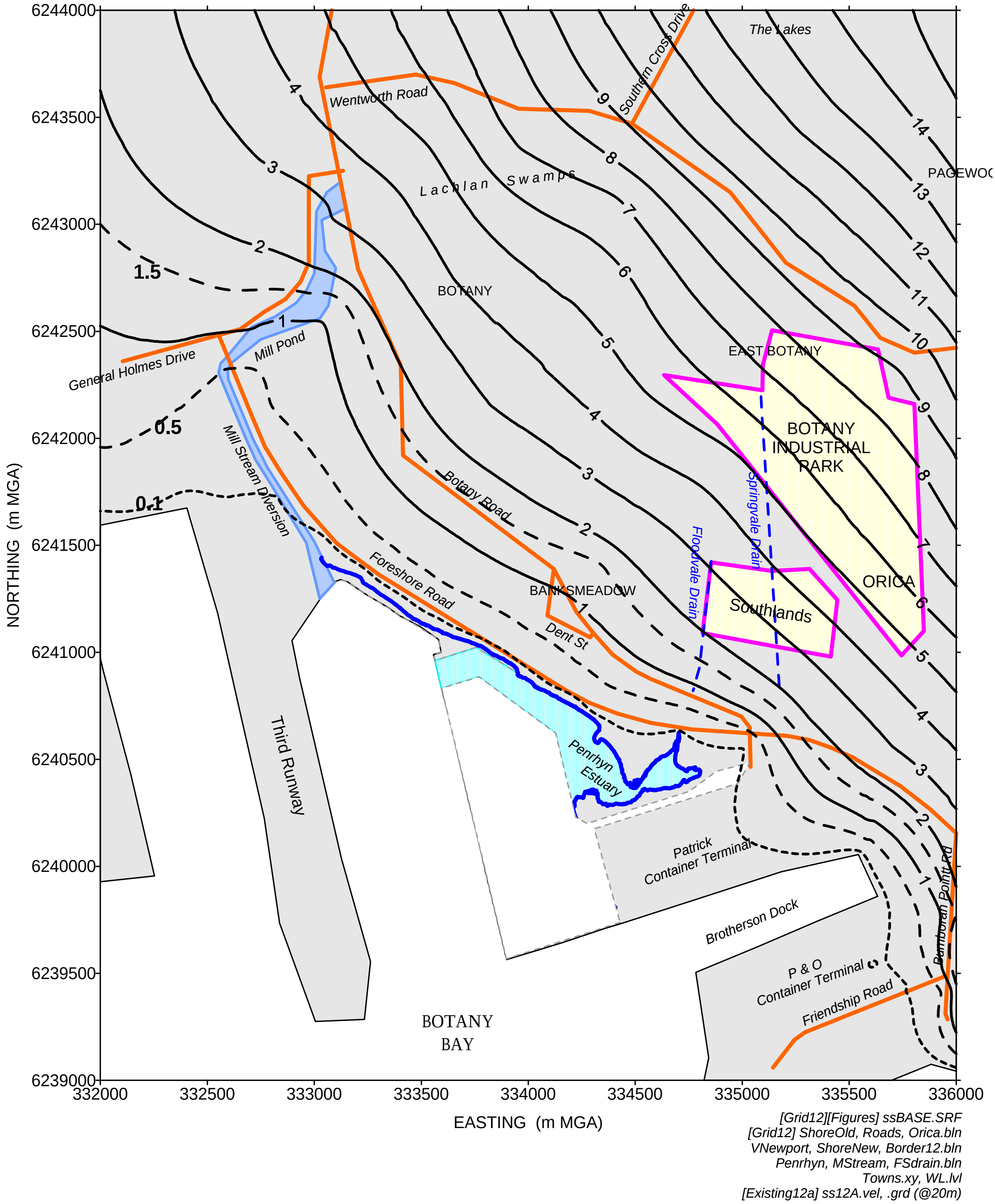


Figure 12. Benchmark simulated groundwater levels (mAHD) prior to reclamation

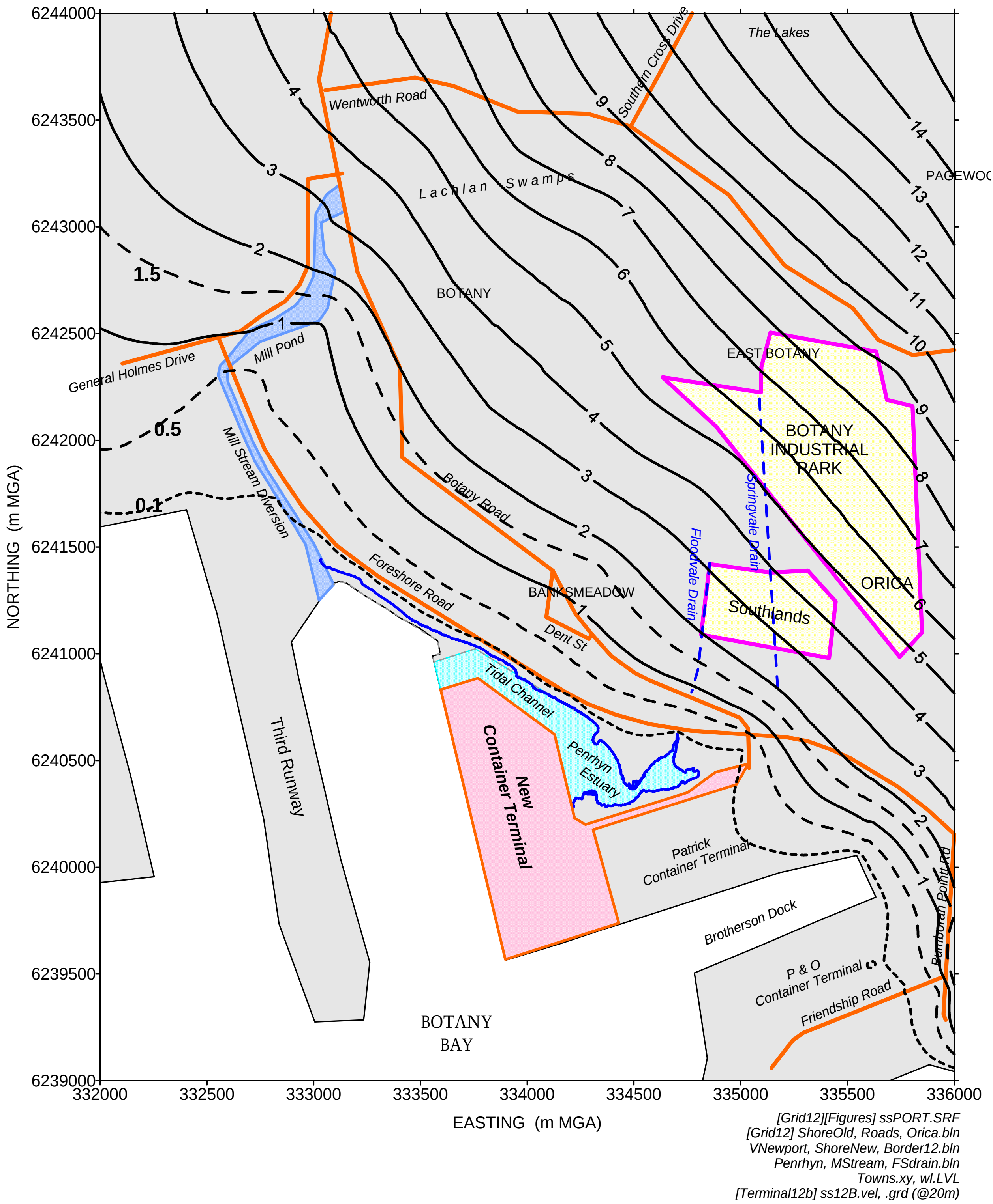


Figure 13. Simulated groundwater levels (mAHD) for terminal reclamation only, without foreshore works

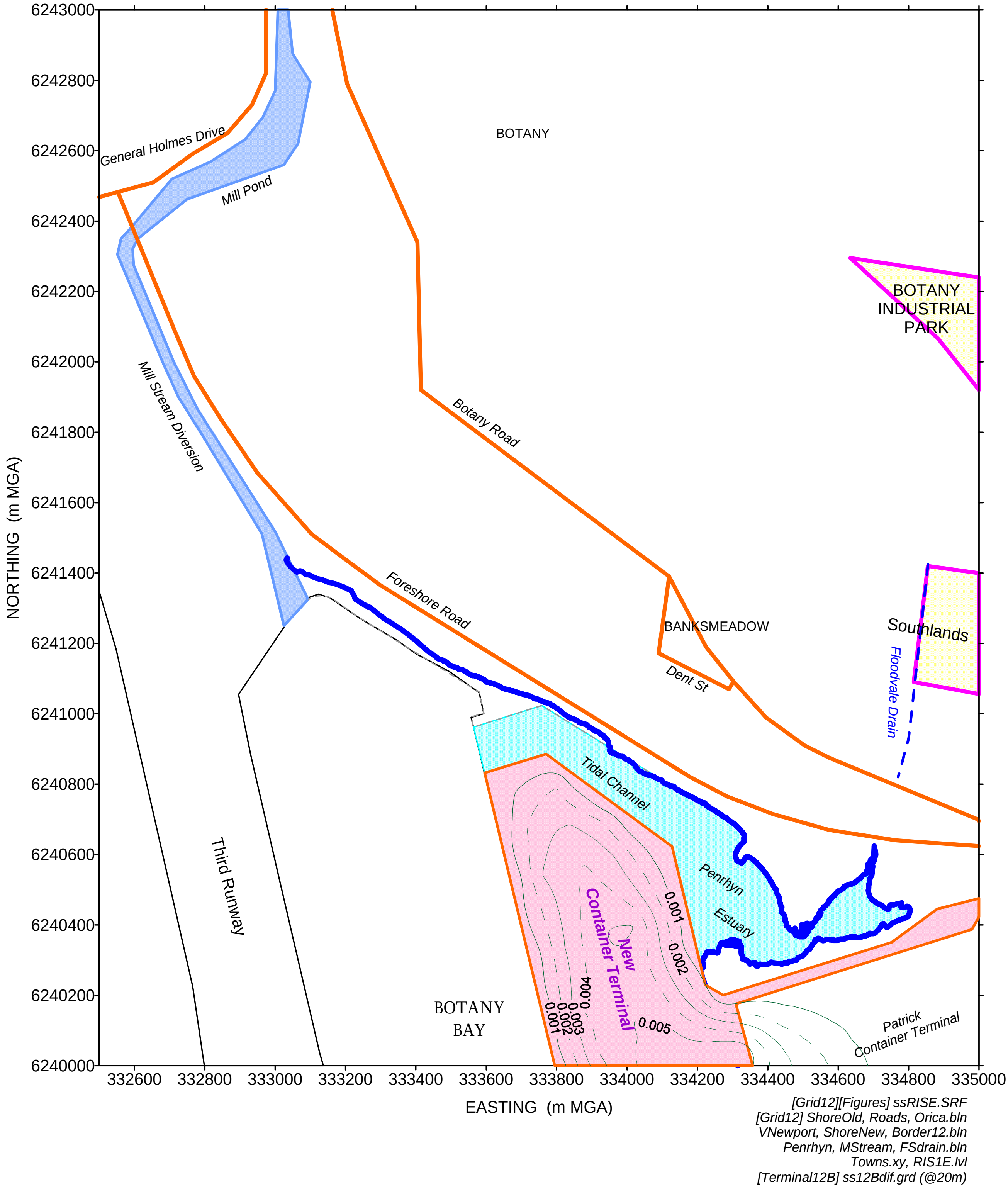


Figure 14. Simulated rise in groundwater levels (metres) for terminal reclamation only, without foreshore works

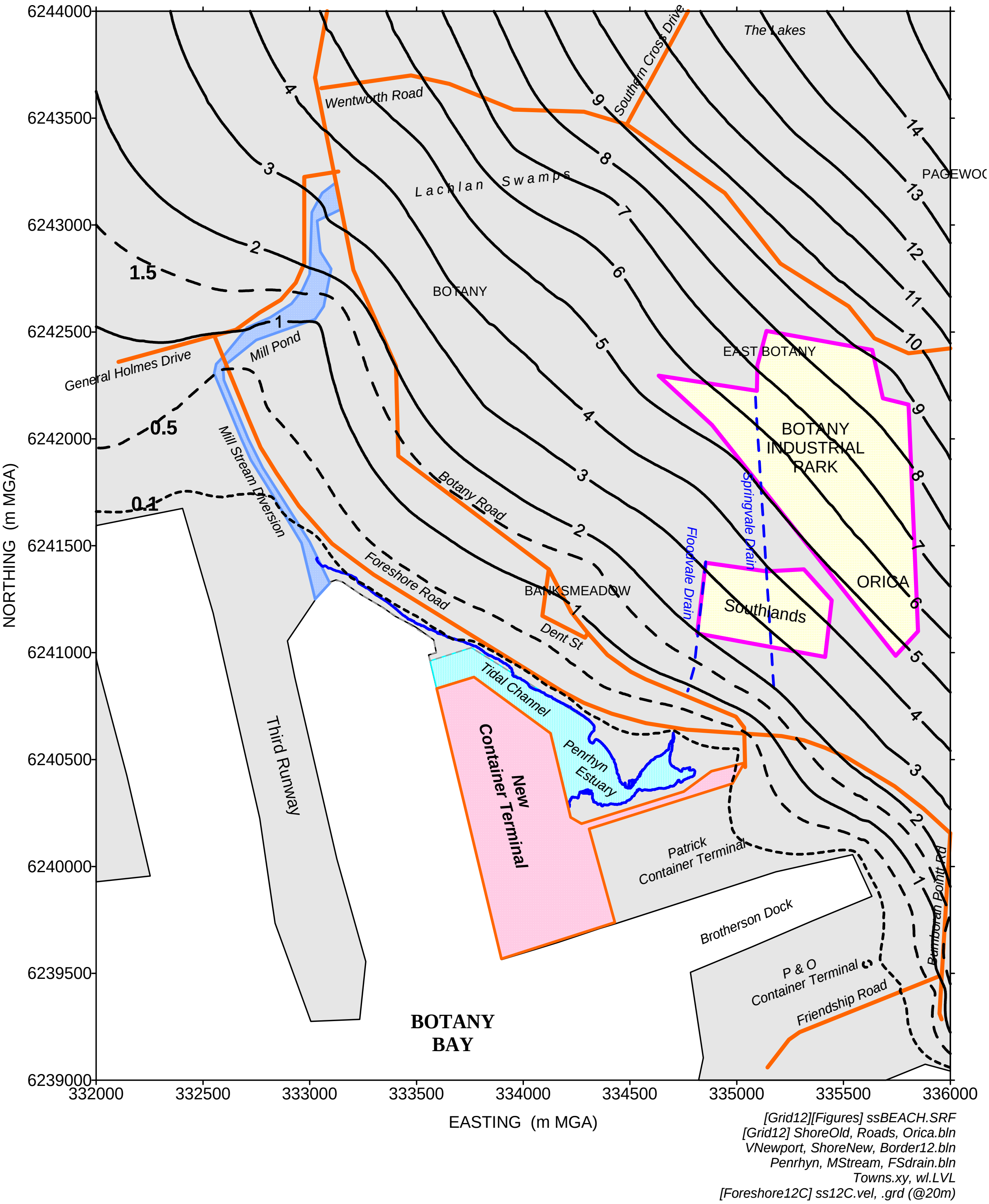


Figure 15. Simulated groundwater levels (mAHD) for terminal reclamation with foreshore works

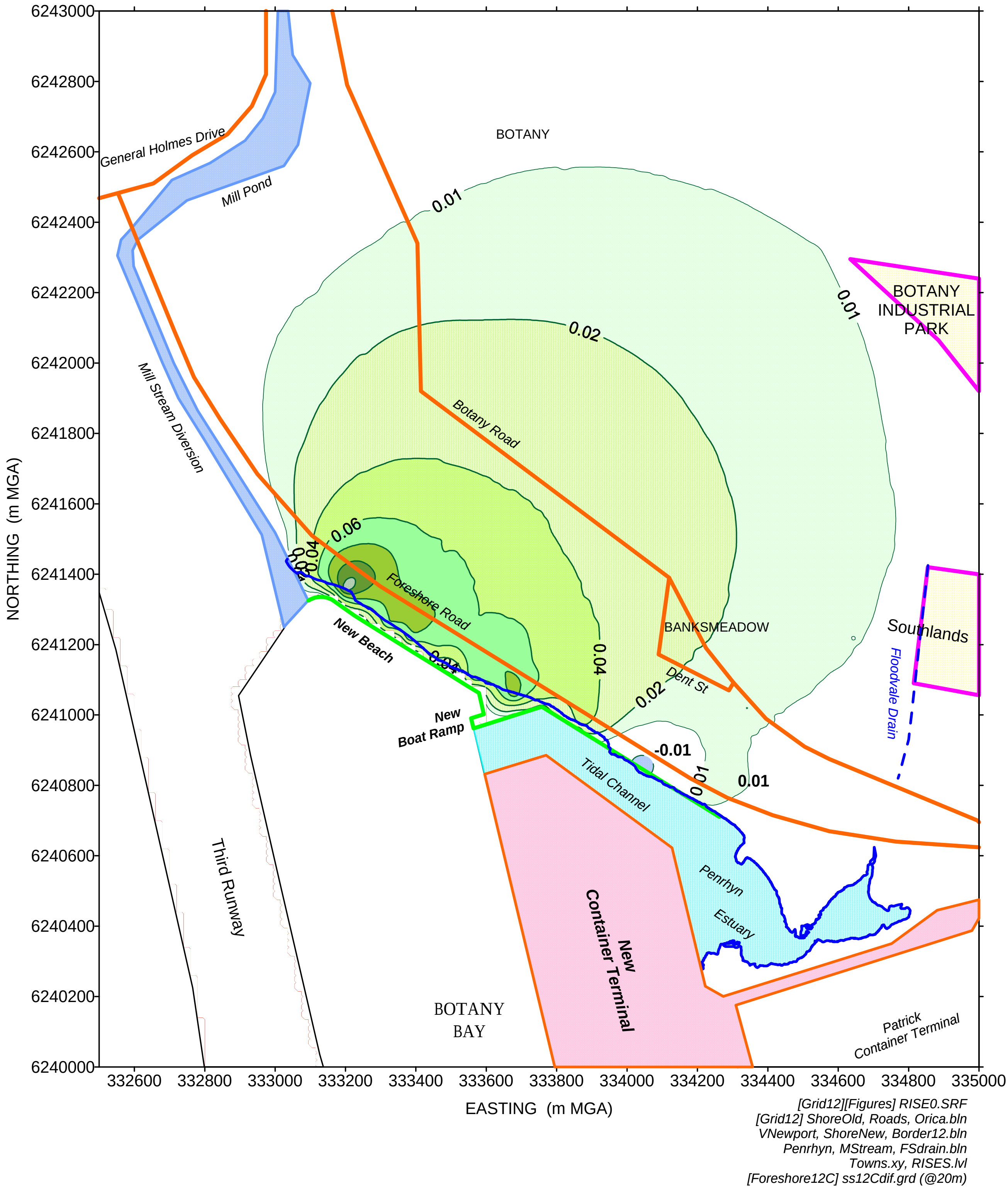
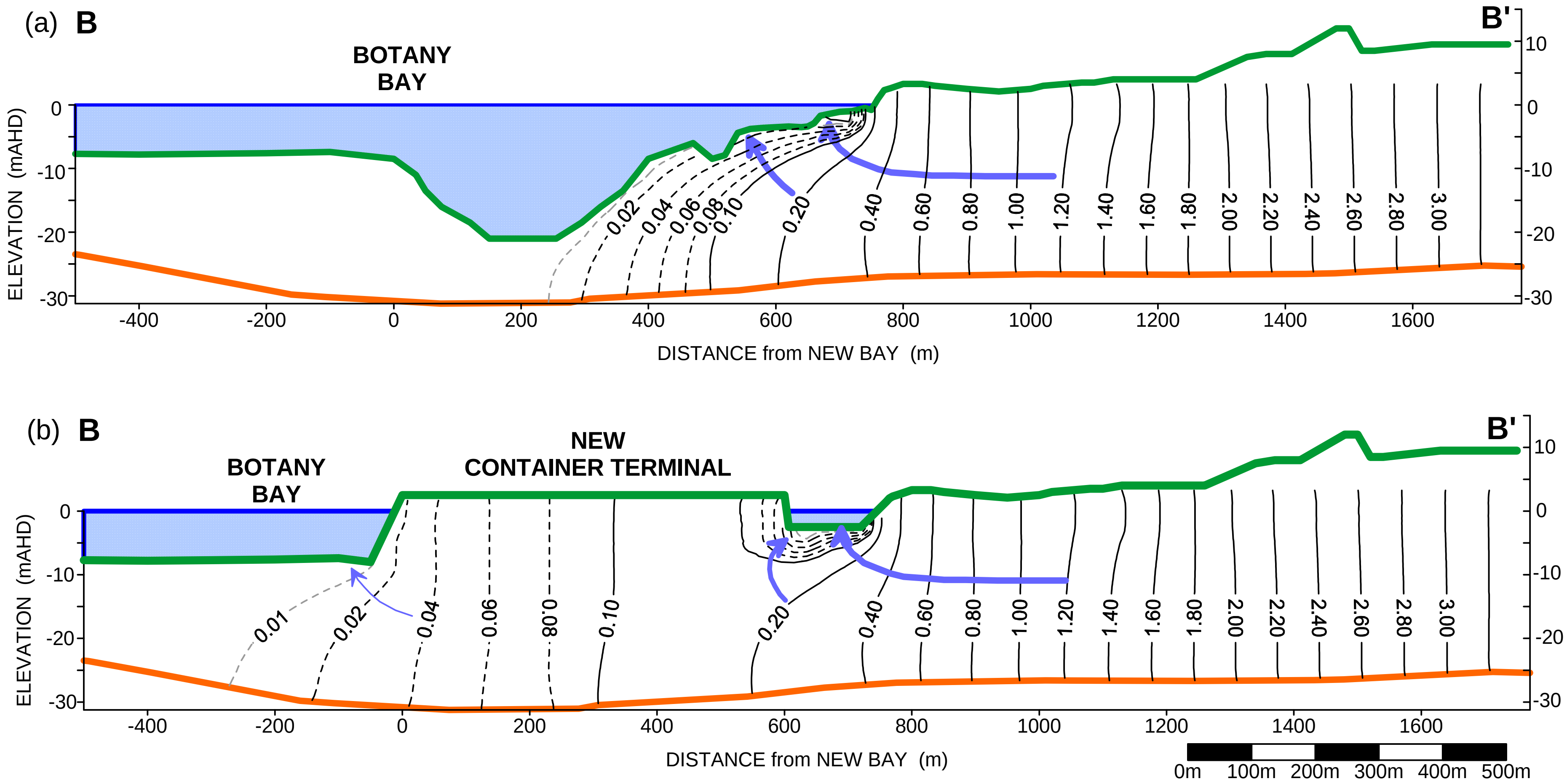


Figure 16. Simulated rise in groundwater levels (metres) for terminal reclamation with foreshore works and no shoreline drainage



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GroundBB, ReclamBB, BedrockBB
Bay1, Bay2.bln

Figure 17. Simulated groundwater heads (mAHD) along Line B-B':
(a) before reclamation; (b) after reclamation.

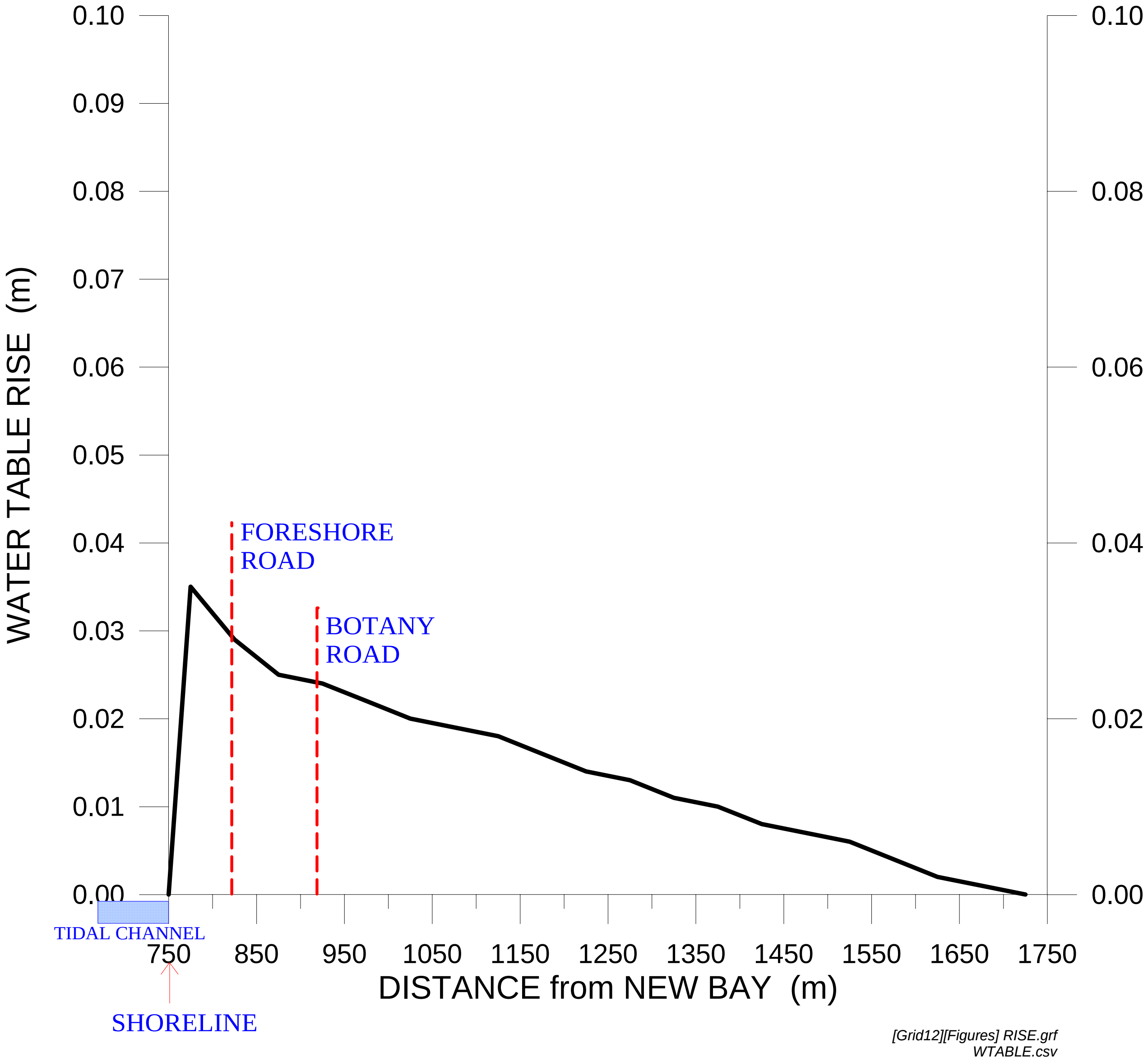


Figure 18. Simulated water table rise along Line B-B' due to reclamation (without drainage)

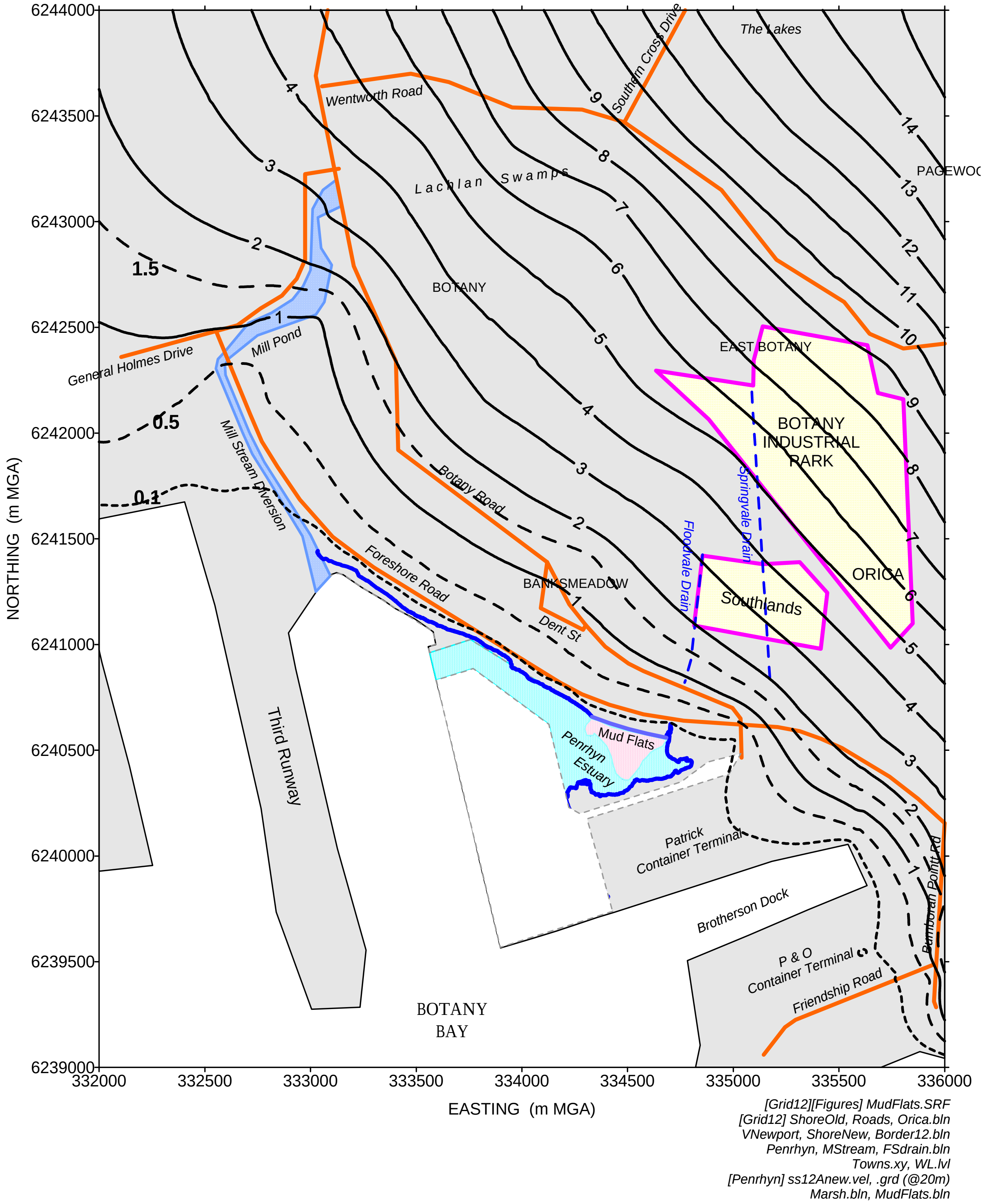


Figure 19. Simulated groundwater levels (mAHD) for shoreline re-alignment due to the Penrhyn Estuary habitat enhancement works

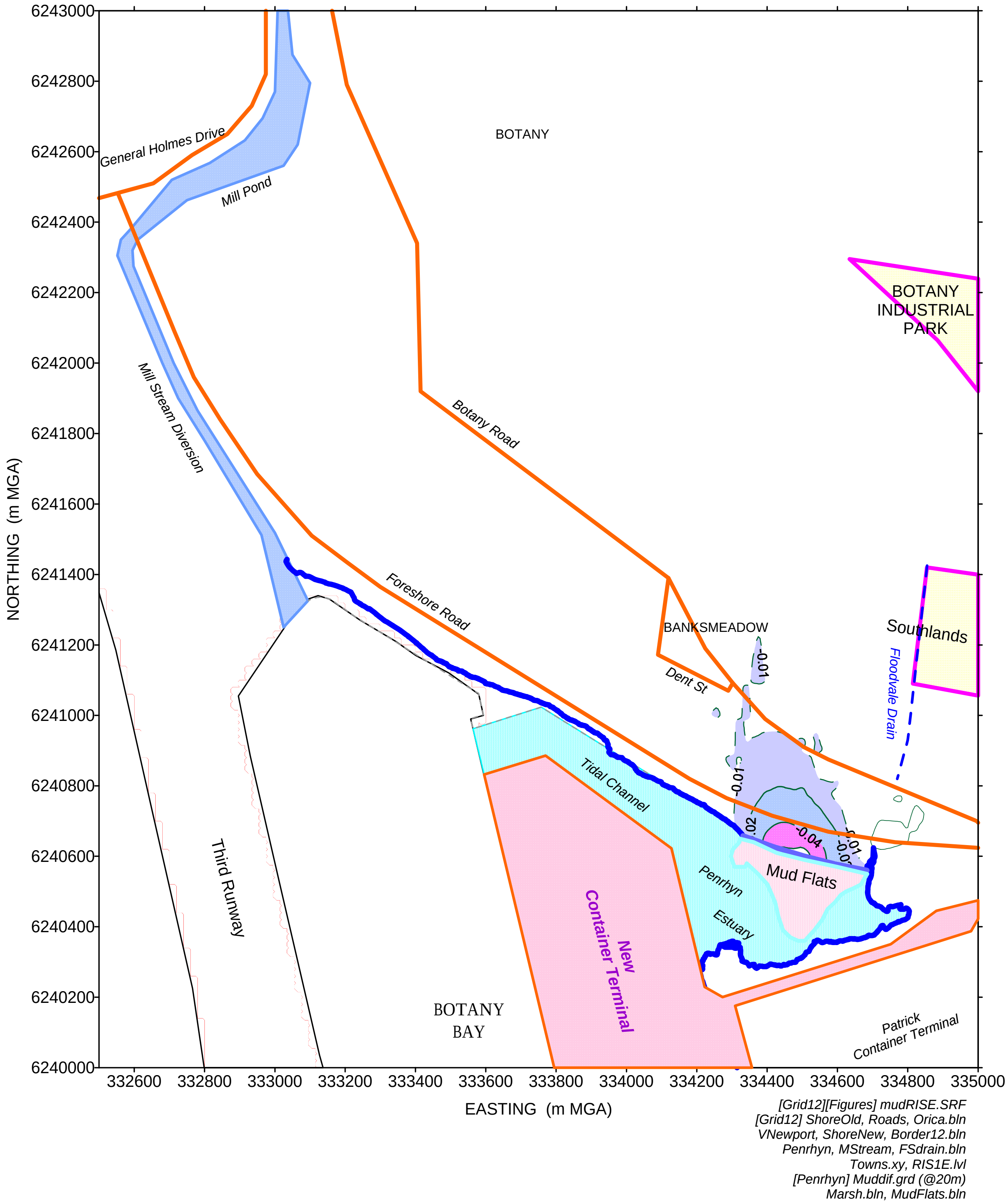


Figure 20. Simulated fall in groundwater levels (metres) for shoreline re-alignment due to the Penrhyn Estuary habitat enhancement works

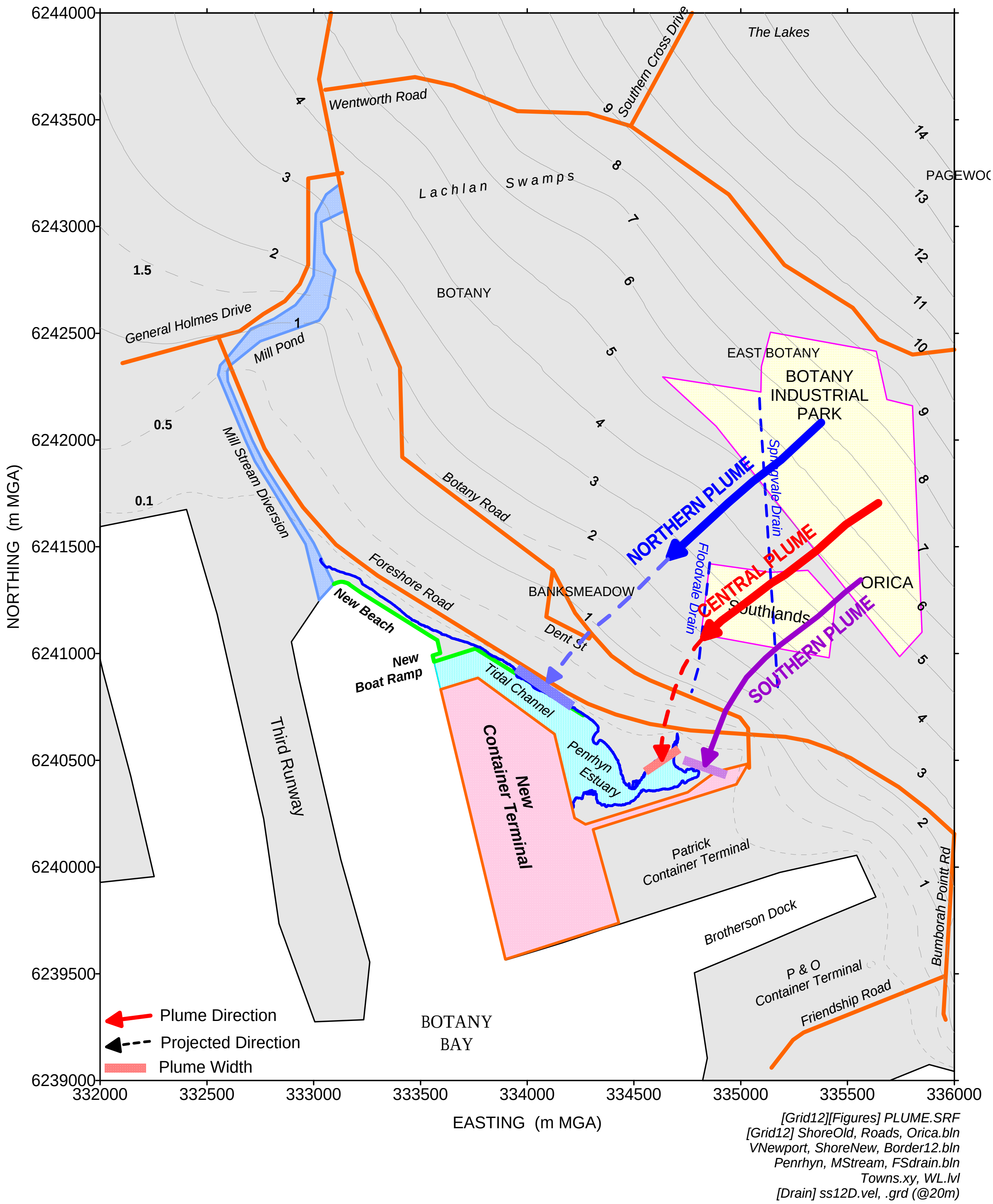


Figure 21. Contaminant plume axial directions, superimposed on steady-state simulated groundwater level contours (mAHD)

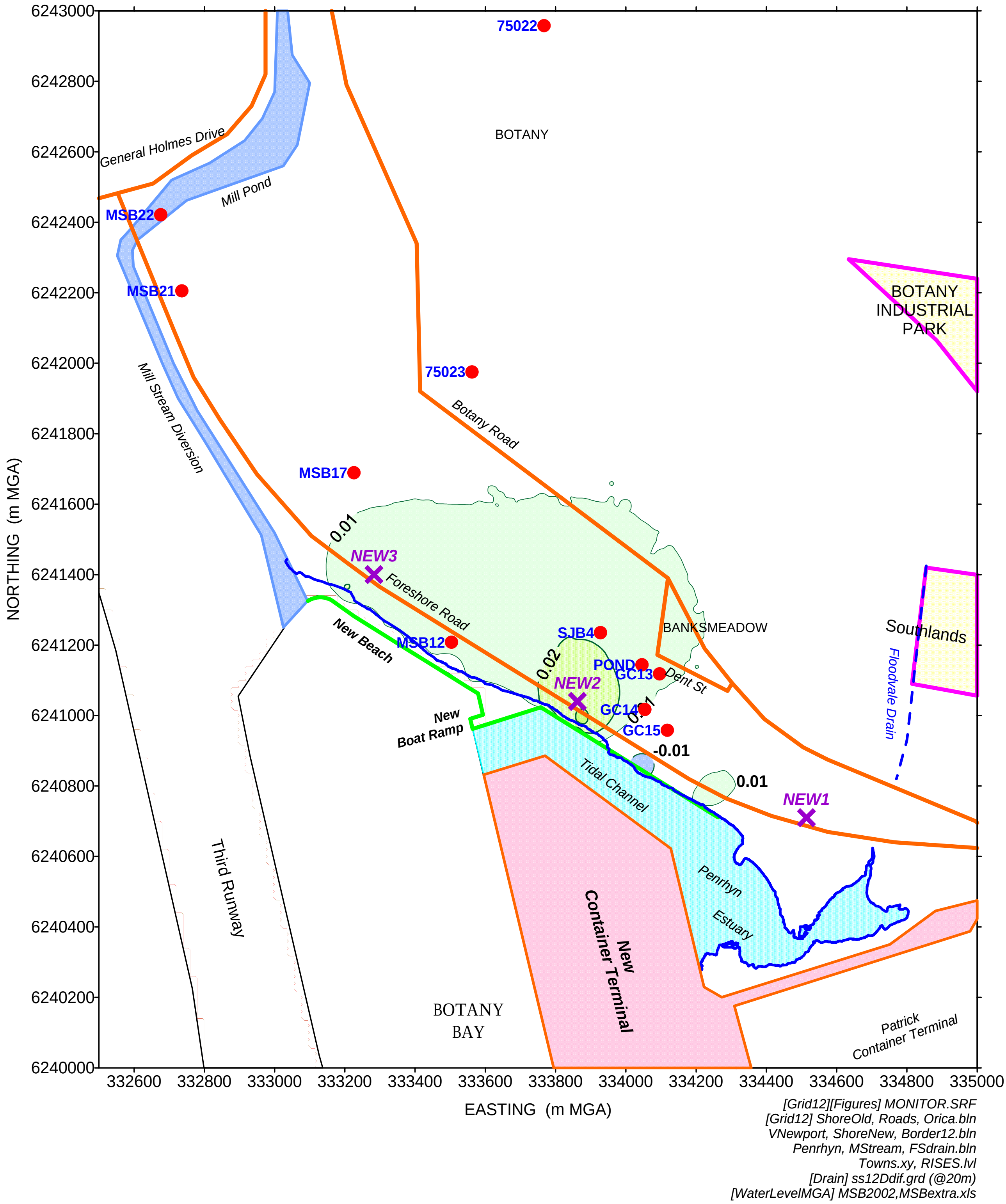


Figure 22. The present SPC groundwater monitoring network, with preferred sites for additional monitoring

[overlaid on simulated rise in groundwater levels (metres) for terminal reclamation with foreshore works and shoreline drainage (Drain unit conductance 100 m/day)]

APPENDIX A -
FINITE ELEMENT GRID AND SENSITIVITY TO DRAINAGE

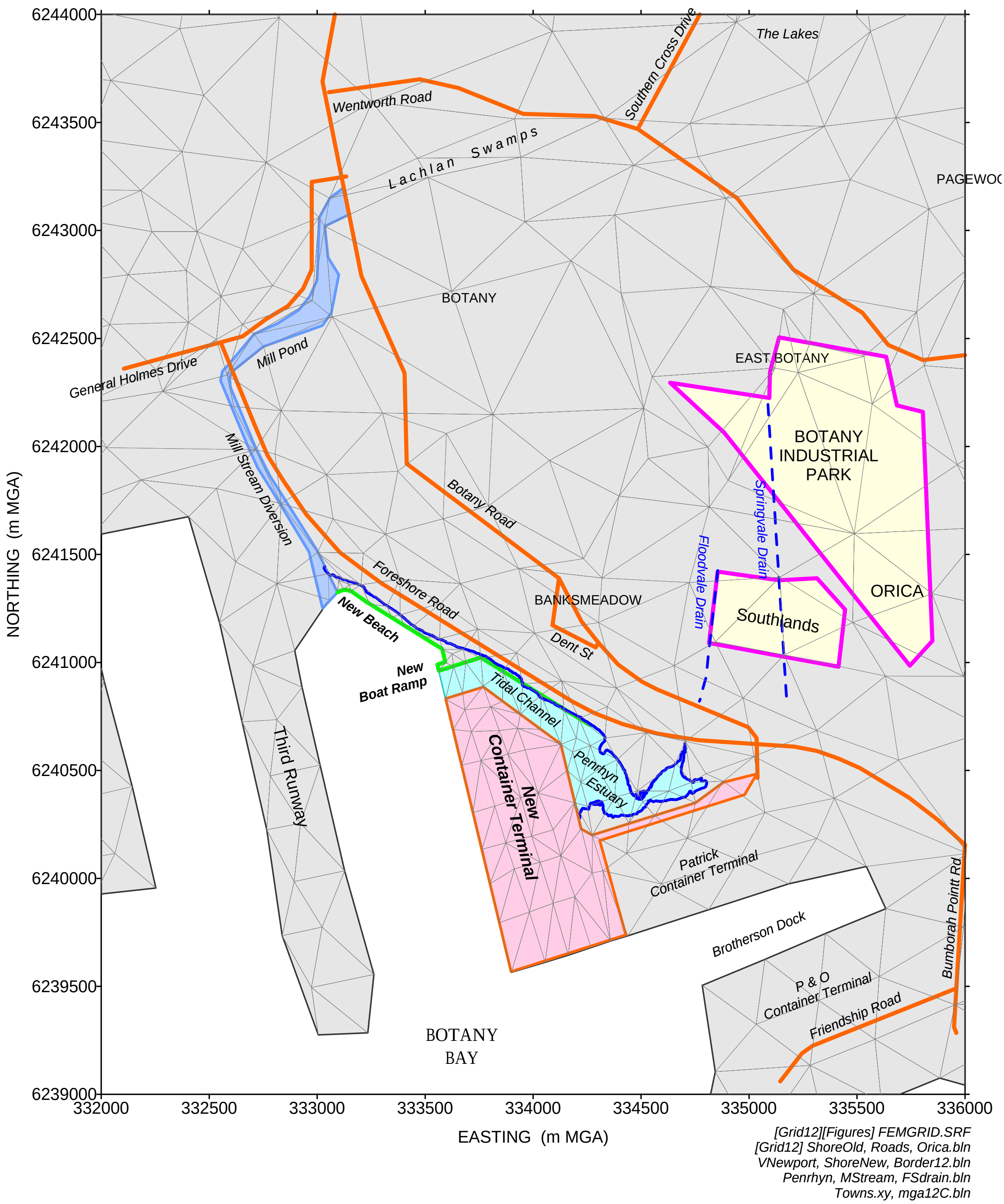


Figure A1. Portion of finite element grid near Botany Bay
(the full grid extends to Centennial Park in the north)

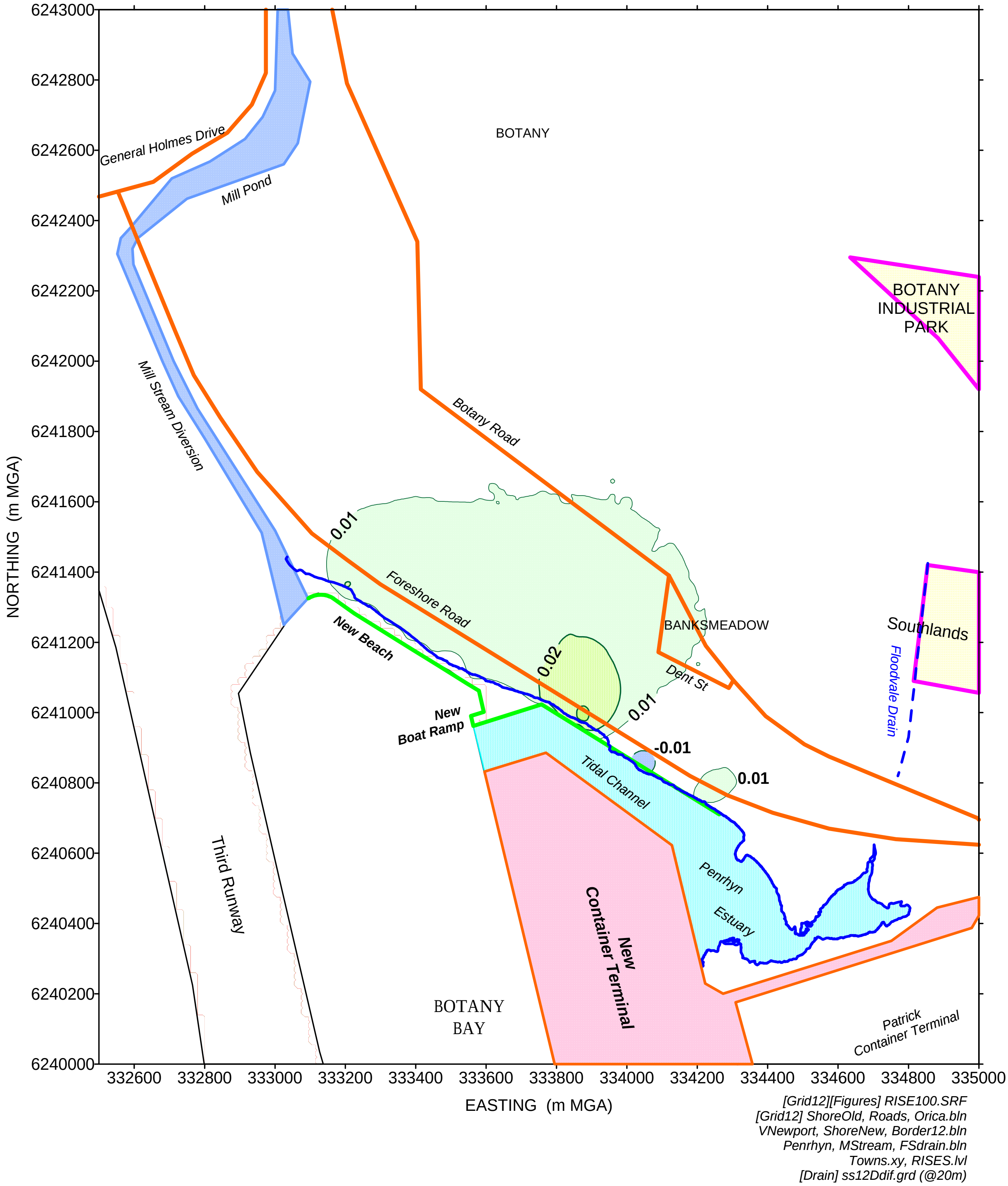


Figure A2. Simulated rise in groundwater levels (metres) for terminal reclamation with foreshore works and shoreline drainage
(Drain unit conductance 100 m/day)

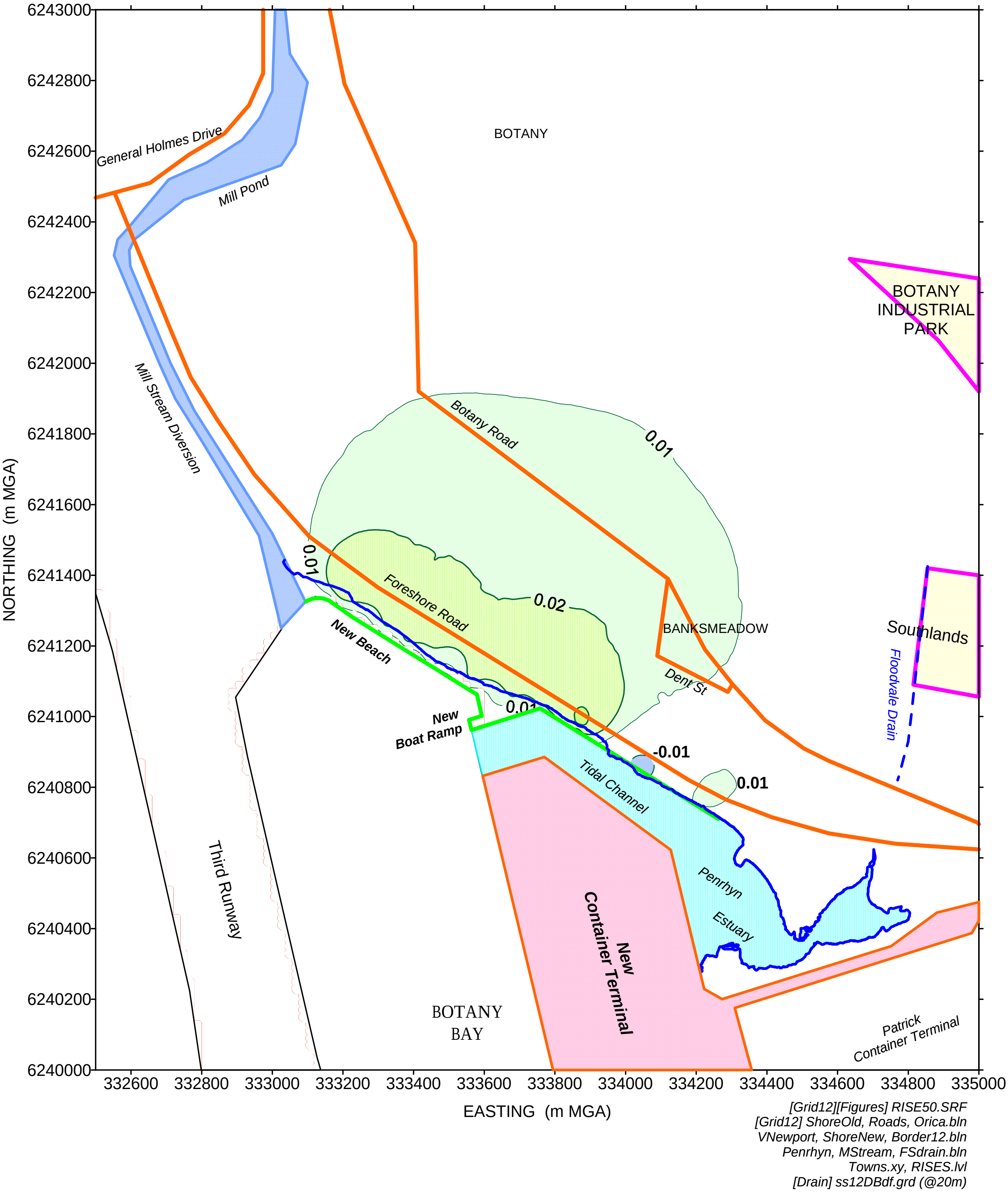


Figure A3. Simulated rise in groundwater levels (metres) for terminal reclamation with foreshore works and shoreline drainage
(Drain unit conductance 50 m/day)

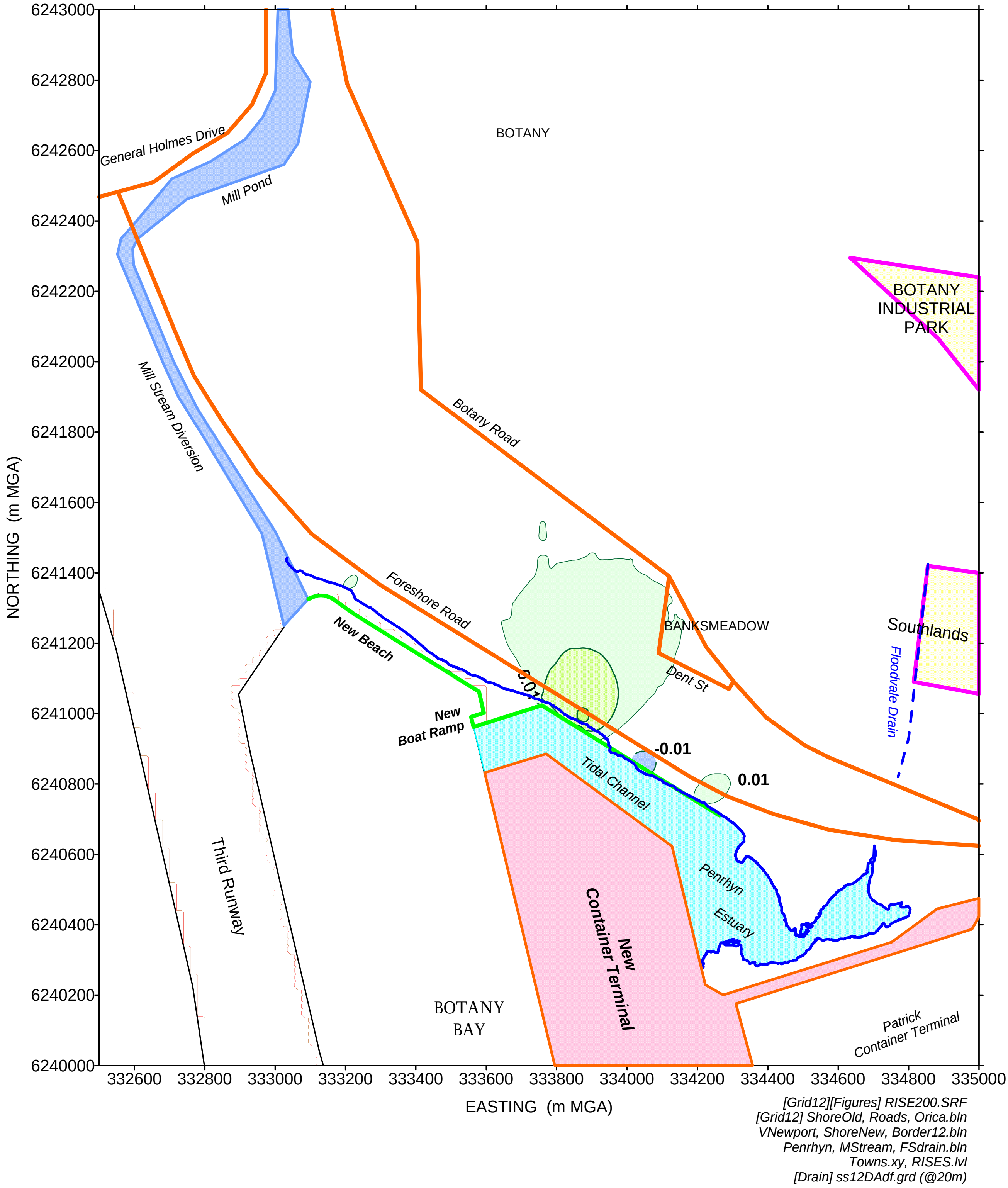


Figure A4. Simulated rise in groundwater levels (metres) for terminal reclamation with foreshore works and shoreline drainage

(Drain unit conductance 200 m/day)

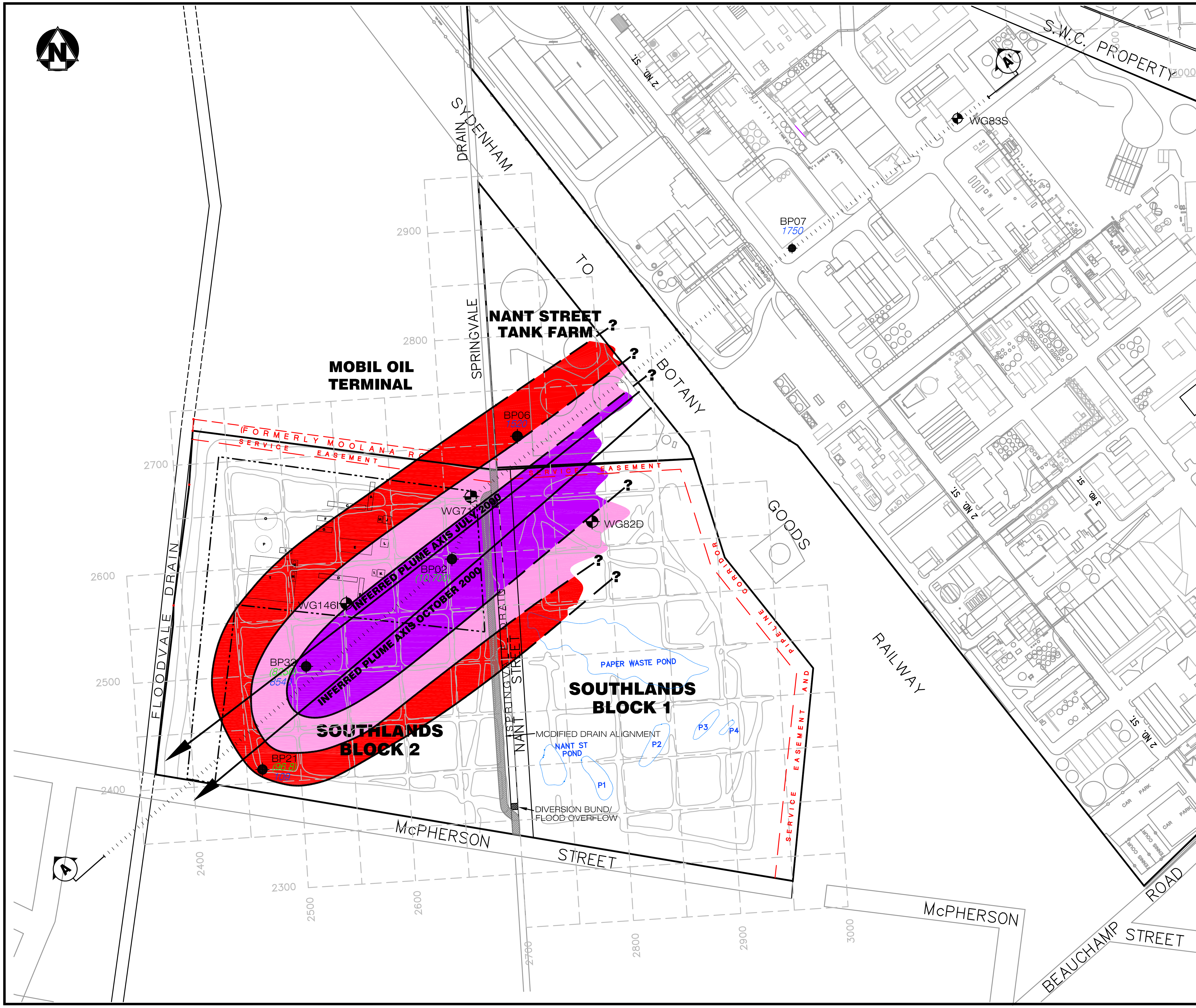
APPENDIX B -
CONTAMINANT PLUME

FIGURE B1 = FIGURE 2.2 (ORICA 2001)

FIGURE B2 = FIGURE 5.2 (ORICA 2002)

FIGURE B3 = FIGURE 2.3 (ORICA 2001)

FIGURE B4 = FIGURE 2.9 (ORICA 2002)



DESIGNED: EKS
DRAWN: HC
CHECKED:
APPROVED:
DATE:
STATUS: FINAL
PROJECT: 46160-002
CAD FILE: G438
REVISION: A

CLIENT
ORICA ENGINEERING PTY LIMITED

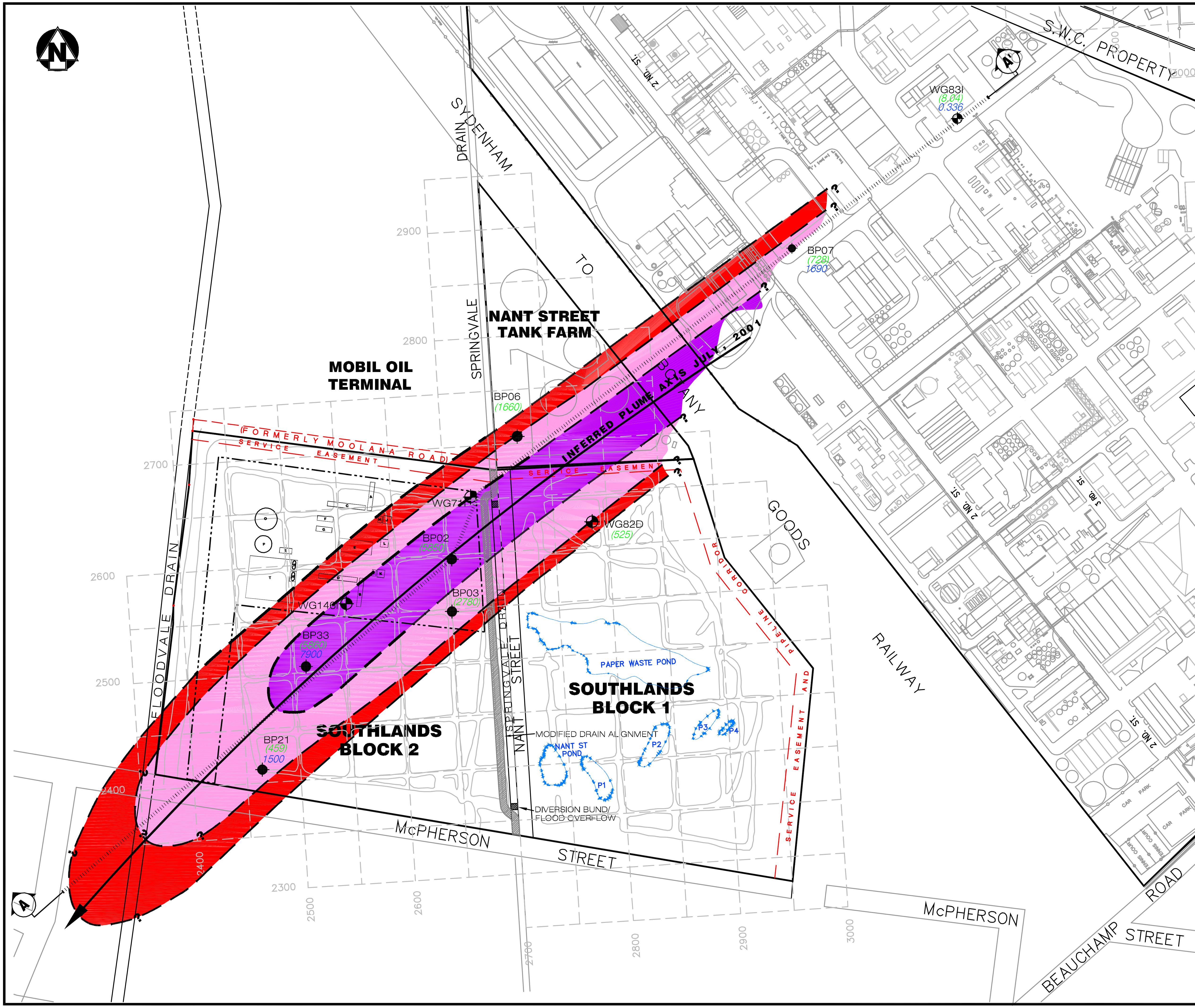
PROJECT
ORICA BOTANY ENVIRONMENTAL SURVEY, STAGE 3 - REMEDIATION

TITLE
INFERRED EDC DISTRIBUTION DEEP GROUNDWATER - CENTRAL EDC PLUME OCTOBER 2000

A3

URS

FIGURE
2.2



DESIGNED: GJB
DRAWN: HC
CHECKED:
APPROVED:
DATE:
STATUS: FINAL
PROJECT: 46160-002
CAD FILE: G473
REVISION: A

0 20 40 60 80 100 200
metres

LEGEND

- WG20 GROUNDWATER MONITORING WELL LOCATION
- BP01 BUNDLE PIEZOMETER LOCATION
- EXISTING PIPELINE/ACCESS EASEMENTS
- 1000 HIGH ZONE EDC PLUME CONTOUR IN mg/L
- A CROSS SECTION A - A'

EDC CONCENTRATION

- >5000 mg/L
- >1000 mg/L
- 100 - 1000 mg/L
- 10 - 100 mg/L
- 1 - 10 mg/L
- 0.1 - 1mg/L
- 0.01 - 0.1mg/L
- 0.001 - 0.01mg/L

(4290) EDC CONCENTRATION (mg/L) FEBRUARY/MARCH, 2001

1500 EDC CONCENTRATION (mg/L) JULY, 2001

NOTE: Locations of pipeline easements are indicative only.

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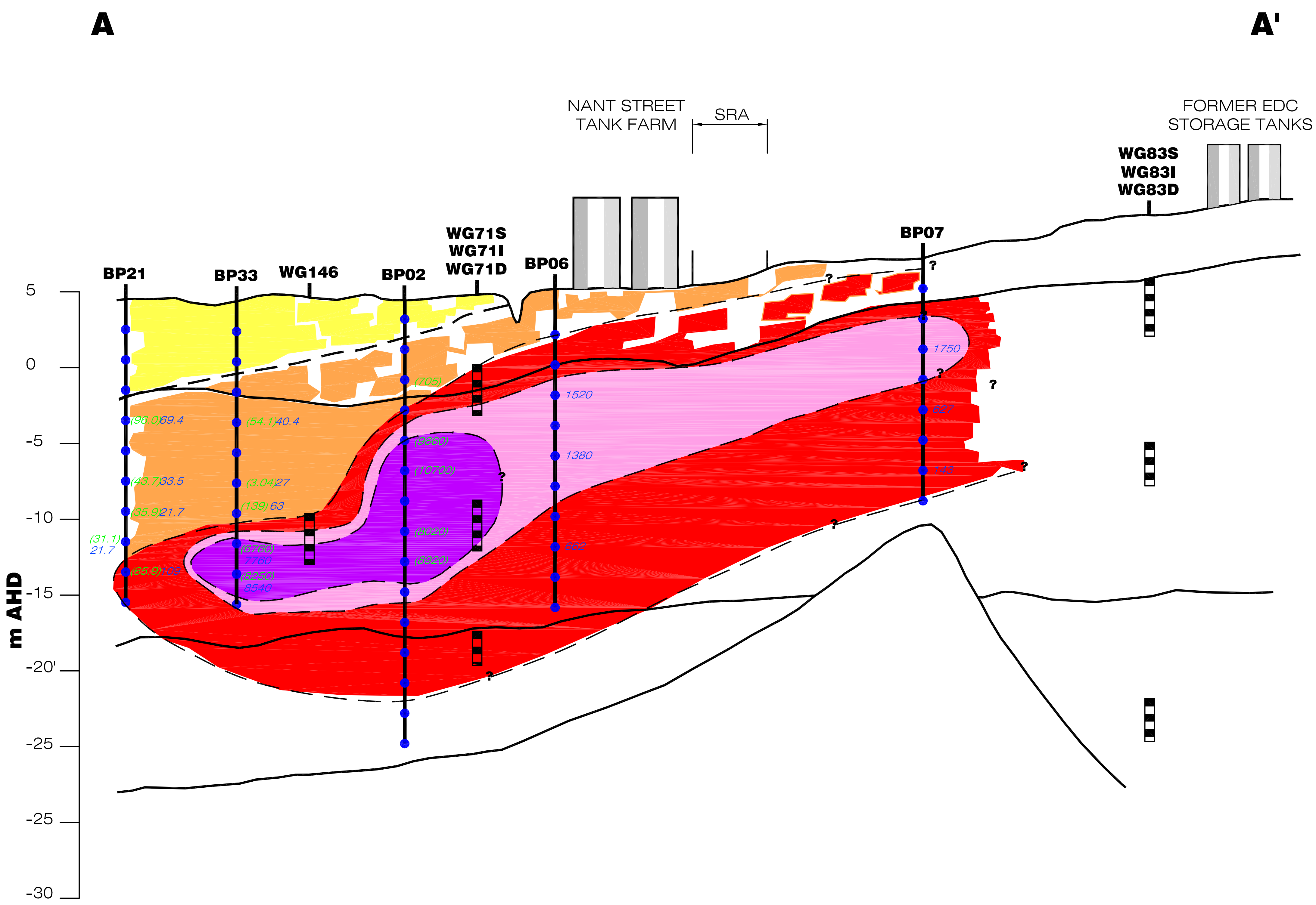
ORICA BOTANY ENVIRONMENTAL SURVEY, STAGE 3 - REMEDIATION

TITLE
INFERRED EDC DISTRIBUTION DEEP GROUNDWATER - CENTRAL EDC PLUME JULY, 2001

A3

URS

FIGURE **5.2**



DESIGNED: EKS	APPROVED:
DRAWN: HC	DATE:
CHECKED:	STATUS: FINAL

PROJECT: 46160-002-1001
CAD FILE: G439
REVISION: A

0 50 100 200
metres (horizontal)

LEGEND

EDC CONCENTRATION

- >5000 mg/L
- >1000 mg/L
- 100 - 1000 mg/L
- 10 - 100 mg/L
- 1 - 10 mg/L
- 0.1 - 1mg/L
- 0.01 - 0.1mg/L
- 0.001 - 0.01mg/L
- 14.4 SAMPLE PORT SHOWING EDC CONCENTRATION IN (mg/L)
- 1.2 MONITORING WELL SCREEN + EDC CONCENTRATION

EDC CONCENTRATION

- 31.1 OCTOBER 2000
- (27.8) JULY 2000

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ORICA ENGINEERING PTY LIMITED

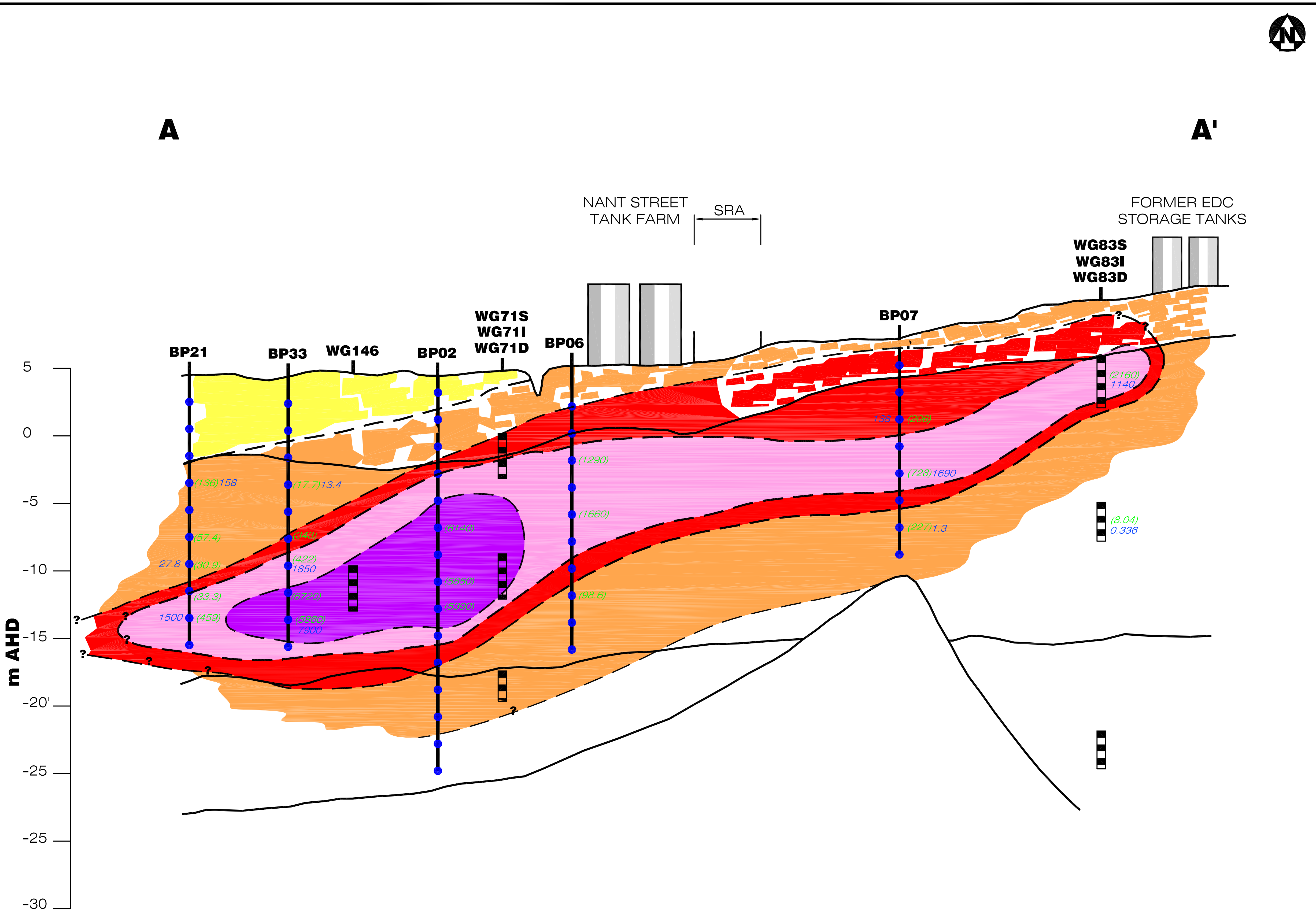
PROJECT
ORICA BOTANY ENVIRONMENTAL SURVEY, STAGE 3 - REMEDIATION

TITLE
CROSS SECTION A - A' EDC DISTRIBUTION - CENTRAL EDC PLUME - OCTOBER 2000

A3

URS

FIGURE
2.3



LEGEND

EDC CONCENTRATION

- >5000 mg/L
- >1000 mg/L
- 100 - 1000 mg/L
- 10 - 100 mg/L
- 1 - 10 mg/L
- 0.1 - 1mg/L
- 0.01 - 0.1mg/L
- 0.001 - 0.01mg/L
- SAMPLE PORT SHOWING EDC CONCENTRATION IN (mg/L)
- 1.2 MONITORING WELL SCREEN + EDC CONCENTRATION

EDC CONCENTRATION

- (33.3) FEBRUARY/MARCH 2001
- 33.3 JULY, 2001

DESIGNED: GJB	APPROVED:
DRAWN: HC	DATE:
CHECKED:	STATUS: FINAL
PROJECT: 46160-002	
CAD FILE: G495	
REVISION: A	

0 50 100 200
metres (horizontal)

CLIENT
ORICA ENGINEERING PTY LIMITED

PROJECT
ORICA BOTANY ENVIRONMENTAL SURVEY, STAGE 3 - REMEDIATION

TITLE
CROSS SECTION A - A' EDC DISTRIBUTION - CENTRAL EDC PLUME - JULY, 2001

A3

URS

FIGURE
2.9