F I N A L   R E P O R T

Orica Botany GTP Operation Ecological Monitoring Program

Prepared for

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1.1 Introduction

URS Australia Pty Ltd (URS) was commissioned by Orica Australia Pty Ltd (Orica) to undertake ecological monitoring of receiving environments potentially affected by the operation of a groundwater treatment plant (GTP) that was established as part of the Botany Groundwater Cleanup (BGC) Project. The ecological monitoring has been undertaken in accordance with the requirements of the Final Ecological Monitoring Workplan for the Groundwater Treatment Plant and its Operations (Workplan) dated 13 October 2005 (URS, 2005a).

The Workplan was prepared in accordance with the requirements of Orica's Environment Protection Licence 2148 and a Permit from NSW Fisheries (refer to Section 1.4). The Workplan was prepared in consultation with the Department of Environment and Climate Change (DECC), NSW Department of Health (NSW Health), Sydney Water Corporation (Sydney Water), Sydney Ports Corporation, Botany Bay Council, the Department of Natural Resources (DNR) and NSW Maritime Authority (NSW Maritime).

Ecological monitoring commenced in July 2005 and the first ecological monitoring report was issued in December 2005 (URS 2005b) with two subsequent reports issued in August 2006 (URS 2006) and January 2007 (URS 2007). This report is the final monitoring report required under the Workplan.

1.2 Background

The groundwater beneath the Botany Industrial Park (BIP) and nearby areas has been contaminated with chlorinated hydrocarbons (CHCs). The groundwater flow beneath the BIP is in a south-westerly direction toward Penrhyn Estuary on the northern shore of Botany Bay (Fig.1). To prevent the contaminant plume reaching the estuary, the DECC issued Orica with a Notice of Clean-up Action in 2003 (NCUA No. 1030236). That notice set a framework and timeframe for Orica to contain the contaminant plumes. Orica elected to use hydraulic containment (i.e. capture of groundwater) established at several locations, including the secondary containment line along Foreshore Road, which is up-gradient of Penrhyn Estuary (Fig.1).

Penrhyn Estuary consists of an inner and outer estuary, with surface water entering the inner estuary via the Springvale and Floodvale stormwater drains that discharge into the eastern and northern upper reaches of the estuary respectively (Fig.2). The most sensitive ecological receptors (e.g. saltmarsh and seagrass) are found in the inner estuary; therefore, this ecological monitoring program has focused on potential impacts of groundwater containment on the inner estuary.

In common with estuaries elsewhere, the discharge of groundwater to Penrhyn Estuary is controlled by pressures exerted during the tidal movement of marine water in the estuary (i.e. tidal pumping). Tidal pumping is the reversing flow of groundwater in coastal environments resulting from the changing tides – at high tide, the pressure exerted from estuarine water slows, stops or reverses the discharge of groundwater to the estuary; while at low tide, the reduced pressure of overlying estuarine water allows groundwater to discharge.

Monitoring of groundwater at Penrhyn Estuary has confirmed that fresh groundwater is not discharged directly into the estuary but is mixed with saline water in a zone of diffusion approximately 2 m below the intertidal ground surface (URS, 2005a). The volume of fresh groundwater entering the mixing zone beneath the estuary is expected to be reduced by hydraulic containment occurring along Foreshore Road. However, this is not considered likely to adversely impact the ecological receptors in the estuary since the natural mixing of groundwater and seawater occurs well below the ground surface.

Section 1 Introduction

At Penrhyn Estuary, dune vegetation grows in areas above the influence of the tides (supratidal) on flat 'dune' areas that were created with sandy spoil from dredging operations within Botany Bay (Fig.1). In addition, a zone of saltmarsh vegetation separates the dune vegetation from the estuary waters along the upper limits of the intertidal zone. Mangroves predominate along the southern shores of the estuary; particularly in areas that are frequently inundated at high tides adjacent to the water course from Springvale Drain. Sandy mudflats cover the main part of the central estuary area. Seagrasses are found along the edges of the inner estuary; particularly along the southern margin near the mangroves and periodically in small areas of the central mudflat and along the northern shore.

Hydraulic containment along Foreshore Road commenced in October 2004, and by July 2005, an interim volume of approximately 1 ML/day of groundwater was being extracted from the hydraulic containment lines. The GTP commenced water treatment at the end of January 2006, with full scale hydraulic containment (with expected extraction volumes of approximately 7.5 ML/day) planned for 2006. However, the volume of groundwater treated by the GTP fluctuated between 2.0 and 4.0 ML/day throughout 2006, achieving a maximum average rate above 4.0 ML/day during January and March 2007 (monthly average of 4.2 and 4.4 ML/day respectively). As indicated in the Workplan (URS, 2005a), achievement of steady state extraction rates is dependent on the pumping regime which will inevitably change over the life of the program.

In order to understand potential changes in ecological receptors and the relationship of observed changes to the operation of the GTP, it was considered necessary to assess changes in the physico-chemical characteristics of groundwater beneath the estuary. Therefore, the quantity and quality of groundwater was monitored during this project, along with the distribution and health of the main receptors in Penrhyn Estuary – dune vegetation, saltmarsh, seagrass, mangroves and wading shorebirds.

1.3 Objectives

The main objective of the ecological monitoring program was to assess whether detectable impacts to key ecological receptors in Penrhyn Estuary occurred following interception of groundwater along Foreshore Road during the operation of the GTP. Furthermore, the specific program objectives included:

- Monitoring of physico-chemical conditions of groundwater in Penrhyn Estuary before and during hydraulic containment;
- Monitoring of the distribution and health of key ecological receptors in Penrhyn Estuary before and during hydraulic containment; and
- Review of requirements for long term monitoring during full scale hydraulic containment with respect to results from the above two objectives.

The ecological monitoring program covers the period July 2005 to April 2007 for the vegetation components and from mid-September 2005 to June 2007 for the wading shorebird component. Note that it was anticipated that the hydraulic containment of groundwater would increase from interim rates during establishment of the containment lines through to full rates as full scale hydraulic containment was achieved when the GTP became operational. In fact, the expected treatment of groundwater at full scale (approximately 7.5 ML/day) has not been undertaken by the GTP to date.

Potential impacts of groundwater containment on the receiving ecosystem were identified as mostly related to the discharge of treated waters and/or the extraction of groundwater (URS, 2005a). Discharge of treated waters is licensed under Orica's Environment Protection Licence 2148 (EPL2148) and excess treated water is discharged into a Sydney Water stormwater channel that flows into Brotherson Dock. Conditions of EPL2148 require Orica to monitor the volume and quality of discharge waters on a weekly basis (with the exception of conductivity and temperature which are continuously monitored). The discharge licence limits are based on ANZECC (2000) trigger levels for the protection of freshwater aquatic ecosystems.

In contrast, potential impacts to biota as a result of containment and extraction of groundwater are not covered by EPL2148, and therefore form the basis of the ecological monitoring program discussed in this and earlier reports (URS 2005b, 2006, 2007).

1.4 Licences and Approvals

A number of approvals are required for the Botany Groundwater Cleanup (BGC) Project. Two of these approvals stipulate specific ecological monitoring requirements:

1) The special conditions in the revised Environment Protection Licence (EPL2148) – issued by DECC under the *Protection of the Environment Operations Act 1997*; and

2) Permit 05-030 issued by the NSW Department of Primary Industries (specifically NSW Fisheries) under Part 7 of *the Fisheries Management Act 1994*.

The ecological monitoring requirements of each of these approvals were reviewed and agreed upon in the Workplan dated 13 October 2005 (URS 2005a).

1.5 Reporting Requirements

The following table summarises the monitoring and reporting schedule described in the Workplan (URS, 2005a). This current report is the final report (of four reports in total) for the ecological monitoring program and details results of the fifth and final round of monitoring with discussion of results of all five monitoring rounds within the context of project objectives.

Monitoring and Reporting Schedule

Activity	Report Type	Date
Round 1 (July 2005) Monitoring	Reported in Report No.1	
Round 2 (October 2005) Monitoring	Initial/Progress Report No.1	December 2005
Round 3 (April 2006) Monitoring	Progress Report No.2	June 2006
Round 4 (October 2006)	Progress Report No.3	January 2007
Round 5 (April 2007)	Final Report	April 2008

Section 2 Monitoring Methodology

2.1 Monitoring Program

The ecological monitoring program was designed to assess whether changes in ecological receptors were occurring in Penrhyn Estuary, and whether observed changes (if they occurred) could be attributable to the containment of natural groundwater flow during the operation of the groundwater treatment plant (GTP). Consequently, any changes observed in ecological receptors were assessed within the context of changes in groundwater physico-chemical parameters that could be considered a specific result of groundwater containment.

Physico-chemical Parameters

The Workplan identified the need to establish and monitor the physico-chemical parameters of groundwater in Penrhyn Estuary both prior to the operation of the GTP and after GTP commencement (URS, 2005a). Initial assessment of groundwater physico-chemical properties was undertaken in a review of existing data (September 2003 to June 2005). The monitoring program was then established to measure key physico-chemical parameters in three distinct areas of the estuary environment for two years during the pre- and post-commissioning phase of the GTP. Monitoring of groundwater parameters was undertaken within the dune system, the saltmarsh vegetation community, and on the intertidal mudflats (porewater). The key physico-chemical parameters measured during the monitoring program included salinity (measured as electrical conductivity), dissolved oxygen, water temperature, redox potential and pH. Sampling locations for physico-chemical parameters are indicated in Fig.2.

Ecological Receptors

Identification of key ecological receptors was undertaken during the EIS process (URS, 2004a). The key ecological receptors identified for monitoring in Penrhyn Estuary were:

- Dune vegetation;
- Saltmarsh;
- Seagrass;
- Mangroves; and
- Wading shorebirds.

The EIS contained the hypothesis that dune vegetation may be dependent upon groundwater beneath the dune system. If dune vegetation is groundwater dependent, and the quality (e.g. salinity) or quantity (i.e. water table elevation) of groundwater changes significantly in response to hydraulic containment, then the dune vegetation may be expected to decline in health or change in community structure. Alternatively, if dune vegetation is primarily dependent on surficial groundwater derived from rainfall percolation, then the dune vegetation should remain unaffected by the containment of groundwater.

Monitoring of physico-chemical characteristics of the groundwater beneath the dunes was undertaken in order to assess possible changes associated with groundwater containment. The dune vegetation communities were simultaneously monitored to provide an indication of possible changes in vegetation receptors that might be related to any observed changes in groundwater.

The EIS (URS, 2004a) also included the hypothesis that potential changes in shallow groundwater beneath upper intertidal areas and estuarine mudflats could potentially lead to changes in the saltmarsh and seagrass communities respectively. Consequently, the physico-chemical characteristics of shallow groundwater and intertidal porewater were monitored, and the distribution and health of saltmarsh and seagrass communities were assessed within the context of any observed changes in groundwater.

Mangroves were not considered likely to be affected by changes in the groundwater discharge regime because they are adapted to fully saline conditions. However, during the initial monitoring assessments it was noted that mangrove abundance in Penrhyn Estuary had increased in recent years due to expansion into areas formerly occupied by saltmarsh and seagrass. Mangroves were therefore monitored as part of this program to provide an indication of whether any observed changes in the distribution of seagrass or saltmarsh receptors could be attributed to invasion by mangroves rather than impacts of groundwater containment.

Finally, it was hypothesised in the EIS that the abundance of wading shorebirds could be indirectly affected by any changes in saltmarsh vegetation cover and/or change in abundance of food species found on the mudflats as a result of groundwater containment. Shorebirds use saltmarsh vegetation areas for shelter and roosting and their local numbers may change if suitable vegetation cover declines. Similarly, if prey species on the mudflats are not abundant then wading shorebirds will move elsewhere to feed. Therefore, potential changes to the shorebird community found in Penrhyn Estuary were assessed in relation to GTP operations by observing bird numbers and bird health during the project period.

Specific methods were adopted for each component of the monitoring program in order to address the overall aims; details are provided below.

2.2 Physico-chemical Parameters

Changes in key ecological receptors in Penrhyn Estuary that might result from hydraulic containment can best be assessed in the relation to changes in physico-chemical conditions of groundwater beneath the estuary and surrounding habitats. Monitoring of physico-chemical parameters commenced in September 2005 in order to establish conditions prior to full-scale hydraulic containment and the commissioning of the GTP.

To assess potential changes in dune vegetation, saltmarsh and seagrass communities, the physico-chemical parameters of groundwater were monitored beneath the following three key areas:

- Sand dunes (groundwater);
- Saltmarsh beds (shallow groundwater); and
- Intertidal mudflats (porewater).

Sand Dunes - groundwater

Bundle piezometers were installed at three locations in the sand dunes (BP108, BP109 and BP115) amongst dune vegetation to the north of Penrhyn Estuary (Fig.2). Each bundle piezometer consisted of three 25 mm inside diameter tubes with stainless steel drive points (Solinst™ Model 615) that were inserted to specific depths below the ground surface (BGS) enabling sampling of groundwater from each specific depth using sampling pumps. The installation details are summarised in the table below.

Bundle Piezometer Installation Details

BP108			
Nominal Depth	2.0 m	3.0 m	4.0 m
Depth Interval	1.90 – 2.20 m	2.85 – 3.15 m	3.85 – 4.10 m
BP109			
Nominal Depth	2.0 m	3.0 m	4.0 m
Depth Interval	1.85 – 2.15 m	2.85 – 3.15 m	3.90 – 4.20 m
BP115			
Nominal Depth	4.5 m	5.5 m	6.5 m
Depth Interval	4.25 – 4.50 m	5.25 – 5.5 m	6.50 – 6.75 m

At each sampling time, the bundle piezometers were purged and sampled for groundwater that was subsequently measured for the standard physico-chemical parameters of conductivity (EC), total dissolved solids (TDS), pH, temperature (T), redox potential (REDOX), and dissolved oxygen (DO).

Saltmarsh - shallow groundwater

Shallow groundwater beneath the saltmarsh beds in the inner estuary was monitored using ten shallow, PVC monitoring wells (maximum depth approximately 1.0 m below ground surface) that were installed in the upper intertidal zone of the inner estuary (Fig.2). These wells were established in order to assess water quality parameters of surficial groundwater immediately beneath the saltmarsh vegetation. At each sampling event, hand-held probes were used to measure *in situ* water quality in the monitoring wells.

Intertidal mudflats - porewater

Interstitial porewater in the intertidal mudflats was monitored by bundle piezometers (Solinst™ Model 615) that were installed to depths of 0.1, 0.5 and 2.0 m below the mudflat surface. At each sampling time, the bundle piezometers were purged and sampled for porewater that was subsequently measured for the standard physico-chemical parameters of EC, TDS, pH, temperature, REDOX, and DO.

Porewater monitoring was undertaken by URS on a quarterly basis from September 2003 through to March 2007 as part of a general groundwater monitoring project for Orica.

2.3 Dune Vegetation

The abundance, distribution and health of the dune vegetation community was monitored by URS ecologists to assess whether the containment of groundwater was having a detectable impact on terrestrial plants down-gradient of the Foreshore Road containment line. It was hypothesised in the EIS (URS, 2004) that if the dune vegetation is groundwater dependent, it could be expected to exhibit an indication of impacts if the groundwater table was altered (either dropping in height or becoming more saline in the absence of freshwater recharge). Alternatively, it was suggested that surficial groundwater beneath the dune system might be derived from rainfall percolation and, in that case, dune vegetation could be expected to remain unaffected by groundwater containment.

The dune vegetation at Penrhyn Estuary is not listed as an Endangered Ecological Community (EEC) under the *Environmental Protection and Biodiversity Conservation Act* (EPBC Act) or the *Threatened Species Conservation Act* (TSC Act) and is unlikely to support threatened plant species (URS 2004b). No threatened plant species were recorded during the surveys conducted as part of the ecological monitoring program.

A review of available resources revealed the Eastern Suburbs Banksia Scrub (ESBS) in the Sydney Basin Bioregion is present in the local area and is listed as an endangered ecological community under both the EPBC and the TSC Acts. However, the Penrhyn Estuary dune vegetation is not considered to constitute ESBS (as per the NSW Scientific Committee Final Determination (2002) for this plant community) since the shrubland was planted in the 1980s on artificial dunes formed from dredged marine material deposited during development of Sydney Airport and Port Botany.

The dune vegetation is therefore considered of low to moderate conservation value. However, this planted community does include species that are considered to be representative of the indigenous Coastal Dune Heath community and therefore might possess local conservation value by providing habitats for native fauna such as birds.

Section 2 Monitoring Methodology

Vegetation Survey

The methodology for dune vegetation monitoring was designed to assess changes in species composition and/or health of the dune vegetation community that could result from hydraulic containment. The experimental design tests the null hypothesis that hydraulic containment does not alter the depth or physico-chemical characteristics of groundwater beneath the dunes, and consequently has no impact upon dune vegetation. The assessment of dune vegetation involved:

- Repeated surveys of permanent plots within the vegetation community;
- Assessment of changes in vegetation cover using aerial photographs; and
- Monitoring of *Banksia* spp. that are showing signs of senescence.

Five vegetation monitoring plots (20 x 20 m) were established in the sand dunes north of Penrhyn Estuary and along Foreshore Beach (Fig.3). Four plots were located down-gradient of the hydraulic containment whilst one control plot (Plot 5) was located further west, beyond the influence of the groundwater containment line.

The following data were collected for each vegetation plot:

- Projective foliage cover, height and stem diameter of the dominant stratum (tree or tall shrub layers);
- Vegetation structure according to the nomenclature of Specht (1970);
- Height and density of sub-strata (shrub and groundcover layers);
- List of all plant species present;
- A cover/abundance rating for each species present based on the modified Braun-Blanquet scale;
- The number and relative abundance of age classes present;
- Physiographic attributes including soil type, aspect, gradient and landform;
- Degree of disturbance and degree of weed infestation;
- Reproductive processes, such as flowering, fruiting and seeding; and
- Signs of senescence, such as fallen and standing deadwood, dieback, leaf-yellowing or leaf fall.

The methodology has been progressively updated with further understanding of site conditions. The recording of Braun-Blanquet scores for each species was included in the October 2005 (Round 2) survey and all subsequent rounds. This system quantifies any significant changes in community structure that may occur such as decline in the relative abundance of groundwater-dependent species or increase in the degree of weed infestation.

A further refinement involved the targeted assessment of senescent *Banksia* spp. observed on site, as recommended in the First Monitoring Report (Section 5.2, URS, 2005b). This approach was initially triggered by the observation of numerous dead and stressed *Banksia* spp., particularly in the strip adjacent to Foreshore Rd. in the north of the Site. That area encompasses Plots 4 and 5 but a substantial area of vegetation containing *Banksia* spp. dieback was observed in vegetation to the north of Plots 1 to 3. Accordingly, the entire site was surveyed using a ‘random meander’ technique and *Banksia* spp. showing signs of senescence were mapped using a hand-held GPS unit. This methodology allows greater flexibility than the plot-based survey and provides a record of both spatial and temporal variability in the extent of *Banksia* spp. dieback.

The results of a literature review did not suggest that *Banksia* spp. is groundwater dependent (URS 2005b). Nonetheless, it may be an appropriate indicator species for the overall health of the dune vegetation. *Banksia* spp. is the tallest species of the dune vegetation and, as the dominant stratum, has the largest biomass and deepest tap root. Accordingly it may respond most rapidly to changes in the depth or quality of groundwater.

Data on *Banksia* spp. size, health and signs of stress were recorded. An initial *Banksia* spp. survey was performed in July 2006 with further surveys performed in October 2006 and April 2007.

Almost two years of dune vegetation data has been collected during surveys undertaken in August and October 2005, April, July (*Banksia* spp. only) and October 2006, and April 2007. Where possible, surveys were undertaken each April and October in order to coincide with peak growth and reproductive periods of vegetation communities in temperate south-eastern Australia.

Aerial Photo Interpretation

In addition to vegetation monitoring conducted during ground surveys, aerial photographs of Penrhyn Estuary were analysed using a raster pixel classification tool within a geographical information system (GIS). Aerial photographs were digitally classified into ground cover types on the basis of pixel colouration. The GIS was used to calculate the areal extent (in m^2) of the specified ground cover types, such as vegetation and sand, allowing comparison of spatial differences across successive aerial photographs to provide an indication of temporal change in ground cover.

Dune-cover interpretation was completed using aerial photography undertaken in 2001, 2005 and 2006.

2.4 Saltmarsh

Saltmarsh within Penrhyn Estuary (Fig.1) was monitored by The Ecology Lab (TEL) during an initial monitoring round undertaken in July 2005, with further monitoring rounds undertaken in October 2005, April and October 2006, and April 2007.

Spatial distribution of saltmarsh was initially undertaken using aerial photographs at a scale of 1:1500 with subsequent ground-truth surveys conducted by experienced ecologists using differential GPS (DGPS). During each monitoring round, fine scale changes in saltmarsh communities were monitored using percent cover, species composition, number of epifaunal invertebrates and condition of saltmarsh plants at Penrhyn Estuary and two control locations (Woolooware Bay and Quibray Bay). Assessment was undertaken along three permanent transects at four sites within Penrhyn Estuary (Fig.4) and two sites at each of the controls (total 24 transects). Transects began close to the shoreline and ran perpendicular to the shore to the top of the saltmarsh. The exception was at Woolooware Bay where transects stopped after 40 m as the width of the saltmarsh community was too extensive to survey (~200 m). Four random (1 m^2) quadrats were sampled along each transect (total 96 quadrats).

The condition of saltmarsh plants was categorised using three 'health' categories: *good condition* (greater than 50% of the plant fleshy, growing tips present), *poor condition* (less than 50% of the plant fleshy, growing tips present) and *dead* (no growing tips on plant). Condition of the saltmarsh community was assessed prior to the commissioning of the GTP (effectively no groundwater containment) and then during the operation of the GTP (sustained groundwater containment).

In the EIS (URS, 2004a), it was hypothesised that saltmarsh species might be dependent on shallow groundwater and may therefore be adversely affected if groundwater levels were altered by hydraulic containment (and the operation of the GTP). However, sampling of groundwater quality parameters undertaken during the development of the Workplan (URS, 2005a) indicated that the presence of fresh water was not continuous across the area and that shallow groundwater was most likely recharged by percolation of rainfall. Therefore, the saltmarsh species would be expected to remain unaffected by the loss of groundwater during hydraulic containment. Nevertheless, since the saltmarsh community is considered a critical habitat (particularly for shorebirds), the monitoring of saltmarsh communities and local groundwater was continued throughout the program.

As noted in the Workplan (URS 2005a), saltmarsh areas are being colonised by mangroves throughout Botany Bay and Port Jackson, and mangroves have recently established in areas adjacent to the saltmarsh vegetation at Penrhyn Estuary. Key saltmarsh habitat in Penrhyn Estuary has already been lost due to colonisation by mangrove species (URS, 2004b). As a consequence, the number of mangrove seedlings and pneumatophores was also assessed in each saltmarsh survey quadrat.

Statistical analysis of saltmarsh survey results were undertaken using asymmetrical analyses of variance (ANOVA) to compare temporal and spatial variation in the percentage cover at Penrhyn Estuary with reference locations. In addition, multivariate procedures were used to examine differences in the number of types and relative abundances of organisms in saltmarsh assemblages. Full details of the statistical design are provided in Section 2.5, Appendix A.

Identification of significant negative trends in the health of saltmarsh community during monitoring events warranted notification of the Department of Primary Industry (DPI) as required by Permit 05-030 issued under Part 7 of the *Fisheries Management Act 1994*. No such trends were identified and notifications were not required during this project.

2.5 Seagrass

Seagrass within Penrhyn Estuary (Fig.1) was monitored by TEL during an initial monitoring round undertaken in July 2005, with further monitoring rounds undertaken in October 2005, April and October 2006, and April 2007.

Initially, the spatial extent of seagrass was determined using aerial photography at a scale of 1:1500 with subsequent ground-truth surveys conducted by experienced ecologists using differential GPS (DGPS). During each monitoring round, the fine scale changes in the nature of the seagrass beds was monitored by recording seagrass density, leaf length and width, and the number of leaves per shoot at Penrhyn Estuary and two reference locations (South Towra and Quibray Bay). The density of seagrass shoots (along with the number of mangrove pneumatophores) was counted in five haphazardly placed, 30 x 30 cm quadrats. In addition, in each of the quadrats the length and width of four haphazardly chosen seagrass leaves were measured to the nearest 5 mm and 1 mm respectively, and the number of leaves per shoot was recorded.

Suggestions that the health of seagrass in the Penrhyn Estuary is dependent on groundwater and is likely to show adverse effects as a result of groundwater containment (URS, 2004a) form the basis of the seagrass assessment undertaken for this ecological monitoring program. Groundwater discharged to Penrhyn Estuary interacts with marine waters below the sediment surface as a result of tidal pumping. As a result, no fresh groundwater is discharged directly to Penrhyn Estuary and fresh groundwater is only present at a depth of approximately 2.0 m below the sediment surface. Consequently, the porewater at a depth of 0.1 m below the sediment surface of the estuary mudflats has salinity levels similar to that of estuarine surface waters and indicates that seagrasses are not reliant on sources of freshwater.

Seagrass areas within Penrhyn Estuary are located adjacent to established mangrove trees. Expansion of new mangroves into areas occupied by seagrasses has occurred in recent years. Monitoring of mangrove pneumatophores and seedlings was undertaken during the assessment of seagrass distribution in order to distinguish between variation of seagrass cover resulting from mangrove encroachment and possible impacts of groundwater containment.

Identification of significant negative trends in the health of seagrass beds during monitoring rounds warranted notification of the DPI as required by Permit 05-030 issued under Part 7 of the *Fisheries Management Act 1994*. No such trends were identified and notifications were not required during this project.

2.6 Mangroves

Mangroves within Penrhyn Estuary (Fig.1) were monitored by TEL during an initial monitoring round undertaken in July 2005, and during further monitoring rounds undertaken in October 2005, April 2006 and 2006, and April 2007.

Mangroves within Penrhyn Estuary are considered to be of low conservation value (URS, 2004a). The mangroves are not considered likely to be affected by hydraulic containment and were primarily monitored to assess whether there was measurable encroachment into saltmarsh and seagrass areas. Consequently, the assessment of mangroves during this monitoring program was undertaken by counting the number of mangrove seedlings and pneumatophores within quadrats during the saltmarsh and seagrass assessments described above (Section 2.4 and 2.5 respectively). Trends in mangrove distribution provide a check on whether any variation in saltmarsh and/or seagrass community distribution is due to a general loss of seagrass and saltmarsh or could be attributed to mangrove invasion.

Identification of significant negative trends in the health of mangroves during monitoring rounds warranted notification of the DPI as required by Permit 05-030 issued under Part 7 of the *Fisheries Management Act 1994.* No such trends were identified and notifications were not required during this project.

2.7 Wading Shorebirds

Penrhyn Estuary provides important feeding and roosting areas for a range of waterbirds, especially migratory shorebirds that depend on the intertidal areas for foraging. Migratory bird species are protected under international agreements between the Government of Australia and the Government of Japan (JAMBA) and the People’s Republic of China (CAMBA) for the protection of migratory birds and birds in danger of extinction and their environment; also under Australia’s EPBC Act. In addition, some bird species are considered threatened and are protected under the TSC Act.

Twenty-four species of resident and migratory shorebirds and seabirds, listed under the TSC and/or the EPBC Acts, are known to occur, or have previously been recorded in Penrhyn Estuary (URS, 2004a). The importance of Botany Bay for migratory shorebirds has significantly reduced in recent decades due to habitat loss and disturbance throughout the bay. Although extensive bird habitats are still present in Botany Bay, these are generally located along the southern shoreline.

Shorebirds at Penrhyn Estuary were monitored weekly by Avifauna Research & Services from mid-September 2005 to the end of June 2007. Counts were carried out at high tide and low tide; usually on the same day, except during the winter months if both tides did not occur during daylight hours. High tide counts targeted roosting shorebirds on the assumption that shorebirds generally roost at the most convenient sites to their foraging area. Low tide counts were undertaken to determine which parts of the estuary were used as feeding habitat and to determine whether those patterns changed over time. Low tide counts also confirmed whether all birds feeding at the estuary roosted there or moved elsewhere.

Birds were counted and identified using high quality optical 10 x 50 binoculars and/or a 25 x 77 spotting scope. Data was collected in a field note book then entered into Excel™ spreadsheets for storage and analysis.

Section 2 Monitoring Methodology

For the purpose of assessing which parts of the estuary were used by bird species over time, Penrhyn Estuary was divided into six sections and five sub-sections (Fig.5):

- Section 1 - Upper Estuary
  - Sub-section 1a - Springvale Creek
  - Sub-section 1b - Floodvale Creek
- Section 2 - Outer Estuary
  - Sub-section 2a - Northern Shore
  - Sub-section 2b - Southern Shore
- Section 3 - Port Spit
- Section 4 - Port Beach
- Section 5 - Jetty Beach
  - Sub-section 5a - Old Government Jetty
- Section 6 - Foreshore Beach

A baseline study (prior to groundwater containment) was not possible since groundwater containment was already occurring at the time of the initial bird surveys. However, data collected by the NSW Wader Study Group since 2001 includes monthly high tide counts of shorebirds at Penrhyn Estuary, and was used for pre-containment comparison.

Seven species of shorebird were identified as key monitoring species due to their local importance and/or relative abundances within Botany Bay:

- Sharp-tailed Sandpiper (*Calidris acuminate*)
- Red Knot (*Calidris canutus*)
- Curlew Sandpiper (*Calidris ferruginea*)
- Red-necked Stint (*Calidris ruficollis*)
- Double-banded Plover (*Charadrius bicinctus*)
- Bar-tailed Godwit (*Limosa lapponica*)
- Pacific Golden Plover (*Pluvialis fulva*)

The temporal trends in abundance of these species are discussed separately in this report.

In addition, the Bar-tailed Godwit (*Limosa lapponica*) was used as an indicator species for the assessment of body condition due to the fact that those birds were present at the estuary throughout the year. This species is also an ideal indicator species as it is the largest of the migratory birds found at the estuary and therefore is the easiest to photographically assess for body condition. The qualitative rating of body fat used during monitoring is on a scale from one to five, with one being the fat free weight of the bird and five being the maximum weight prior to migration.

Section 3 Monitoring Results

3.1 Hydraulic Containment

The average volume of treated water being discharged from the groundwater treatment plant (GTP); was used as a proxy of the volume of groundwater containment. The volume of discharge has risen over the monitoring period from approximately 1 ML/day in February 2006 to more than 4.0 ML/day in March 2007 (Fig.6). Note that treated volumes decreased during May/June 2006 due to ongoing maintenance of the GTP. The volumes are well short of the expected ‘full-scale hydraulic containment’ levels of 7.5 ML/day (URS 2005a).

3.2 Physico-chemical Parameters

Monthly rainfall for the monitoring period (June 2004 to March 2007) recorded at Sydney Airport by the Bureau of Meteorology (BOM) indicates that 23 of the 34 months (68%) were drier than the thirty-year average (Fig.7). Dry conditions were particularly apparent during almost the entire period from March 2005 to March 2007 with winter 2006 (June to August plus September) the only season that had higher than average rainfall.

Rainfall could be expected to have a direct influence on the quality and quantity of groundwater. Consequently, the drier-than-average conditions experienced throughout the monitoring period may confuse monitoring outcomes.

3.2.1 Groundwater – Sand Dunes

Results for physico-chemical parameters in samples obtained from the bundled piezometers located within the dune vegetation are provided in Tables 1a-1g. Note that the shallow (2.25 m) piezometers were dry for both the 2005/06 and 2006/07 summer months; possibly reflecting the ongoing drought conditions.

The standing water level (SWL) in the dune piezometers varied between monitoring rounds but showed no definite trend over time (Fig.8). Despite decreased levels reported in previous monitoring reports, the SWL of dune piezometers appears to exhibit seasonal variation with lower levels during summer months and higher levels at other times due to rainfall recharge. Confounding issues of drier-than-average conditions experienced throughout the region, with 56% of the monthly rainfall averages being less than 50% of the long term averages, complicate actual patterns that could be related to groundwater containment.

The SWL of groundwater at BP115 (eastern dunes) is consistently 1.0 to 1.5 m further below the ground surface than at the other dune piezometer locations (BP108 and BP109, western dunes). However, this difference has been apparent from the initial sampling period in July 2005 and therefore, is not related to groundwater containment.

Throughout the monitoring period, the conductivity of groundwater at all depths in dune piezometers BP109 and BP115 have consistently been less than 2600 µS/cm (Fig.9). These values are indicative of low salinity (fresh) water. In contrast, at piezometer BP108 the groundwater conductivity at 3.5 and 4.25 m depths is more varied than at the other locations; with some values above 30,000 µS/cm (Fig.9). These results indicate that seawater is influencing the groundwater at this location and probably relates to a saltwater wedge intruding beneath the dunes. The location of BP108 is close to the outer margin of the estuary and closer to the foreshore than the other dune piezometer locations, and is therefore more likely to be influenced by stronger tidal pumping than locations within the dunes of the inner estuary.

Groundwater beneath the dunes at shallow (2.25 m) and medium (3.25 m) depths generally has pH values between 6.5 and 8.0 (Fig.10). In contrast, the pH of deeper groundwater (4.25 – 5.25 m) at BP115 is generally more variable and has values as low as 6.05. Overall, the pH values for dune groundwater are typical for brackish (and marine) waters though higher than would be expected for pure rainwater (i.e. pH <6.0). There are no apparent trends in pH through time at any of the dune sampling locations.

3.2.2 Shallow Groundwater – Saltmarsh

Physico-chemical results for the shallow monitoring wells in the saltmarsh beds are provided in Tables 2a-g.

Conductivity values for shallow groundwater below the saltmarsh beds are generally above 30,000 µS/cm which indicates a strong estuarine/marine water influence (Fig.11). The lowest conductivity values (15,000 to 30,000 µS/cm) were measured during September 2006 and most likely reflect the heavy rainfall experienced in the area within the preceding four months (see rainfall graph, Fig.7). Similarly, a reduction in conductivity values at several monitoring wells during December 2005 is probably related to high rainfall in the preceding two months. These observations confirm that the groundwater beneath the saltmarsh is generally saline throughout the year but with dilution due to rainfall when it occurs.

Measurements of pH in groundwater beneath the saltmarsh beds (Fig.12) indicates that the range of values (generally between 7.0 and 8.0) are typical of seawater rather than freshwater and further supports the theory that estuarine/marine water rather than low salinity groundwater is typically present beneath the saltmarsh vegetation.

3.2.3 Porewater – Intertidal Mudflats

Porewater data for Penrhyn Estuary mudflats throughout the monitoring period is provided in Tables 3a to 3f.

Conductivity measurements of shallow porewater (0.1 and 0.5 m below the mudflat surface) are generally in the range 30,000 to 55,000 µS/cm, indicating a strong estuarine/marine water influence (Fig.13). However, porewater conductivity at 2 m depth (below the mudflat surface) is more variable between times and locations and indicates that freshwater percolation might be occurring at this depth. There is no indicative trend of conductivity changes in any of the mudflat piezometer data that could be attributed to the containment of groundwater up-gradient of the estuary.

3.3 Dune Vegetation

The dune vegetation within the study area is classified “Planted Shrubland” and occurs on marine sands along Foreshore Beach and at Penrhyn Estuary (Fig.1). This community features a sparse to moderate tree stratum dominated by *Banksia integrifolia* to approximately 7 m height, a sparse to moderately dense and wind-pruned native shrub stratum dominated by *Melaleuca armillaris, Leptospermum laevigatum* and *Acacia longifolia var. sophorae* to 4 m height, dense stands of the exotic shrub *Chrysanthemoides monilifera*, and a sparse groundcover of herbs and grasses to 0.5 m height.

The dune vegetation is highly disturbed and is subject to ongoing impacts from pedestrian traffic and rubbish; particularly adjacent to Foreshore Road and in the narrow stretch along Foreshore Beach (western margin of the study area). The community is subject to erosion at the high water mark and along drainage lines. Most of the area is heavily infested with the exotic shrub Bitou Bush (*Chrysanthemoides monilifera*). In places there are also moderate to dense infestations of herbaceous weeds such as Mother-of-Millions *(Bryophyllum delagoense),* Turkey Rhubarb (*Acetosa sagittata*), Panic Veldt Grass (*Ehrharta* erecta) and Bridal Creeper (*Asparagus asparagoides*).

The plant species recorded on the dunes at Penrhyn Estuary and their specific conservation status are listed in the table below.

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Species Present in Dune Vegetation Sample Plots

Common Name	Scientific Name	Conservation Status
Sydney Golden Wattle	*Acacia longifolia longifolia*	Unprotected / Common
Coast Wattle	*Acacia longifolia var sophorae*	Unprotected
Turkey Rhubarb	*Acetosa sagittata*	Environmental weed
Bridal Creeper	*Asparagus asparagoides*	Noxious weed
Berry Saltbush	*Atriplex semibaccata*	Probably adequate
Coast Banksia	*Banksia integrifolia*	Unprotected / Common
Old Man Banksia	*Banksia serrata*	Unprotected / Common
Cobblers Pegs	*Bidens pilosa*	Environmental weed
Mother-of-Millions	*Bryophyllum delagoense*	Noxious weed
Sea Rocket	*Cakile edentulata* var *edentulata*	Exotic/common
Carex	*Carex sp.*	Unprotected
Pig Face	*Carpobrotus glaucescens*	Unprotected / Common
Green Cestrum	*Cestrum parqui*	Noxious weed
Bitou Bush	*Chrysanthemoides monilifera*	Weed of National Significance
Native Wandering Jew	*Commelina cyanea*	Unprotected / Common
Fleabane	*Conyza sp.*	Environmental weed
Pampas Grass	*Cortaderia selloana*	Noxious weed
Australian Stonecrop	*Crassula sieberiana*	Unprotected
Tuckeroo	*Cupaniopsis anacaroides*	Unprotected
Plume grass	*Dichelachne crinita.*	Unprotected
Panic veldt Grass	*Ehrharta erecta*	Environmental weed
African Lovegrass	*Eragrostis curvulata*	Noxious weed
Cud weed	*Gamochaeta pennsylvanica*	Environmental weed
Kurnell Curse	*Hydrocotyle bonariensis*	Unprotected
Knobby Club Rush	*Isolepsis nodosa*	Unprotected
Lantana	*Lantana camara*	Weed of National Significance
Coast Teatree	*Leptospermum laevigatum*	Unprotected
Bracelet Honey Myrtle	*Melaleuca armillaris*	Unprotected
Native Geranium	*Pelargonium australe*	Unprotected
Poa	*Poa poiformis*	Unprotected
Pigweed	*Portulaca oleracea*	Environmental weed
Dock	*Rumex sp.*	Environmental weed
Fireweed	*Senecio madagascariensis*	Environmental weed
Blackberry Nightshade	*Solanum nigrum*	Environmental weed
Sowthistle	*Sonchus oleraceous*	Environmental weed
Hairy Spinifex	*Spinifex sericeus*	Unprotected
NZ Spinach	*Tetragona tetragonioides*	Unprotected
	Vulpia muralis	Environmental weed
Sand Couch	*Zoysia macrantha*	Unprotected

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Presence - absence results from July 2005 to April 2007 are presented in Table 4 with the Braun-Blanquet values for October 2005 to April 2007 presented in Table 5. Cells highlighted in grey reflect a change in Braun-Blanquet values between survey rounds. Ten species were recorded in plots for the first time in April 2007, including these nine new species:

- a seedling of the native tree, *Cupaniopsis anacaroides*;
- the native, perennial herb, *Commelina cyanea*;
- the exotic perennial noxious weed, *Cortaderia selloana*; *and*
- the exotic environmental weeds, *Conyza* sp., *Sida rhombifolia*, *Solanum nigrum*, *Bidens* sp., *Sonchus oleraceus*, and *Portulac oleracea*.

The recent appearance of these species represents colonisation of the plots since the last survey round. This is not surprising since most of these species are bird or wind-spread exotic weeds that readily colonise disturbed areas. While the first two new species represent natural recruitment of native species indigenous to the local area.

Three species (*Dichelachne crinita*, *Crassula sieberiana* and *Vulpia muralis*) were absent from Plot 1 after being recorded there during the October 2006 surveys. One species, *Senecio madagascarienis*, was absent from Plot 2 and one species, *Carex* sp., was absent from Plot 5. No species became absent from Plots 3 or 4 over the monitoring period.

Species diversity is too low for quantitative assessment of the significance of any changes in the overall number of species present at the site. However, the seven-point Braun-Blanquet index allows for quantitative assessment of the significance of changes in species abundance. These results are presented in Table 5. A one-point change in the Braun-Blanquet rating for a species between survey rounds is considered significant and has been highlighted in the table.

The presence and relative abundance data infers dominance by Bitou Bush (*Chrysanthemoides monilifera*) which was recorded in all five plots in all five surveys; with Braun-Blanquet ratings of between 4 and 5 (Plots 1, 2 and 4) recorded in April 2007. This indicates that Bitou Bush currently makes up 30 to 90% of all individual plants present in each of these plots. Percentage cover has fluctuated, although the overall dominance of Bitou Bush relative to other species has been consistent throughout the survey period. A significant decrease in this species was observed in Plot 5 (control) between October 2005 and October 2006 – with a Braun-Blanquet rating decline from 4 (25 - 50% of all individuals) to 2 (5 - 10%). However, by April 2007 the Braun-Blanquet rating of this species at that location had increased to 3 (10-25%). Conversely, Bitou Bush declined over the same time period in Plot 3. This variability may suggest ongoing senescence of adults and recruitment of juveniles and natural variability in the cover abundance of this species.

The invasive weed, *Lantana camara*, was observed in all plots except Plot 5. *L.camara* was not present in Plot 1 before April 2006, suggesting colonisation by seedlings in the months prior to October 2006. *L.camara* is less dominant than Bitou Bush and accounts for 5 to 10% of individuals in each plot.

Banksia integrifolia and *Banksia serrata* were the most abundant tree species although they were still sub-dominant to shrub species (Braun-Blanquet rating of 3 or less). *Banksia integrifolia* declined in Plot 4 between October 2006 and April 2007, reflecting the death of a number of adult trees in the plot.

The most abundant native species occupying the large shrub/small tree stratum differed from plot to plot but generally consisted of *Melaleuca ericifolia*, *Leptospermum laevigatum* and *A. longifolia* var *sophorae*. Braun-Blanquet ratings ranged from 2 to 4 (5 to 50%) between species and between plots. In each plot at least one of these species approached Bitou Bush in dominance, demonstrating that despite the infestation by exotic weeds, there is a significant biomass of native species on site.

No significant change in the abundance of *Acacia longifolia* var *sophorae* was recorded from April 2006 to October 2006. *Acacia longifolia longifolia* was present in Plot 5 in October 2005 and *Acacia saligna* was recorded as present in Plot 3 in August 2005. However, both were absent in April 2006 and all subsequent surveys.

The native shrub, *Leptospermum laevigatum*, declined in abundance in Plot 3 and declined from a Braun-Blanquet rating of 1 to 0 (absence) in Plot 2.

Groundcover species recorded over the survey period comprised native grasses such as Hairy Spinifex (*Spinifex sericeus*), Plume Grass (*Dichelachne crinita*), and Sand Couch (*Zoysia macrantha*); the native herbs, Pig Face (*Carpobrotus glaucescens*), and Native Geranium (*Pelargonium australe*), Knobby Club Rush (*Isolepsis nodosa*), and Australian Stonecrop (*Crassula sieberiana*); and exotic weeds such as Mother-of-Millions (*Bryophyllum delagoense*), Turkey Rhubarb (*Acetosa sagittata*), Sea Rocket (*Cakile edentulata var edentulata*), Dock (*Rumex* sp.), Fireweed (*Senecio madagascariensis*), African Lovegrass (*Eragrostis curvulata*), Bridal Creeper (*Asparagus asparagoides*) and *Vulpia muralis*.

The presence and abundance of these species has varied throughout the survey period: African Lovegrass, Knobby Club Rush, Sand Couch and Hairy Spinifex were recorded as absent in some plots in April 2006 compared to October 2005; whereas, Sea Rocket, Fireweed, Dock, Plume Grass, African Lovegrass, Australian Stonecrop and *Vulpia muralis* were recorded for the first time in October 2006.

Panic Veldt Grass (*Ehrarta erecta*) was sub-dominant in Plot 5 in October 2005, absent in April 2006, but was abundant (10 to 25% of all individuals) in Plots 4 and 5 in October 2006. It should be noted that this species was probably present as rhizomes throughout the entire period but was not detected at times when its leaves had died back. Eight groundcover species were recorded for the first time in April 2007; although five other species were absent from one or more plots after being recorded in October 2006. The variation observed over the five survey rounds suggests that populations of herbs and grasses fluctuate significantly through time within this community.

The native sedge, *Carex* sp., declined significantly in abundance (Braun-Blanquet rating from 3 to 1) in Plot 5 between April and October 2006 and was absent in April 2007; this species has not been recorded in the other plots.

Vegetation plots in Penrhyn Estuary are generally described as having low species diversity, low groundcover and moderate shrub density. Groundcover density increased in Plots 4 and 5 in October 2006 compared to the previous three rounds. This reflects an increase in the overall abundance and diversity of herbs and grasses but with dominance of cover by the exotic Panic Veldt Grass.

The canopy and understorey in all plots were disturbed and there is moderate to high density of tracks in the vicinity of all plots. Species composition and abundance is therefore likely to be affected by ongoing human influences as well as environmental factors.

A large amount of woody debris, the majority of which was recorded on *Melaleuca ericifolia* and Bitou Bush, was noted in all plots during all monitoring rounds. Woody debris was also noted on *Leptospermum laevigatum*, *Lantana camara*, *Isolepsis nodosa*, *Acacia longifolia* var*.sophorae* and *Banksia integrifolia*.

Dead individuals of Bitou Bush, *L.camara*, *A.longifolia* var*.sophorae* were noted in all rounds. However, all of these species are short lived, colonising species. Increases in cover, abundance and numbers of seedlings were also observed throughout the survey period. Observed variation in growth and senescence probably reflect natural population dynamics.

Dead individuals of *Banksia* spp*.* were also observed in all rounds and are discussed in detail below.

Banksia survey

Banksia spp. showing signs of senescence were surveyed and mapped in July and October 2006, and April 2007. Data on species, size, health and signs of stress were recorded and are summarised in the table below. The distribution of senescent *Banksia* spp. recorded during April 2007 is shown in Fig. 15.

There are two species of *Banksia* present: *Banksia integrifolia* (Coastal Banksia) and *B.serrata* (Old Man Banksia). The majority of dead and stressed individuals were *B.integrifolia*; however, this species is also more numerous overall. Ten of the dead *Banksia* spp. observed were located on the eroded southern edge of the dune and had probably been killed by seawater after collapse of the dune.

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The number of dead *Banksia* spp. increased between July 2006 and October 2006, and also prior to the final survey period in April 2007. There were 48 additional dead *Banksia* spp. counted during the final round of surveying, of which one was directly attributed to dune erosion. Thirteen of the 'stressed' trees in the October 2006 survey were dead by April 2007, and the number of *Banksia* spp. showing signs of stress also increased by nine over the same period. This demonstrates that senescence of *Banksia* spp. within the dune vegetation is ongoing.

Number of Dead and Stressed Banksia spp. in Dune Vegetation at Penrhyn Estuary

	July 2006	October 2006	April 2007
Dead	28	41	88
Dead due to dune erosion	5	9	10
Long dead	6	8	8
Total dead	**39**	**58**	**106**
Slight stress			1
Yellowing leaves	2	4	2
Defoliation	5	6	1
Dieback	9	10	14
Severe dieback	7	2	
Total showing signs of stress	**23**	**22**	**18**

Aerial Photo Interpretation

Classification of ground cover types using GIS tools was completed for the 2001, 2005 and 2006 aerial photographs of Penrhyn Estuary. Ground cover was classified into two types: vegetation (including trees, shrubs and grasses), and bare sand. The total area classified on each aerial photograph was approximately the same (see tables below).

Results from Pixel-Based Classification of Ground Cover

Ground cover type	2001 image		2005 image		Temporal difference	
	Area (m^2)	% of total area	Area (m^2)	% of total area	Area (m^2)	% change
vegetation	82813	84	83521	85	708	0.85
bare sand	15614	16	14888	15	-726	-4.76
total area	**98426**	**100**	**98409**	**100**	**-18**	**-0.02**

Ground cover type	2005 image		2006 image		Temporal difference	
	Area (m^2)	% of total area	Area (m^2)	% of total area	Area (m^2)	% change
vegetation	83521	85	94425	96	10904	13.06
bare sand	14888	15	3953	4	-10935	-73.45
total area	**98409**	**100**	**98378**	**100**	**-31**	**-0.03**

A small difference in the spatial extent of the two ground cover types was evident between the 2001 and 2005 aerial photographs, although the magnitude of the change could be attributed to analysis error. Qualitative assessment of those aerial photographs suggests that the vegetation appeared to be thinning and areas of Bitou Bush infestation were evident (URS 2005b).

Between 2005 and 2006, the spatial extent of vegetation covered area increased and open sand area decreased by almost 11,000 m^2 (or 13.06 and >73% respectively). The reduction in open sand is mainly attributed to the increase in groundcover plants in general and the emergence of nine new species (mainly noxious weeds) that were first recorded during the April 2007 surveys. Unfortunately, the GIS-based classification method could not easily differentiate between trees, shrubs and grasses thereby preventing an assessment of temporal change in the relative proportions of each vegetation type.

3.4 Saltmarsh

Three species of saltmarsh plants were found at the monitoring sites. *Suaeda australis* was present at all sites throughout the monitoring program. *Sarcocornia quinqueflora* was not present at Penrhyn Site 4 and was only found twice at Penrhyn Site 3. *Sporobolus virginicus* was not recorded at Penrhyn Site 2 and was only found once at Penrhyn Site 4.

Saltmarsh beds at Penrhyn Sites 1, 2 and 4 were dominated by *S.australis*, whereas Site 3 was dominated by *S.virginicus*. The sites at Woolooware were dominated by *S.quinqueflora* whereas the two sites at Quibray were dominated by *S.quinqueflora* and *S.australis*, respectively.

3.4.1 Spatial Extent

The combined spatial extent of all saltmarsh communities in Penrhyn Estuary varied over time.

Areal Extent of Saltmarsh at Penrhyn Estuary Over Time

Survey 1	Survey 2	Survey 3	Survey 4	Survey 5
July 2005	October 2005	April 2006	October 2006	April 2007
6435 m^2	6558 m^2	6479 m^2	7846 m^2	7115 m^2

The area of saltmarsh habitat remained fairly stable between Surveys 1 and 3 (Fig.16a-c); with slight differences attributed to measurement error. A 21% increase in area was apparent during Survey 4 (October 2006) and is attributed to the colonisation of bare space between the access road and Springvale Drain at the eastern margin of the site (Fig.16d). Eleven separate saltmarsh habitats were identified at that time, comprising dispersed patches along the southern shoreline and more extensive patches along the northern and eastern margin of the estuarine mudflats. During Survey 5 (April 2007) a new habitat type – mangrove-saltmarsh – was identified (Fig.16e); classification using this new habitat type resulted in a 9% reduction of the total area categorised as purely saltmarsh.

Full statistical analysis of saltmarsh survey data is provided in the TEL report (Appendix A). Major findings are discussed below.

3.4.2 Saltmarsh Assemblages

Saltmarsh assemblages at Penrhyn were significantly different from those averaged across the Control locations during each survey. However, the magnitude of difference between assemblages did not change over time; average dissimilarity at all locations varied from 47.6% to 52.1%.

The major features that contributed to dissimilarity between assemblages did vary over the course of the monitoring period. ‘Good’ *S.virginicus* and *S.quinqueflora* were identified as principal discriminators during all five surveys; whereby ‘good’ *S.virginicus* was always more abundant at Penrhyn than at the Controls, and ‘good’ *S.quinqueflora* was more abundant at Controls than at Penrhyn. ‘Good’ *S.australis and* ‘poor’ *S.quinqueflora* were also consistent discriminators in four of the surveys, with ‘good’ *S.australis* being more abundant at Penrhyn and ‘poor’ *S.quinqueflora* being more abundant at the Controls.

3.4.3 Temporal Trends in Health

Saltmarsh plants were categorised as ‘good’, ‘poor’ or ‘dead’ in an effort to monitor changes in the health of plants throughout the monitoring period.

General temporal trends in the proportion of ‘good’ *S.australis* and ‘good’ *S.virginicus* over the duration of the monitoring period differed between sites (Fig.17a and 18a, respectively), although, no obvious trends in the percentage cover of ‘good’ *S.australis* were evident at any of the Penrhyn sites. In contrast, there was a gradual increase in percentage cover of ‘good’ *S.australis* at the Woolooware and Quibray sites, but only during the period up to Survey 3 (April 2006); thereafter the percentage cover was relatively stable. A slight increase in percentage cover of ‘good’ *S.virginicus* was evident at Penrhyn Site 3 and Quibray Site 2 between Surveys 1 and 4 (July 2005 and October 2006, respectively), but there were no distinct patterns at the other sites (Fig.18).

Temporal trends in ‘good’ and ‘dead’ *S.quinqueflora* were not significant at Penrhyn or Control sites (Fig.19). The percentage cover of ‘good’ *S.quinqueflora* was initially small at all sites but a marked increase was evident at most sites between Surveys 2 and 3 (October 2005 and April 2006, respectively), followed by relatively stable cover. The temporal variation of ‘poor’ *S.quinqueflora* (decreasing over time) was significant at Control sites but not at Penrhyn.

Due to obvious differences in saltmarsh vegetation at Penrhyn Estuary sites, statistical analysis was undertaken in two sets: Penrhyn Sites 1 and 2 compared with Control sites, and Penrhyn Sites 3 and 4 compared with Control sites. Each analysis set is discussed separately below.

Comparison of Penrhyn Sites 1 and 2 with Woolooware and Quibray

A matrix of statistical results derived from comparisons of percentage cover of the three health categories for the three species of saltmarsh at various levels of scale is provided below. Note that areas with significant temporal variation (SIG) are highlighted and the relative variability between Penrhyn Sites 1 and 2 and Controls is provided (based on results of two-tailed F-tests); where P>C means temporal variability in percentage cover at Penrhyn Sites 1 and 2 was significantly higher than variability averaged across all Controls, P=C means temporal variability was not significantly different between Penrhyn Sites 1 and 2 and Controls, and P<C means temporal variability in percentage cover at Penrhyn Sites 1 and 2 was significantly lower than variability averaged across all Controls.

Transects

Significant temporal variation in percentage cover of ‘good’ and ‘dead’ *S.australis* was evident among Penrhyn transects but not among Control transects . This trend is highlighted by the higher temporal variability found in transects at Penrhyn Sites 1 and 2 than in transects averaged across all Control locations (P>C). In contrast, the temporal variation in ‘poor’ *S.australis* was not significant among either set of transects; with no difference apparent in comparisons between transects at Penrhyn Sites 1 and 2 and the average across Control locations (P=C).

The temporal variation in percentage cover of ‘good’ *S.virginicus* was not significantly different among either Penrhyn Sites 1 and 2 or Control transects; however, temporal variability averaged among all Control transects was significantly greater than among Penrhyn Sites 1 and 2 transects (P<C).

At the scale of transects, the temporal variation in percentage cover of ‘good’, ‘poor’ and ‘dead’ *S.quinqueflora* was not significant at either Penrhyn Sites 1 and 2 or the Controls. In addition, the temporal variability in the three health categories of *S.quinqueflora* among transects at Penrhyn Sites 1 and 2 was not significantly different from that averaged across all Control transects (P=C).

Comparisons of Temporal Variability in Percentage Cover of Saltmarsh Species Penrhyn Sites 1 and 2 versus Woolooware and Quibray

Saltmarsh species	*Suaeda australis*			*Sporobolus virginicus*			*Sarcocornia quinqueflora*		
Plant health	Good	Poor	Dead	Good	Poor	Dead	Good	Poor	Dead
Among Penrhyn Sites 1 + 2 transects	SIG	ns	SIG	ns	-	-	ns	ns	ns
Among Control transects	ns	ns	ns	ns	-	-	ns	ns	ns
Between Penrhyn Sites 1 + 2 and Control transects	P>C	P=C	P>C	P<C	-	-	P=C	P=C	P=C
Among Penrhyn Sites 1 + 2	ns	ns	ns	ns	-	-	ns	ns	ns
Among Control sites	ns	ns	ns	ns	-	-	ns	SIG	ns
Between Penrhyn Sites 1 + 2 and Control sites	P=C	P=C	P=C	P=C	-	-	P=C	P<C	P=C
Among Control locations	ns	ns	ns	ns	-	-	SIG	SIG	ns
Between Penrhyn Sites 1 + 2 and Control locations	P>C	P=C	P=C	P=C	-	-	P=C	P=C	P=C

'SIG' = significant, 'ns' = not significant; '-' = no data, 'P' = Penrhyn, 'C'= Control
shaded cells denote statistically significant results

Sites

Temporal variation in percentage cover of 'good', 'poor' and 'dead' *S.australis* was not significantly different between Penrhyn Sites 1 and 2 or sites at Control locations, and there was no significant difference in temporal variability in percentage cover of any of the health categories between Penrhyn Sites 1 and 2 and the average across all Control sites (P=C).

The temporal variation in percentage cover of 'good' *S.virginicus* was not significantly different among either Penrhyn Sites 1 and 2 or Control sites; nor was there significant differences in temporal variability averaged among all Control sites compared to Penrhyn Sites 1 and 2 (P=C).

At the scale of sites, the temporal variation in percentage cover of 'good' and 'dead' *S.quinqueflora* was not significant at Penrhyn Site 1 and 2 or the Controls. In addition, the temporal variability in 'good' and 'dead' *S.quinqueflora* at the Penrhyn sites did not differ from the average variability across all Control sites (P=C). However, temporal variability in 'poor' *S.quinqueflora* was significant among Control sites though not among Sites 1 and 2 at Penrhyn, with temporal variability in 'poor' *S.quinqueflora* being greater among Control sites than among Penrhyn Site 1 and 2 (P<C).

Locations

The temporal variation in percentage cover of 'poor' and 'dead' *S.australis* did not differ among Control locations and changes in these variables at Penrhyn Sites 1 and 2 were not different from those averaged across Control locations (P=C). The temporal variation in percentage cover of 'good' *S.australis* also did not differ among Control locations, but the temporal variation at Penrhyn Sites 1 and 2 was higher than the average variation across all Control locations (P>C). SNK tests showed that there was significantly more 'good' *S.australis* averaged across Penrhyn Sites 1 and 2 than at either Control locations during surveys 1, 2, 3 and 5 (Fig.20a).

The temporal variation in percentage cover of ‘good’ *S.virginicus* (Fig.18) and ‘dead’ *S.quinqueflora* (Fig.19c) did not differ among Control locations, nor did the temporal variability at Penrhyn Sites 1 and 2 differ from variability at the Controls (P=C). In contrast, the temporal variation in percentage cover of ‘good’ and ‘poor’ *S.quinqueflora* differed significantly among Control locations, but temporal variability at Penrhyn Sites 1 and 2 did not differ from variability averaged across the Controls (P=C).

Comparison of Penrhyn Sites 3 and 4 with Woolooware and Quibray

Temporal variation in *S.quinqueflora* was not examined because this species was either absent or scarce at Penrhyn Sites 3 and 4.

A matrix of statistical results derived from comparisons of percentage cover of the three health categories for the two species of saltmarsh at various levels of scale is provided below. Note that areas with significant temporal variation (SIG) are highlighted and the relative variability between Penrhyn Sites 3 and 4 and Controls is provided (based on results of two-tailed F-tests); where P>C means temporal variability in percentage cover at Penrhyn Sites 3 and 4 was significantly higher than variability averaged across all Controls, P=C means temporal variability was not significantly different between Penrhyn Sites 3 and 4 and Controls, and P<C means temporal variability in percentage cover at Penrhyn Sites 3 and 4 was significantly lower than variability averaged across all Controls.

Comparisons of Temporal Variability in Percentage Cover of Saltmarsh Species Penrhyn Sites 3 and 4 versus Woolooware and Quibray

Saltmarsh species	*Suaeda australis*			*Sporobolus virginicus*			*Sarcocornia quinqueflora*		
Plant health	Good	Poor	Dead	Good	Poor	Dead	Good	Poor	Dead
Among Penrhyn Sites 3 + 4 transects	ns	ns	ns	ns	-	-	-	-	-
Among Control transects	ns	ns	ns	ns	-	-	-	-	-
Between Penrhyn Sites 3 + 4 and Control transects	P=C	P<C	P=C	P=C	-	-	-	-	-
Among Penrhyn Sites 3 + 4	ns	ns	ns	ns	-	-	-	-	-
Among Control sites	ns	ns	ns	ns	-	-	-	-	-
Between Penrhyn Sites 3 + 4 and Control sites	P=C	P=C	P=C	P=C	-	-	-	-	-
Among Control locations	ns	ns	ns	ns	-	-	-	-	-
Between Penrhyn Sites 3 + 4 and Control locations	P>C	P=C	P=C	P=C	-	-	-	-	-

‘ns’ = not significant; ‘-‘ = no data, ‘P’ = Penrhyn, ‘C’= Control
shaded cells denote statistically significant results

Transects

Significant temporal variation in percentage cover of ‘good’, ‘poor’ and ‘dead’ *S.australis* and ‘good’ *S.virginicus* was not evident among the Penrhyn Sites 3 and 4 transects nor among Control transects. The temporal variability in ‘good’ *S.australis*, ‘good’ *S.virginicus* and ‘dead’ *S.australis* among Penrhyn Sites 3 and 4 transects was not significantly greater than the average of all Control transects (P=C). However, the temporal variability in ‘poor’ *S.australis* among all Control transects was significantly greater than that among Penrhyn Sites 3 and 4 transects (P<C).

Sites

The temporal variation in percentage cover of 'good', 'poor' and 'dead' *S.australis* and 'good' *S.virginicus* was not significant among Penrhyn Site 3 and 4 or Control sites. There was also no indication that the temporal variability in these plants differed among Penrhyn Site 3 and 4 and the average across all Control sites (P=C).

Locations

The temporal variation in percentage cover of 'poor' and 'dead' *S.australis* did not differ among Control locations and changes in percentage cover at Penrhyn Sites 3 and 4 were not different from those averaged across all Control locations (P=C). The temporal variation in percentage cover of 'good' *S.australis* also did not differ among Control locations, but the changes at Penrhyn Sites 3 and 4 did differ from those at the Control locations (P>C). In this case, SNK tests showed that there was significantly more 'good' *S.australis* averaged across Penrhyn Sites 3 and 4 than at either Control locations during surveys 1, 3 and 5 (Fig.20b).

3.4.4 Saltmarsh Plant Height

Temporal variation in the height of saltmarsh plants was not consistent across all transects, sites or locations through time. A matrix of statistical results derived from comparisons of temporal variation in heights of the three species of saltmarsh at various levels of scale is provided below. Note that areas with significant temporal variation (SIG) are highlighted and the relative variability between Penrhyn site pairs (1+2 or 3+4) and Controls is provided (based on results of two-tailed F-tests); where P>C means temporal variability in height at Penrhyn site pair was significantly higher than variability averaged across all Controls, P=C means temporal variability was not significantly different between Penrhyn site pair and Controls, and P<C means temporal variability in heights at Penrhyn site pair was significantly lower than variability averaged across all Controls.

Comparisons of Temporal Variability in Height of Saltmarsh Species
Penrhyn Sites 1+2 and 3+4 versus Woolooware and Quibray

Saltmarsh species	*Suaeda australis*		*Sporobolus virginicus*		*Sarcocornia quinqueflora*	
Penrhyn site pairs	**1+2**	**3+4**	**1+2**	**3+4**	**1+2**	**3+4**
Among Penrhyn Sites transects	ns	ns	ns	ns	ns	ns
Among Control transects	ns	ns	SIG	ns	ns	SIG
Between Penrhyn Sites and Control transects	P=C	P=C	P=C	P=C	P=C	P<C
Among Penrhyn Sites	ns	ns	ns	ns	ns	ns
Among Control sites	ns	ns	ns	ns	ns	ns
Between Penrhyn Sites and Control sites	P=C	P=C	P=C	P=C	P=C	P<C
Among Control locations	ns	ns	SIG	ns	ns	ns
Between Penrhyn Sites and Control locations	P=C	P>C	P=C	P=C	P=C	P<C

'SIG' = significant, 'ns' = not significant; 'P' = Penrhyn, 'C'= Control
shaded cells denote statistically significant results

The temporal variation in heights of *S.australis* was not significantly different among transects, sites or locations at Penrhyn Sites 1 and 2, 3 and 4 or Control locations. Temporal variability among transects, sites and locations was not significantly different at Penrhyn Sites 1 and 2 compared to the average across all Control locations (P=C). However, temporal variability in the heights of *S.australis* was greater for the average of Penrhyn Sites 3 and 4 when compared to the average across all Control locations (P>C).

Significant differences in the temporal variability of heights of *S.virginicus* were apparent at the Control locations when considering transect and location scales. However, the differences were not significantly different when comparing Penrhyn site pairs (1 and 2 or 3 and 4) with variability averaged across the Control locations at any scales (P=C).

The temporal variation in heights of *S.quinqueflora* was not significantly different among transects, sites or locations at Penrhyn Sites 1 and 2 or 3 and 4. Temporal variability among transects, sites and locations was not significantly different at Penrhyn Sites 1 and 2 compared to the average across all Control locations (P=C). However, there were significant differences in the temporal variation in heights among transects at the Control locations, and at all scales, the temporal variation in heights was less when averaged for Penrhyn Sites 3 and 4 than the average across all Control locations (P<C).

3.5 Seagrass

Seagrass in Penrhyn Estuary consists mainly of *Zostera capricorni* that was found in discrete patches along the margins of the mudflats in areas exposed at low tides. Seagrasses were found in two habitats - open mudflat and mudflats at the seaward margin of mangroves (with associated pneumatophores).

3.5.1 Spatial Extent

The distribution and total areal extent of seagrass varied between monitoring rounds and is summarized below:

Areal Extent of Seagrass Beds at Penrhyn Estuary Over Time

	Survey 1	Survey2	Survey 3	Survey 4	Survey 5
	July 2005	October 2005	April 2006	October 2006	April 2007
open seagrass beds	572 m^2	1306 m^2	1492 m^2	37 m^2	17 m^2
seagrass + mangrove	293 m^2	263 m^2	278 m^2	332 m^2	285 m^2
total cover	**865 m^2**	**1569m^2**	**1770 m^2**	**369 m^2**	**302 m^2**

During the initial survey (July 2005), a single bed of seagrass was found along the southern shore of the estuary, seaward of mangroves, and extending into the mangrove pneumatophore zone (Fig.16a). Survey 2 (October 2005), revealed a 128% increase in the areal extent of seagrasses with a large bed located on the northern shore and a smaller bed on the central estuary mudflat (Fig.16b). Results from Survey 3 (April 2006) showed little net change of seagrass area; however, the northern bed increased in size, the southern bed decreased in size and the small bed on the central estuary mudflat was not found (Fig.16c). Also, a new seagrass bed was found along the eastern shore of the northern estuary arm leading from Floodvale Drain (Fig.16c). A marked decline in seagrass coverage was recorded during Survey 4 (October 2006) with only small remnant patches of the northern seagrass bed evident, and a significant decline in the size of the southern beds (Fig.16d). Results of the final survey (April 2007), show that the only open seagrass bed observed in the estuary area is a small patch along the northern shore (Fig.16e).

The absence of the northern and central seagrass beds in Round 1 and again in Round 4 highlights the variable nature of seagrass distribution in Penrhyn Estuary.

The seagrass bed in the mangrove pneumatophore area on the southern margin of the estuary varied only slightly in size throughout the monitoring period (±20%) with differences attributed to either natural variation (e.g. seasonality) or the difficulty of defining boundaries. Observed changes between sampling periods were both positive (i.e. increased area) and negative (i.e. decreased area) with no distinct trend through time.

3.5.2 Density

The density of *Z.capricorni* seagrass within the beds at Penrhyn Estuary and control locations varied through time (Fig.21a). Between Survey 1 (July 2005) and Survey 2 (October 2005) the seagrass densities increased at all three locations; the increase was particularly evident at Penrhyn Estuary sites and is consistent with the observed expansion of seagrass areal extent. Seagrass density declined at all locations between Survey 2 (October 2005) and Survey 3 (April 2006); especially noticeable at Penrhyn Sites 3 and 4 where seagrass beds were absent. By Survey 4 (October 2006), seagrass was present at only one of the four Penrhyn sites (Site 1); with increased density consistent with density increases at both control locations. During Survey 5 (April 2007), *Z.capricorni* was still present at Penrhyn Site 1, but at smaller densities than previously, and was found at only one of the two control locations (South Towra).

3.5.3 Leaf Number

The pattern of change in number of leaves per shoot at Penrhyn Site 1 was similar to that observed at Quibray Bay (Fig.21b). At these locations, the number of leaves per shoot was similar during the first two surveys, showed a marked decline between Survey 2 and Survey 3, and a slight increase between Surveys 3 and 4. During Survey 5, a marked increase in the number of leaves per shoot was observed at Penrhyn Site 1 but there was little change at South Towra (and no *Z.capricorni* was found at Quibray Bay).

3.5.4 Leaf Length

Substantial changes in the length of seagrass leaves over time were evident at Penrhyn Site 1 and Quibray Bay, with smaller changes evident at South Towra (Fig.22a). The pattern of change was not consistent at all sites:

Between Surveys 1 and 2, there was a marked decline in mean leaf length at Penrhyn, but no change at Quibray Bay and South Towra;

Between Surveys 2 and 3, a substantial increase in mean length was evident at Penrhyn Site 1 and Quibray but not at South Towra. The marked difference in mean length that is evident among the three Penrhyn Estuary sites probably reflects the younger age of seagrass plants in the 'new' *Z.capricorni* beds at Sites 2 and 3;

Between Surveys 3 and 4, there was a marked decrease in leaf length at Penrhyn Site 1 and Quibray, but a small increase in length at South Towra; and

Between Surveys 4 and 5, there was a marked increase in length at Penrhyn Site 1, but little change at South Towra (and no *Z.capricorni* beds were found at Quibray).

3.5.5 Leaf Width

The changes in leaf widths that occurred at the three locations did not mirror the changes in leaf length (Fig.22b). At Penrhyn Site 1, mean leaf width remained relatively stable throughout the first three surveys, increased between Surveys 3 and 4 and remained stable between Surveys 4 and 5. At South Towra, mean leaf width decreased slightly between Surveys 1 and 2, but remained stable until Survey 5 when there was a marked increase. At Quibray Bay, leaf width doubled between Surveys 1 and 2 and then remained relatively stable. Mean leaf width was similar at the four sites in Penrhyn Estuary during Survey 2, but there was a marked decrease in width at Sites 2 and 4 between Surveys 2 and 3.

3.6 Mangroves

The mangrove community at Penrhyn Estuary is predominantly composed of the grey mangrove (*Avicennia marina)* with a few river mangroves (*Aegiceras corniculatum)*. Mangroves in Penrhyn Estuary are mainly found along the southern shore of the inner estuary. A review of the areal extent of mangrove cover using aerial photographs of Penrhyn Estuary shows an increasing trend over time which is believed to be due to gradual encroachment of mangrove seedlings into saltmarsh and seagrass habitat.

Areal extent of mangroves at Penrhyn Estuary over time

Survey 1	Survey 2	Survey 3	Survey 4	Survey 5
July 2005	October 2005	April 2006	October 2006	April 2007
7659 m^2	7951 m^2	8807 m^2	9327 m^2	10200 m^2

Mangrove coverage has steadily increased in Penrhyn Estuary throughout the monitoring period. The areal extent of mangrove habitat has increased by 4, 11, 6 and 9% between each succeeding monitoring event respectively (i.e. between 1 and 2, 2 and 3, 3 and 4, 4 and 5); with an overall increase of 33% between July 2005 and April 2007. This increase in coverage is evident even with the distinction of a new habitat type – mangrove / saltmarsh – that was described in the final survey (April 2007). If this new habitat is included with the mangrove coverage estimates, the total area in the final survey was 12,064 m^2; an increase of more than 57% since the first survey in July 2005.

Changes in the density of pneumatophores at Penrhyn Site 1 did not mirror those observed at the Control locations (Fig.23). At Penrhyn Site 1, there was a marked decrease in the density of pneumatophores between Surveys 1 and 2, a significant increase in density between Surveys 2 and 3, little change in density between Surveys 3 and 4 and a decrease between Surveys 4 and 5. At South Towra and Quibray, there was an increase in the density of pneumatophores between Surveys 1 and 2. At South Towra, there was a gradual decline in density thereafter, but at Quibray there was a marked decline between Surveys 2 and 3 followed by a substantial increase between Surveys 3 and 4. Density of mangrove pneumatophores at Penrhyn Site 1 was greater than at control locations for all surveys except Survey 2. No pneumatophores were found in the new Penrhyn seagrass beds recorded during Survey 2, but a few were found at Site 2 during Survey 3 (April 2006).

3.7 Wading Shorebirds

The full *Bird Monitoring Final Report, July 2007* from Avifauna Research & Services is provided in Appendix B. Major findings are summarised below.

A total of 51 species of birds were observed at Penrhyn Estuary between September 2005 and April 2007 (see table below). Some migratory shorebirds were late leaving Penrhyn Estuary during the last season of the monitoring program (April/May 2007) which resulted in larger numbers of birds, such as the Bar-tailed Godwit, evident in survey results. More birds were observed in full breeding plumage (normally acquired along the migration routes) than in previous years. All birds appeared to be in good physical condition with fat deposits approaching those of pre-migratory birds, and had presumably delayed their departure due to unfavourable weather conditions.

Counts of all shorebirds during 2006/07 were similar to those in the previous year of monitoring for most species. However, an increase in the maximum count of Sharp-tailed Sandpipers 72 (22), Red-necked Stints 63 (45) and Red-capped Plover 14 (8) were noted (numbers in brackets are maximum counts during 2005/06). Little Terns increased in numbers and frequency of visits, and successfully nested at the mouth of Penrhyn Estuary for the first time for many years; raising 14 chicks to fully flying stage. The seven bird species considered as key indicators for Penrhyn Estuary (bold text in the species table above) exhibited various temporal trends in population numbers:

- **Sharp-tailed Sandpiper (*Calidris acuminate*)**
  Numbers of Sharp-tailed Sandpipers increased during the second year of this monitoring program, with significantly more birds observed at Penrhyn Estuary than at other survey times.
- **Red Knot (*Calidris canutus*)**
  Botany Bay is known as an important staging area for Red Knots along their migration path to Victoria and New Zealand, although numbers have been in decline for a number of years. These birds only spend a few days at Penrhyn Estuary, and significantly fewer birds were counted during 2006/07 (seven birds) compared to 2005/06 (18 birds). However, due to their short residence time, higher numbers may have been missed between survey events.
- **Curlew Sandpiper (*Calidris ferruginea*)**
  Most of the Curlew Sandpipers associated with Botany Bay occur at Penrhyn Estuary. This species, more than most others, has declined in Botany Bay; however, such declines are evident throughout south-eastern Australia for unknown reasons and are believed to represent a broad population-level decline.
- **Red-necked Stint (*Calidris ruficollis*)**
  The Red-necked Stint is a migratory species that is present in reasonably high numbers in Penrhyn Estuary. This species has shown an overall increasing abundance trend at Penrhyn Estuary over the past year.
- **Double-banded Plover (*Charadrius bicinctus*)**
  Penrhyn Estuary has been identified as the main site in Botany Bay for Double-banded Plovers. The population has been comparatively steady in recent years with maximum counts of between 50 and 60 birds.
- **Bar-tailed Godwit (*Limosa lapponica*)**
  The Bar tailed Godwit is the most numerous arctic-breeding migratory bird present in the estuary. The counts of this species have remained relatively constant over the past five years (apart from seasonal variation due to migratory activity), although there appears to be a gradual decline at Penrhyn Estuary. In addition, it appears that this bird's preferred feeding habitat has moved from the upper and outer reaches of the estuary during early monitoring surveys to the outer reaches in more recent surveys.

Section 3 Monitoring Results

Birds recorded at Penrhyn Estuary, September 2005 to June 2007

Scientific name	Common name	max count	resident / migratory	listing
Tringa nebularia	Common Greenshank	1	M	J/C/EPBC
Actitis hypoleucos	Common Sandpiper	1	M	J/C/EPBC
Arenaria interpres	Ruddy Turnstone	1	M	J/C/EPBC
Calidris acuminate	**Sharp-tailed Sandpiper**	**72**	M	J/C/EPBC
Calidris alba	Sanderling	3	M/Th	J/C/EPBC
Calidris canutus	**Red Knot**	**18**	M	J/C/EPBC
Calidris ferruginea	**Curlew Sandpiper**	**16**	M	J/C/EPBC
Calidris malanotos	Pectoral Sandpiper	1	M	J/C/EPBC
Calidris ruficollis	**Red-necked Stint**	**63**	M	J/C/EPBC
Calidris tenuirostris	Great Knot	2	M/Th	J/C/EPBC
Charadrius bicinctus	**Double-banded Plover**	**54**	M	EPBC
Charadrius ruficapillus	Red-capped Plover	14	R	
Elseyornis melanops	Black-fronted Dotterel	2	R	
Haemotopus fuliginosus	Sooty Oystercatcher	1	R/Th	
Haemotopus longirostris	Pied Oystercatcher	2	R/Th	
Heteroscelus brevipes	Grey-tailed Tattler	3	M	J/C/EPBC
Himantopus himantopus	Black-winged Stilt	12	R	
Limosa lapponica	**Bar-tailed Godwit**	**162**	M	J/C/EPBC
Pluvialis fulva	**Pacific Golden Plover**	**18**	M	J/C/EPBC
Pluvialis squatarola	Grey Plover	1	M	J/C/EPBC
Xenus terek	Terek Sandpiper	1	M/Th	J/C/EPBC
Numenius madagascariensis	Eastern Curlew	1	M	J/C/EPBC
Numenius phaeopus	Whimbrel	1	M	J/C/EPBC
Vanellus miles	Masked Lapwing	2	R	
Other Birds Associated with Wetlands				
Anas superciliosa	Pacific Black Duck	2	R	
Anas castanea	Chestnut Teal	6	R	
Anhinga melanogaster	Darter	1	R	
Ardea novaehollandiae	White-faced Heron	1	R	
Ardea ibis	Cattle Egret	4	M	J/C/EPBC
Egretta alba	Great Egret	2	M	J/C/EPBC
Egretta garzetta	Little Egret	1	R	
Butorides striatus	Striated Heron	2	R	
Threskiornis molucca	Australian White Ibis	16	R	
Platelea regia	Royal Spoonbill	1		
Pelecanus conspicillatus	Australian Pelican	12	R	
Phalacrocorax carbo	Great Cormorant	2	R	
Phalacrocorax melanoleucos	Little Pied Cormorant	4	R	
Phalacrocorax sulcirostris	Little Black Cormorant	55	R	
Phalacrocorax varius	Pied Cormorant	3	R	
Sterna nilotica	Gull-billed Tern	2	R	
Sterna albifrons	Little Tern	48	M/En	J/C/EPBC
Sterna bergii	Crested Tern	24	R	
Sterna caspia	Caspian Tern	2	M	J/C/EPBC
Sterna striata	White-fronted Tern	1	M	EPBC
Sterna hirundo	Common Tern	130	M	J/C/EPBC
Chlidonias leucopterus	White-winged Black Tern	1	M	J/C/EPBC
Chlidonias hybridus	Whiskered Tern	1	R	
Larus dominicanus	Kelp Gull	2	R	
Larus novaehollandiae	Silver Gull	410	R	
Falco peregrinus	Peregrine Falcon	1	R	
Falco berigora	Brown Falcon	1	R	

M = migratory R = resident
En, Th = listed under the TSC Act as Endangered or Threatened
J/C/EPBC = listed under JAMBA (Japan), CAMBA (China) or EPBC Act (Australia) as migratory species

- **Pacific Golden Plover (*Pluvialis fulva*)**

  Since the 1970s and 1980s, the Pacific Golden Plover has declined in numbers in Botany Bay. This species has been associated with Penrhyn Estuary since the construction of the Sydney Airport Parallel Runway, when habitat was lost in the north-western part of Botany Bay. Counts at Penrhyn Estuary have varied considerably from no birds during April to August 2006, followed by up to 11 birds during the final six months of this monitoring program.

The Bar-tailed Godwit was used as the indicator species for the assessment of bird body condition. The body fat rating is from one to five, with one being the fat free weight of the bird and five being the maximum weight prior to migration. All birds were above the minimum value of one; however, none had a value of five, suggesting that Penrhyn Estuary is not the main launch site for migration of this species to the Yellow Sea.

3.8 Quality Control Elements

Data quality control elements for the monitoring program included the equipment used in fieldwork and the collation, investigation and interpretation of field data. Similar procedures were employed by URS, TEL and Avifauna Research & Services.

The field equipment included quadrats for vegetation monitoring, water level probes and water quality meters. Before use, all equipment was visually inspected to ensure that it was in good repair, functional and accurate. Water quality meters were calibrated and checked daily before sample collection and measurement. Calibration of water quality meters was recorded on data sheets (Appendix C). Water quality parameters were recorded on URS Monitoring Well data sheets.

All field and analytical data were appropriately reduced and validated prior to reporting. Records and numerical calculations were legible and sufficiently complete to permit reconstruction of the work by a qualified individual other than the originator.

The originating person reduced and validated the data package to ensure that:

- Appropriate standard operating procedures had been followed;
- Field sample results were correct and complete;
- QA check sample results were correct and complete; and
- Documentation was complete.

Once data were input into the appropriate spreadsheet, a second hard copy was maintained with the project file. The spreadsheet was then checked by an independent reviewer. If the reviewer identified possible validation errors in relation to non-conformance with the above checklist, the data was flagged and appropriate corrective procedures were initiated. Flagged data errors were brought to the attention of the originating person so that the cause of the errors could be addressed. Once the originating person had re-validated the data package, it was then passed onto the project manager for independent review. In the event that further errors were identified, the data were more thoroughly checked than would otherwise be necessary. A hard copy of all data and calculations, where appropriate, is maintained on file for review should electronic data become corrupted or lost.

Section 4 Discussion

Groundwater containment commenced prior to the start of ecological monitoring, thereby preventing the collection of specific data to illustrate the distribution and health of receptors within Penrhyn Estuary before changes to the groundwater flow occurred. The design of the monitoring program has therefore incorporated the use of control sites for comparison of trends in vegetation communities within the area of potential impact with those outside the influence of the groundwater containment. Furthermore, with increasing volumes of groundwater being treated by the GTP over time, the results of the vegetation and bird surveys have been assessed with respect to the trend of increased containment. In this way, it is possible to assess whether an increase in groundwater containment over time is reflected in groundwater physico-chemical parameters within Penrhyn Estuary and/or the distribution and health of ecological receptors.

4.1 Physico-chemical Parameters

Physico-chemical parameters measured during the monitoring period indicate water level and water quality beneath the dune vegetation and the saltmarsh beds; and the quality of porewater within the estuary mudflats. The original hypotheses regarding potential changes in the ecological communities presented in the EIS were based on the assumption that fresh groundwater is discharged to the estuary. This assumption was found to be incorrect. Groundwater discharge undergoes a complex interaction with tidal inundation resulting in salinisation of the groundwater prior to release into the estuary (discussed in Section 3 of the Final Workplan, URS 2005a).

The main concern of Botany Bay Council was that, in response to groundwater containment for treatment in the GTP, the level of groundwater beneath the dune system would drop causing an intrusion of seawater from the estuary. In that scenario, a significant increase in the influence of seawater on the groundwater being utilised by dune and saltmarsh vegetation (increased pH and conductivity) could be expected to affect vegetation health. However, the monitoring results show that groundwater is generally between 2 and 3 m below the dune surface, and is therefore too deep for access by the majority of shrubs identified in the vegetation surveys. In addition, the low conductivity of groundwater beneath the dunes indicates that surficial water is likely to be derived from rainwater percolation, and therefore is independent of the GTP operation.

Standing water levels (SWL) beneath the dunes fluctuated with the seasons and changes were generally similar in magnitude to daily tidal-induced fluctuations that are evident in the groundwater table. There were no trends (decreasing or increasing) of significant changes identified in the SWL data. In addition, the drier-than-average rainfall experienced during much of the monitoring period would have an influence on the availability of groundwater recharge. Consequently, it is considered unlikely that the observed groundwater SWL fluctuations are attributable to the containment of groundwater and operation of the GTP, but are probably natural tide-induced fluctuations that are exacerbated by reduced rainfall during the monitoring period.

Water quality results from the shallow monitoring wells installed in the saltmarsh beds indicate that the water beneath the saltmarsh beds is heavily influenced by seawater from the estuary, and that freshwater lenses are generally absent. The lowest conductivity values were only recorded in saltmarsh boreholes after periods of heavy rain (i.e. December 2005, September 2006). These observations confirm that groundwater beneath the saltmarsh is generally saline throughout the year but with dilution due to rainfall when it occurs. There is no indication that the saltmarsh plants are dependant on low salinity groundwater that might be affected by the containment of groundwater up-gradient.

The range of pH measurements from groundwater beneath the saltmarsh beds is typical of seawater rather than freshwater and further supports the theory that estuarine/marine water rather than low salinity groundwater is typically present beneath the saltmarsh vegetation.

Similarly, mudflat porewater data throughout the monitoring period clearly indicates that seawater is the major influence down to a depth of 2 m below the mudflat surface. The strong influence of seawater (i.e. salinisation) on shallow groundwater prior to discharge to the estuary is a result of tidal pumping. Consequently, containment of groundwater as a result of GTP operations up-gradient is considered unlikely to affect the mudflat porewater characteristics and estuarine vegetation.

Overall, there is no evidence of change in the physico-chemical parameters of the Penrhyn Estuary groundwater and porewater that can be attributed to containment of groundwater along Foreshore Road.

4.2 Dune Vegetation

The five vegetation surveys confirmed the original classification of the dune vegetation as Planted Shrubland. The community is highly disturbed and features moderate to severe weed infestation, particularly by Bitou Bush (*Chrysanthemoides monilifera*). The dune vegetation has low species diversity but may have local conservation value due to the presence of plant species associated with the Coastal Dune Heath plant community, and its overall value as habitat for faunal species.

Variation in the presence of dead wood on the large shrub/small tree stratum is attributed to seasonal variations and drought conditions that were reported for the period August 2005 to March 2006. The dominant shrub species, Bitou Bush, *Acacia longifolia* var *sophorae* and *Melaleuca ericifolia*, are all relatively short-lived, colonising species that display rapid variation in population health.

The decline in health and density of groundcover plants observed between October 2005 and April 2006 was reversed during the period October 2006 to April 2007. There was an overall increase in the density and diversity of groundcover species with 16 groundcover species recorded for the first time. These consisted of native herbs, exotic grasses and annual herbs, and exotic, perennial noxious weeds. Observed groundcover species are all typical coloniser-type species and increased densities may be an indication of more favourable growing conditions (e.g. more rainfall) over the last year than in previous survey periods. The GIS-based analysis of ground cover illustrated the increase in abundance of vegetation on the dunes with a 73.45% reduction in open sand area between 2005 and 2006 – the increase was mainly attributed to the spread of groundcover species, mainly noxious weeds.

Quantitative assessment of abundance through the Braun-Blanquet index indicated considerable variation over the survey rounds including changes within the control plot that is located outside the influence of groundwater containment. Variation over the five sampling rounds shows that considerable fluctuation in the composition of the dune vegetation occurs both naturally and as a result of ongoing human disturbance.

A total of 106 dead or stressed *Banksia* spp. individuals were recorded, with a steady increase in the overall number between the July 2006 and April 2007 surveys. This demonstrates that senescence of *Banksia* spp. within the dune vegetation is ongoing. The observed mortality of the *Banksia* spp. is considered most likely to result from the sustained drought conditions in the region, or age-related deaths of the older plants.

The Penrhyn Estuary dunes are considered an environment highly disturbed by human activity and weed infestation, and any changes to the dune vegetation must be considered in the context of other impacts as well as the containment of groundwater. The literature review suggests that the Planted Shrubland community is probably not groundwater dependent, nor is there any specific indication that either *Banksia integrifolia* or *Banksia serrata* rely on groundwater for survival. However, the relationship between Australian terrestrial vegetation and groundwater is poorly understood.

A number of alternative factors may be responsible for the observed deaths in *Banksia* spp. individuals, including:

- ongoing drought conditions resulting in water-stress and death of trees;
- unsuitable growth media (dredged marine sands) resulting in nutrients becoming limiting for plant species over time;
- natural senescence (i.e. *Banksia* spp. reaching the end of their natural lifespan);
- infection by *Phytophthora* or other soil-borne pathogens; or
- toxicity due to environmental contaminant(s).

In April 2007, the surveyed health and vigour of the dune vegetation was generally good. Active growth was apparent on *Melaleuca armillaris*, the next tallest stratum after *Banksia* spp. Therefore, the observed senescense of *Banksia* spp. may reflect a susceptibility of the genus to an adverse environmental factor at the site rather than a general decline in the health of the dune vegetation community.

Dune vegetation surveys in July 2005 (URS, 2005b) recorded plant species that are known to occur in other communities that rely on groundwater - *Melaleuca armillaris*, *Isolepsis nodosa* and *Carex* sp. Those species are believed to be more susceptible to changes in the local groundwater regime, yet variation in their abundance throughout the monitoring period does not indicate trends related to possible impacts from groundwater containment. *Melaleuca armillaris* was present in all plots with both increases and decreases in cover abundance. *Isolepsis nodosa* experienced a minor overall decline in Plots 2 and 3, whereas *Isolepsis nodosa* and *Carex* sp*.* declined and became absent in the Plot 5, which was the control plot beyond the influence of groundwater containment.

In general, the dune vegetation community is considered to be rainfall dependent. No distinct floral abundance or health trends were detected in the dune vegetation community throughout the monitoring period. The observed variations are more likely to be a result of natural fluctuations in plant populations responding to seasonal and local climate influences than directly attributable to containment of groundwater.

4.3 Saltmarsh

The saltmarsh assemblages in Penrhyn Estuary differed from those at the Control locations throughout the monitoring program. Although the magnitude of this difference did not change in accordance with the increases in groundwater extraction rates, the biota contributing to the dissimilarity in these assemblages did change from Survey 3 onwards. Significant changes observed in the Penrhyn Estuary saltmarsh community (i.e. increased abundance of ‘good’ *S.quinqueflora*, and decline in abundance of ‘poor’ *S.quinqueflora*) also occurred at one or other of the control locations and therefore are not considered to be a consequence of groundwater containment. However, significant differences in temporal variability of percentage cover and heights of *S.australis* were apparent at Penrhyn Estuary compared to control locations. The increased variability is attributed to the greater abundance of this species at Penrhyn Estuary, and the observed differences were only apparent during some of the monitoring surveys thereby falsifying a general trend associated with groundwater containment.

Overall, the areal extent of saltmarsh within Penrhyn Estuary has increased slightly since April 2006 (10 to 20%), and shows no detectable effects of groundwater containment.

4.4 Seagrass

The distribution of seagrass beds in Penrhyn Estuary has changed throughout the monitoring program. Initial significant increases in the areal extent of seagrass within the estuary have reversed since April 2006. However, the marked decline in areal extent of seagrass did not coincide with major changes in the containment of groundwater as would be expected if the containment was the cause of the decline. Indeed, the physiological requirements of seagrass plants (regular immersion in brackish or saline water) and their vegetative structure (shallow rhizomes and low flattened leaves) do not support the theory that they are dependant on groundwater; in fact, the fresh groundwater is 2 m beneath the mudflat areas where seagrass were found and therefore beyond the reach of the plants. Therefore, the observed decline in areal extent of seagrass within Penrhyn estuary is not believed to be attributable to the containment of groundwater up-gradient of the estuary.

Furthermore, as seagrass beds are highly dynamic systems exhibiting marked natural seasonal changes in growth and undergoing marked changes in size when subjected to natural forms of disturbance (e.g. strong wave action, major storm events or sediment inundation), it is doubtful whether the dramatic changes observed were associated with groundwater containment. This view is supported by the observation that the changes in the seagrass bed within the mangrove habitat did not mirror those seen in seagrass beds without mangroves.

One potential reason for the observed decrease in the areal extent of seagrass could be related to burial of the seagrass beds in parts of the estuary due to shifting sand/mud during storm events, or due to smothering of the seagrass by increased sedimentation rates within the estuary. This monitoring program was not designed to assess sedimentation dynamics and therefore cannot confirm or deny that such processes have occurred.

4.5 Mangroves

Mangrove distribution has changed throughout the monitoring program with a significant increase in areal extent along the southern shore and adjacent to Springvale Drain. Mangroves are adapted to estuarine habitats and it is not considered likely that their expansion in Penrhyn Estuary is due to the containment of groundwater, but rather continues the expansive trend described previously (URS, 2004a). Although comparisons show that the pattern of change in Penrhyn Estuary did not mirror those observed at the Control locations, they also indicated that they were not correlated with the increase in groundwater extraction rate. There is consequently no conclusive evidence that the removal of groundwater has had any effect on the distribution of mangroves in seagrass habitats.

4.6 Wading Shorebirds

The shorebird monitoring program has provided baseline bird count data for Penrhyn Estuary that can be compared with ongoing bird counts throughout the operation of the GTP. Bird monitoring results revealed no sign of ill health of birds using the area and no apparent decline in overall bird numbers. The only species that has declined in abundance is the Curlew Sandpiper. However, this reflects a regional trend that is evident across all of south-eastern Australia and is not a result of site specific impacts.

While bird numbers fluctuated during the seasons, there appears to be no evidence of any declines beyond those documented in other sites in Botany Bay, or state- or Australia-wide trends to indicate any impacts of the containment of groundwater by Orica. In fact, there were notable increases of maximum counts over previous years for Sharp-tailed Sandpiper, Red-necked Stint and Red-capped Plover, and Little Terns successfully nested and raised chicks along the shore of Penrhyn Estuary for the first time in many years.

Bird monitoring has provided insights into the behaviour and feeding patterns of shorebirds in Penrhyn Estuary. Notably, during spring high tides, shorebirds are unable to feed until the tide recedes beyond the seaward edge of the mangroves. With the observed increase in mangrove coverage, there will be a reduction in feeding times for these birds. Interestingly, Bar-tailed Godwits appear to have shifted their preferred feeding area from the upper reaches to the outer reaches of the estuary.

4.7 Integration of Biotic and Abiotic Data

The assessment of ecological receptors in Penrhyn Estuary and potential effects resulting from the hydraulic containment must be considered in the context of changes in the physico-chemical parameters of the groundwater. If significant changes to the physico-chemical parameters are absent, any observed changes in the identified ecological receptors are likely to be due to factors other than containment of groundwater. The following section discusses the integration of abiotic and biotic parameters.

Groundwater measurements beneath the dune vegetation indicate that the water table is between 2 and 3 m below the ground surface; i.e. deeper than the root system of the majority of shrubs identified from the vegetation monitoring. Fresher water was identified nearer the soil surface; however, the physico-chemical parameters indicate that the source of the water is likely to be rain infiltration rather than groundwater. Fluctuations of the water table are within the range of tidal variation and may also be exacerbated by drought conditions incurred during the monitoring period. This indicates that containment of groundwater for the operation of the GTP is unlikely to have caused variations observed in the surficial groundwater, and that observed changes in dune vegetation cannot be directly attributed to groundwater containment.

Section 4 Discussion

Shallow groundwater beneath the saltmarsh beds was predominantly saline. Where lower salinity water was present, the physico-chemical parameters (and rainfall records) indicate that the source of the water is likely to be rainfall infiltration, rather than groundwater discharge. This indicates that containment of groundwater is unlikely to cause changes to the shallow groundwater associated with the saltmarsh community and consequently, adverse impacts to the saltmarsh vegetation are unlikely to occur as a result. No significant changes in saltmarsh communities at Penrhyn Estuary were observed.

Shallow porewater (<2 m) beneath the mudflats is saline, with salinity values similar to surface waters in the estuary. Seagrass and mangroves are not deeply rooted (<10 cm and <50 cm respectively) and are adapted for living in the marine/estuarine environment. Consequently, these plants do not rely on freshwater like terrestrial plants. The containment of groundwater is therefore unlikely to cause changes in the quality of the mudflat porewater, and seagrass beds and mangroves should not be adversely affected. The decline in seagrass coverage in Penrhyn estuary is believed to be due to influences other than containment of groundwater, and the increased distribution of mangroves is thought to be a natural expansion independent of groundwater.

Mangroves were mainly monitored to assess whether changes in seagrass of saltmarsh distribution is concomitant with an increase in the mangrove distribution. Mangrove areal coverage increased significantly through the monitoring period, but defining a direct relationship between seagrass areal extent and mangrove distribution was not possible.

Wading shorebirds could be indirectly affected by two main factors. Firstly, changes in the availability of food (i.e. the benthic community of the estuarine mud and sand flats) could lead to changes in the abundance of shorebirds utilising the estuary for feeding. However, given that the mudflat porewater is saline (estuarine origin), it is unlikely that containment of groundwater for the operation of the GTP is causing adverse effects to the benthic community of the mudflats. Consequently, the availability of mudflat benthic prey species to wading shorebirds is not expected to change as a result of groundwater containment. Indeed, the wading bird monitoring results do not indicate any significant changes in bird abundance or health throughout the monitoring period.

Secondly, any loss of saltmarsh (roosting) habitat was predicted to cause a decline in shorebird abundance. While the saltmarsh is unlikely to be affected by groundwater containment (see discussion above), the encroachment of mangroves into saltmarsh areas may have a negative affect on the availability of shorebird roosting sites. Clearly, such potential impact on shorebirds is not specific to the Penrhyn Estuary and as such is not related to groundwater containment for the operation of the GTP and therefore is outside the scope of this monitoring program.

Section 5 Conclusions and Recommendations

5.1 Conclusions

After more than 20 months of ecological monitoring, the results of physico-chemical testing of ground and pore waters, in association with vegetation and bird surveys in the Penrhyn Estuary have characterised the degree of variability in the health and distribution of the ecological receptors. Comparison of vegetation changes in Penrhyn Estuary with locations outside of the potential impact area has enabled variability between monitoring events to be considered within the context of natural variability in space and time; variability that could otherwise be considered a result of potential impact from human activity.

Most of the variation is within the range of natural spatial and temporal change that would be expected to occur within a dynamic estuarine system. The only variation components that follow a directional trend through time are the decline in total seagrass coverage since April 2006, the continual increase in spatial extent of mangrove habitat, and the ongoing deaths of mature *Banksia* spp. within the dune vegetation. However, neither seagrass nor mangroves are dependent on freshwater (i.e. groundwater) for survival and as such, it is highly unlikely that the identified trends for these receptors are related to the containment of groundwater as part of the Botany Groundwater Cleanup Program. Specific monitoring of dead *Banksia* spp. has shown that deaths are as prevalent within sites outside the potential influence of groundwater containment and therefore the deaths are not considered to be a result of the loss of groundwater.

The monitoring program has successfully identified both subtle and significant changes in vegetation distribution between sampling events and has therefore fulfilled the aims identified in the *Ecological Monitoring Plan for the Groundwater Treatment Plant and its Operations* (URS 2005a). The monitoring program has evolved over time to address concerns that have been identified with increasing survey data – i.e. monitoring of dead *Banksia* spp. as increasing deaths became apparent, and increased seagrass replication in control locations in response to the expansion of seagrass in Penrhyn Estuary identified in October 2005.

Modifications to the original monitoring program have increased its ability to identify potential impacts of the groundwater containment and therefore provide greater confidence that the following list of conclusions is realistic and reasonable:

- No significant changes in the physico-chemical parameters of groundwater beneath dune vegetation were observed during the monitoring period;
- Small variations in the standing water level (SWL) beneath the dune vegetation have been recorded, but did not exhibit any consistent trend (increasing or decreasing) and are believed to be related to natural cycles of tidal pumping and/or seasonal variation in rainfall;
- Shallow groundwater beneath the saltmarsh vegetation is generally saline (with periodic dilution due to rainfall), and no significant changes in the physico-chemical parameters were observed after commencement of groundwater containment;
- Porewater beneath the mudflats is saline and no significant changes in the physico-chemical parameters were observed after commencement of groundwater containment;
- Dune vegetation has changed over time with both decreases and increases in coverage between survey events. There are no consistent trends of decreasing health or distribution of most plant species found in the dune vegetation communities;
- There have been ongoing deaths of mature *Banksia* spp. within the dune vegetation community but a similar rate of deaths has occurred in the control plot that is outside the influence of groundwater containment. Deaths are believed to be associated with factors unrelated to groundwater containment (e.g. below average rainfall, or natural senescence due to age);
- No changes have been identified in the distribution or health of saltmarsh community;

Section 5 Conclusions and Recommendations

- Seagrass coverage has varied between survey events with an overall decrease in spatial distribution. However, seagrasses are known to be reliant on estuarine/marine water rather than fresh groundwater, and there were no consistent trends of decreasing health or distribution of seagrass beds in Penrhyn Estuary that can be attributed to groundwater containment;
- The distribution of mangroves in Penrhyn Estuary has changed over time with greater numbers of mangrove trees in some areas. Mangroves are not reliant on freshwater, and continual recruitment of seedlings is a natural phenomenon; therefore the expansion of mangrove habitat is unrelated to groundwater containment; and
- The abundance and health of wading shorebirds have not significantly changed at Penrhyn Estuary during the monitoring period, suggesting that any potential changes in the abundance and diversity of mudflat prey species has not significantly changed bird behaviour. In addition, the availability of roosting sites in saltmarsh and foreshore vegetation is believed to be relatively unchanged.

In summary, none of the ecological receptors monitored during this program have exhibited any significant change in health or abundance that can be directly attributed to the current level of groundwater containment along Foreshore Road.

5.2 Recommendations

Given that no significant changes to groundwater quality, water table levels or ecological receptors have been identified throughout the Penrhyn Estuary monitoring program, and considering that the Penrhyn Estuary is to be completely remodelled in the near future during expansion plans for Port Botany, it is recommended that future ecological monitoring of the area be significantly modified.

Considering that the current monitoring program has shown that shallow groundwater beneath both the saltmarsh and tidal mudflats is of estuarine origin and therefore the receptors of interest (i.e. saltmarsh, seagrass and mangroves), do not rely on fresh groundwater, further monitoring of these receptors is not required. Similarly, the dune vegetation is recognised as “highly disturbed” featuring moderate to severe weed infestation that is not relying on groundwater and as such, further monitoring is thought to be unnecessary.

Monitoring of abundance and health of wading birds has shown no significant negative trends over almost two years. Consequently, monitoring of shorebird abundance and/or health at Penrhyn Estuary in the future, as a result of operation of the GTP, is not warranted.

However, quarterly monitoring of groundwater through bundled piezometers installed in the dunes is considered to be an important means of obtaining indicative trends in groundwater quality beneath the dune vegetation and should be continued. Further monitoring of dune groundwater will continue to provide evidence of how groundwater containment up-gradient might be affecting water quality, and will provide warning of any significant changes that might occur with increased rates of groundwater treatment.

In summary, the following amendments to the monitoring of potential effects of groundwater containment on Penrhyn Estuary are recommended:

- Cease monitoring dune vegetation distribution and health;
- Cease monitoring the saltmarsh community and the shallow groundwater beneath;
- Cease monitoring seagrass community distribution and health;
- Cease monitoring mangrove community distribution;
- Cease monitoring wading bird abundance and health;
- Continue quarterly monitoring of dune groundwater via the established bundled piezometers;

- Continue quarterly monitoring of mudflat porewater via the established bundled piezometers; and
- Continue monitoring of quality and contaminant loading of surface waters entering Penrhyn Estuary via Floodvale and Springvale Drains, and mixed surface water within the estuary (component of a wider monitoring program already undertaken by Orica).

These results and conclusions were presented to the Community Liaison Committee in September 2007.

Section 6 References

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URS (2007) *Orica Botany GTP Operation Ecological Monitoring Program Report No.3.* Prepared for Orica Australia Pty Ltd by URS Australia Pty Ltd 13 (28 January 2007)

Section 7 Limitations

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