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SPECIALISTS IN ENVIRONMENTAL, SOCIAL AND SAFETY PERFORMANCE

GROUNDWATER MODELLING ASSESSMENT REPORT - ASH PONDS TALLAWARRA LANDS, YALLAH, NSW

Prepared for:

TRUenergy
Level 33, 385 Bourke Street
MELBOURNE VIC 3000

Report Date: 3 April 2012
Project Ref: ENAUWOLL04009AE

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3 April 2012

TRUenergy
Level 33, 385 Bourke Street
MELBOURNE VIC 3000

Attention: Anthony Savenkov

Dear Anthony,

RE: GROUNDWATER MODELLING ASSESSMENT REPORT – ASH PONDS, TALLAWARRA LANDS, YALLAH, NSW

We are pleased to present our final report for the above site.

We draw your attention to the attached sheets entitled “Important information about your Coffey Environmental Report”. These sheets should be read in conjunction with this report.

Thank you for your commission for this work. Should you have any questions in relation to the report, please do not hesitate to contact the undersigned.

For and on behalf of Coffey Environments Pty Ltd

C. DeCastro

CORINNA DE CASTRO
Senior Hydrogeologist

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ABBREVIATIONS

AHD	Australian Height Datum
bgl	below ground level
CEC	Cation Exchange Capacity
DO	Dissolved Oxygen
EC	Electrical Conductivity
GDE	Groundwater Dependent Ecosystem
µg/L	micrograms per litre
mg/L	milligrams per litre
MW	Monitoring Well
NOW	NSW Office of Water
RL	Reduced Level
SWL	Standing Water Level
TDS	Total Dissolved Solids
TOC	Top of Casing
TOC	Total Organic Carbon

1 INTRODUCTION

1.1 General

Coffey Environments Australia Pty Ltd (Coffey) was commissioned by TRUenergy Tallawarra Pty Ltd (TRUenergy) to carry out a groundwater modelling assessment at the former ash pond areas of the Tallawarra lands surrounding the Tallawarra Power Station, Yallah Bay Road, Yallah, NSW, hereafter referred to as the 'site' (Figure 1). This modelling report provides a summary of the additional data collected since December 2010 and the results of numerical groundwater flow and transport modelling. The work was completed generally in accordance with our proposal, ENAUWOLL04009AE-P01, dated 8 December 2010.

Coffey has previously assessed the groundwater quality at Tallawarra Lands (Coffey Environments, 2010a and 2010b). The assessments identified elevated concentrations of heavy metals (including arsenic, copper, nickel and zinc) and ammonium above the adopted investigation levels for protection of aquatic ecosystems. The report recommended that any future disturbance to the ash ponds should take into account groundwater issues and ensure that the disturbances avoid creating preferential pathways for groundwater to discharge directly into the surrounding receiving environment (Coffey Environments, 2010b).

A preliminary hydrogeological assessment was conducted in the areas of the ash ponds (Coffey Environments, 2010c), including assessing groundwater flow directions and likely preferential pathways in the vicinity of the ash ponds; assessing potential groundwater volumes flowing from the ash ponds and a qualitative assessment of potential impacts to groundwater levels as a result of the proposed development at Tallawarra Lands.

The objective of this assessment by Coffey is to conduct a more detailed and quantitative hydrogeological assessment at the site including numerical groundwater modelling. The assessment will provide more information for the groundwater dependent ecosystem (GDE) study and risk assessment by Eco Logical Australia, including assessing groundwater levels and quality in areas away from the ash ponds such as the wetland area to the east of Ash Pond 3.

This modelling report presents additional hydrogeological data collected since December 2010 (groundwater levels, quality and permeability data) and the results of numerical groundwater flow and transport modelling.

1.2 Scope of Work

The following scope of work was carried out to obtain, analyse, and report the additional data:

- Additional groundwater data collection including:
    - Installation of eight additional groundwater monitoring wells (MW11-MW18). Two monitoring wells were installed in the wetland area to the east of Ash Pond 3, one west of Ash Pond 2, one on the bank of Duck River (discharge location south of Ash Pond 2) and one background well to the west of Ash Pond 3. Three wells were installed for the pumping test in Ash Pond 2 to assess the vertical hydraulic conductivity of the ash (the main factor controlling the capacity of the ash mounds to emit groundwater).
    - Survey of the eight new groundwater monitoring wells.

- Logging of groundwater levels since December 2010 at five selected wells using electronic down-hole data loggers to assess the response of groundwater levels to rainfall recharge and seasonal variations. Following installation of the new monitoring wells, two additional data loggers were installed at two locations.
- Collection of groundwater samples from nine existing wells, six new wells (sampling of one of the three wells installed for the pumping test as distances between these wells is approximately 3m) and an existing well TAGM/D3 (installed by others).
- Collection of two surface water samples, one in the Ash Pond 3 lake and one in the pond west of Ash Pond 2 in the vicinity of the well (MW14) installed in this area.
- Laboratory analysis of groundwater and surface water samples for dissolved heavy metals (arsenic, cadmium, chromium, copper, lead, molybdenum, nickel and zinc), ammonium, nitrate, nitrite, total kjeldahl nitrogen (TKN) and total nitrogen. The following parameters were also measured in the field – pH, temperature, redox potential, dissolved oxygen and electrical conductivity.
- Field assessment of aquifer parameters (hydraulic conductivity and storativity). The aquifer tests included a constant rate pump test with multiple observation piezometers in Ash Pond 2, two slug tests and two constant rate single well pumping tests in natural material and the ash.
- Collection of 15 samples for leachate analysis to further assess the possible source of ammonium on site. Representative samples from the coalwash, ash and natural clay material in the wetland environment were analysed for the nitrogen suite (ammonium, nitrate, nitrite, TKN and total nitrogen) as well as heavy metals (arsenic, cadmium, chromium, copper, lead, molybdenum, nickel and zinc).
- Collection of four natural clay samples for total organic carbon (TOC) and cation exchange capacity (CEC) analysis, as well as the nitrogen suite analysis, to provide site specific data for transport model parameters (information on the binding capacity of the clay). The additional data was used as part of the assessment of retardation factors in the contaminant transport model.

- Data analysis. Data collected as part of the pump test was analysed to provide an assessment of the lateral and vertical hydraulic conductivity and storativity of the ash material. The slug test data was analysed to provide values of hydraulic conductivity within close vicinity of the wells. Data collation included preparation of hydrographs from the water level logger data and tabulation of laboratory results.
- Groundwater flow and transport modelling. A three-dimensional groundwater model was developed, calibrated and used in a predictive capacity to assess changes in groundwater levels, flow and contaminant transport for two analytes (arsenic and ammonium) for the no development and development scenarios.
- Preparation of this report summarising the results of fieldwork and the groundwater flow and transport modelling.

2 SITE CHARACTERISATION

2.1 Site Location and Landuse

The site is located on the eastern side of the Princes Highway, Yallah, NSW and occupies an area of about 535.9 ha. The site is irregular in shape with an approximate length (north-south) of 3.4 km and an approximate width (east-west) of 2 km. The site excludes the area occupied by Tallawarra gas fired power station and public access areas around the Lake Illawarra foreshore, owned by the Lake Illawarra Authority. The northern portion of the site is generally vacant and used as grazing land. The northern portions of the site have the occasional structure and several farm dams. The area south of Yallah Bay Road has been significantly disturbed to allow development of three ash ponds which were filled with ash during the operation of the coal fired power station. This area has also been significantly filled.

The surrounding landuses include:

- Princes Highway to the west;
- Residential dwellings to the north and south;
- Lake Illawarra to the east; and
- The power station located near the central southeastern boundary, north of Yallah Bay Road.

The site locality, site layout and general surrounding landuses are shown in Figure 1.

2.2 Topography and Surface Water Drainage

The study area has varying topography from near level ground to steep slopes. The topography near the northern site boundary forms part of a steep hill side (Mount Brown) sloping down towards the east, south and southeast. South of these steep areas, the slope flattens slightly and becomes rolling hills. The ground surface south of Yallah Bay Road is generally near level (<1°grade) and forms part of an alluvial floodplain and wetlands with exception of areas near the western boundary. The area near the western site boundary (south of Yallah Bay Road) appears to be locally elevated, rising towards the Princes Highway to the west and sloping down towards the east.

Reference to the Albion Park 1:25,000 Topographic Map indicates that the study area ground surface ranges in elevation between 0 m and 100 m above Australian Height Datum (AHD). This is consistent with survey data provided by Landteam which indicated an elevation between 0 m and 110 m AHD.

In areas north of Yallah Bay Road, surface water is expected to follow the land topography initially discharging into several unnamed watercourses and farm dams that occupy this area of the site. Some of these watercourses appear to flow into Duck Creek or directly into Lake Illawarra. The area south of Yallah Bay Road is bisected by Duck Creek which flows from the northwest to the east before discharging into Lake Illawarra. Wollingurry Creek and several drains/unnamed watercourses occupy this area of the site and flow into Duck Creek. This area of the site is also occupied by three ash settling ponds which have been mostly filled with ash derived from the former coal fired power station. One of the ponds (Ash Pond 3) in the south western area of the site was only partially filled with ash allowing the remaining areas to be filled with water.

The topography and watercourses are shown in Figure 1 and Figure 2.

2.3 Rainfall and Evaporation

The Albion Park (Wollongong Airport) automatic weather station (AWS) 68241 is approximately 2 km inland to the south west of the site at an elevation of 8 m AHD. Climate data has been recorded at this location since 1999. The Port Kembla AWS 68131 is located on the coast approximately 12 km to the north east of the site at an elevation of 9 m AHD. Climate data has been recorded at this location since 1963.

Recorded data at Albion Park and Port Kembla has been sourced from the Bureau of Meteorology website www.bom.gov.au. No pan evaporation data is available from the Albion Park or Port Kembla station and limited pan evaporation data is available in the study area. Pan evaporation data was sourced from the University of Wollongong (website), which is located approximately 14 km to the north east of the site.

Table 1 lists the mean rainfall recorded at Albion Park and Port Kembla and the pan evaporation recorded at the University of Wollongong. Mean annual rainfall is approximately 866 mm at Albion Park and 1104 mm at Port Kembla. Mean monthly rainfall is highest in summer and autumn and lowest in winter and spring. Evaporation also varies with the seasons and is highest in the spring and summer months (from October to February). Mean annual evaporation is 1278 mm, which exceeds mean annual rainfall.

Table 1: Mean Rainfall and Evaporation Data

	Albion Park Rainfall (mm)	Port Kembla Rainfall (mm)	Pan Evaporation (mm)
Monthly			
January	64	94	152
February	157	129	120
March	72	141	105
April	71	104	84
May	70	88	71
June	78	112	63
July	69	54	74
August	29	73	90
September	41	59	108
October	73	89	127
November	82	88	129
December	68	74	158
Annual			
Mean	866	1104	1278

2.4 Geology

Reference to the 1:50,000 Kiama Geological Series Sheet (9028-1, First Edition) prepared by the NSW Department of Mines (1974) indicates the study area is underlain by the following four geological units:

- Alluvium;
- Dapto Latite Member;
- Budgong Sandstone; and
- Berry Siltstone.

The Dapto Latite Member, Budgong Sandstone and Berry Siltstone form part of the Shoalhaven Group of rocks. The geological map has been overlaid onto the site aerial photograph and is shown in Figure 2.

The geological map shows the area south east of Ash Pond 2 as alluvium, while subsurface investigations (Coffey Environments, 2010a) have indicated this area is underlain by shallow bedrock of the Berry Siltstone formation. Wollingurry Point (Figure 1) is known to exhibit rock outcrop.

The geological map provides a description of each of these units along with their depositional sequence. This has been summarised in Table 2.

Table 2: Summary of Local Geological Units

Geological Unit	Geological Description	Age and Depositional Sequence
Alluvium (Qa)	Alluvium, gravel, beach and dune sand	Quaternary. At the site typically overlies the Berry Siltstone.
Dapto Latite Member (Psgd)	Melanocratic coarse grained to porphyritic latite	Early Permian. At the site overlies the Budgong Sandstone.
Budgong Sandstone (Psg)	Red-brown and grey volcanic sandstone	Early Permian. At the site overlies the Berry Siltstone.
Berry Siltstone (Psb)	Mid-grey to dark-grey siltstone to fine sandstone	Early Permian. The oldest identified geological formation at the site.

In addition to these natural sequences, the study area also has the three bodies of ash (which each host groundwater) and also coalwash used for the ash dam bund walls and for construction purposes.

2.5 Hydrogeology

Based on local topography and geology, two main aquifer systems have been identified previously in the study area (Camp Scott Furphy, 1993). A shallow aquifer consists of unconsolidated sediments such as gravels, clays and sands within approximately 5m of the ground surface. Deeper aquifers are associated with rock fractures within the Budgong Sandstone or the underlying Berry Siltstone sandstones and siltstones. For the purposes of the current assessment, the shallow aquifer is of greater importance, as the proposed development includes excavations that will generally be shallower than 6 m.

In addition to the groundwater system in natural materials, all three ash bodies maintain saturation, and form additional (artificial) groundwater systems.

The alluvial/estuarine sediments form a continuous groundwater system over the site. Groundwater in the ash will interact with the alluvial/estuarine system by downward vertical flow (given the prevailing groundwater levels). Groundwater flow in the alluvial/estuarine sediments is generally easterly, towards the various watercourses and Lake Illawarra. Further information on groundwater levels and flow on site is provided in Section 6.1 and Section 7.

Away from the ash ponds in the more elevated areas north of Yallah Bay Road, it is likely that the groundwater will be hosted by the Budgong Sandstone. This is consistent with the results of our previous investigation (Coffey Geosciences, 2002) where two groundwater monitoring wells were installed to depths of 1.7 m and 4 m north of the power station within the residual or weathered sandstone rock. These wells were observed to be dry at the time of monitoring. Groundwater within the residual clay above the bedrock may be considered as an ephemeral perched groundwater system depending on rainfall recharge, although most rainfall would run off due to the steep slopes and nature of the clay soils (low infiltration rates).

Groundwater monitoring wells located in the lower areas of the power station near the foreshore of the lake recorded depths to groundwater ranging between 1.8 m and 2.2 m below ground level (Coffey Geosciences, 2002). This is similar to groundwater levels reported for the power station area during 2010 (Earth2Water, 2010).

2.5.1 Groundwater Dependent Ecosystems

Groundwater Dependent Ecosystems (GDEs) are defined as ecosystems whose current composition, structure and function are reliant on a supply of groundwater (Eamus, 2009). Potential GDEs present at the site are detailed in the GDE risk assessment study (Eco Logical Australia, 2010). It was assessed that potential dependency on groundwater was likely for all terrestrial vegetation types at the site, including the SEPP 14 wetlands south of Duck Creek and in the vicinity of Lake Illawarra. The estuarine alluvial wetlands were assessed as being more dependent on tidal inundation of saline waters rather than groundwater dependency.

For all ecosystems on site it was assessed that alterations to hydrological regimes (both surface and groundwater) could potentially threaten the vegetation communities.

Schedule 4 of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 identifies the Macquarie Rivulet Estuary as a high priority GDE (NSW Office of Water, 2011). Macquarie Rivulet Estuary is located next to Lake Illawarra about 700 m south east of the site, and is approximately one hectare in size.

2.5.2 Registered Groundwater Bores

A survey of groundwater bores within a 4.5 km radius of the study area registered with the NSW Office of Water (NOW) was carried out as part of the previous Coffey investigation (Coffey Environments, 2010a). The search results indicated that there were 40 registered bores but only nine of which had work summary sheets. The groundwater bores were located in an inferred upgradient direction and generally to the north and west of the site. The closest bore, GW033541, was located approximately

1.5 km to the north west of the site. The work summary sheets and groundwater bore locations were previously presented in earlier reports (Coffey Environments, 2010a and 2010c).

2.6 Ash Pond Details

2.6.1 History

Three ash ponds were constructed at the site between around 1955 and 1983 for the placement of ash, a by-product of the coal combustion process at the former coal fired power station located to the north. The ash ponds occupy approximately two-thirds of the lower lying area south of Yallah Bay Road. The ash pond walls were constructed of fill comprising a combination of coalwash and soil that appears to have been placed directly on the former ground surface, as there has been no evidence of excavation revealed in the site history (Coffey Environments, 2010a). Typically the ash pond bund walls are in the order of 5 m high and approximately 30 m wide but this is variable. The ash ponds were progressively filled with ash that was hydraulically pumped into the ponds via overland pipelines until the power station ceased operations in 1989. As the ponds reached capacity, they were capped with coalwash and/or general fill and revegetated. Ash Pond 3 did not reach its full capacity with several areas filled with water.

It is known that over an indeterminate trial period between 1955 and 1989, a limited amount of ammonia (in an unknown form) was applied to the coal prior to combustion to reduce the amount of nitrogen gasses in the waste.

2.6.2 Subsurface Conditions

The origin and quality of the fill used to construct the bund walls of the ash ponds were not confirmed through the history study conducted previously (Coffey Environments, 2010a). The fill used to construct the bund walls was assessed as an engineered type fill, and as such it was considered unlikely to contain significant quantities of materials such as concrete, timber, bricks, etc, that would result in areas where preferential groundwater flow could occur.

14 locations were either excavated or drilled through the fill bund walls of the ash ponds (Coffey Environments, 2010a). The materials encountered in the bund walls included a general fill material (comprising clay, clayey silt or sand) and coalwash.

19 locations were either excavated or drilled through the ash ponds. Ash was exposed at the surface, in particular in Ash Pond 3. Typically a coalwash or clay cap was encountered ranging in thickness between 0.05 m and 0.6 m.

Ash was identified below the cap to depths of between 0.15 m and 11 m. Typically, natural clayey soils were noted at the base of the ponds. At some locations silty sand, sand or weathered rock was encountered at the base of the ponds. In general, the average ash thickness at each pond is:

- Ash Pond 1: 13 m;
- Ash Pond 2: 11 m; and
- Ash Pond 3: 3 m.

Low lying areas in the natural ground surface include former water bodies such as Wollingurry Creek through Ash Pond 3 and the arm of Duck Creek south of Ash Pond 2 as well as former wetlands within Ash Pond 1 and 2. These areas are shown in the historical aerial photograph from 1948 (Figure 3) and have been filled during the construction and placement of ash in the ash ponds. Minimal records were found during the current investigation to assess the nature of the construction materials and filling sequences.

Limited information for Ash Pond 1 and 2 was obtained from the Electricity Commission of NSW drawing No. TA77B "Tallawarra Power Station Ash Disposal Layout and Site Plan" revision M, 1957. There are two levels of bund walls in the southern section of Ash Pond 2, a higher elevation of around 10 m AHD and a lower bund around 5 m AHD. The Electricity Commission plan shows that the lower bund closest to Duck Creek was to be built up with tipped stone leaving approximately a 15 m gap in the embankment at the centre of the Duck Creek arm. It is likely that the reclamation fill (coarse rocks and boulders) placed in this area provided hydraulic connection between the ash pond / former wetland area and the Duck Creek arm. Over time, finer-grained soil placed above the reclamation fill may have settled and migrated downwards (by rainfall recharge processes) to infill some of the gaps between boulders and possibly reduce the hydraulic conductivity of the reclamation fill. No subsurface data in this area provided data on the reclamation fill.

Limited information for Ash Pond 3 was obtained from the Electricity Commission of NSW report (1981), which shows the main bund wall constructed over the former Wollingurry Creek watercourse and the upstream diversion works. Discussions with engineers involved with the construction of Ash Pond 3 confirmed that the watercourse was initially filled with coarse material in order to construct the bund wall followed by filling with clay material to limit water flow. In areas away from the bund wall the watercourse was filled with ash placed hydraulically into the ash pond.

In general across the site it is likely that reclamation fill was used as a base in low lying areas or former watercourses, prior to placement of materials such as clay soils and coalwash for structures such as the bund walls and access roads. One record of boulder size material was detailed in test pit CTP75, located in the former wetland beneath Ash Pond 1 (Coffey Environments, 2010a). The test pit was located on the edge of the road constructed between the bund wall and Lake Illawarra. At a depth within the fill between 2 m and 2.8 m (RL 1.1 to RL 0.3 m AHD), cobbles and boulders of siltstone and concrete up to 0.55 m in size were recorded. In this area, reclamation fill was not assessed to provide a pathway between the ash ponds and Lake Illawarra as the former wetland did not extend to the lake, located approximately 50 m further east.

2.6.3 Geotechnical Laboratory Results

The laboratory testing results previously reported (Coffey Environments, 2010a) indicated the following:

- Most of the samples from the ash material indicated about 90% of the material passed the 75 µm sieve, indicating the tested samples contained silt or clay sized particles.
- For the ash samples, a significant proportion of the soil was graded in the 'silt' particle size range in three out of the four samples tested in hydrometer test samples.
- Out of the 16 samples tested within the ash, 6 contained predominantly (>50%) sand sized particles. The remaining 10 samples tested within the ash contained predominantly silt or clay sized particles.
- Some variability occurs within the ash materials, with some silty and some sandy ash materials.

3 PROPOSED SITE DEVELOPMENT

The development proposal involves the establishment of a number of land uses throughout the study area. Details regarding the proposed development were obtained from the Urban Design Masterplan (Warren Lee Urban Design, 2010).

The proposed development areas are illustrated in Figure 4 and include:

- Northern Precinct - Residential development in the north east of the site along the Lake Illawarra foreshore.
- Central Precinct - Residential development, a local centre and an employment zone in the central western parts of the site, north of Duck Creek and Yallah Bay Road.
- Central Precinct - An employment area and tourism facility in the central and eastern parts of the site.
- Lakeside (Southern) Precinct - An employment precinct, primary school, retirement village and residential development in the south west of the site.
- Significant dedication of various parts of the site for environmental and open space purposes, as listed by Eco Logical Australia (2010):
    - Provision of a significant environmental corridor for Duck Creek.
    - A large environmental reserve in the south east incorporating two SEPP 14 wetlands.
    - Conservation of two artificial wetlands in the south west for incorporation into open space areas.
    - An environmental reserve on the upper slopes of Mount Brown.
    - An environmental reserve on the central western boundary.
    - Provision of riparian zones for affected waterways.
    - Large areas of open space reserves.

Further information on the proposed site development and predictive modelling sequences are provided in Section 10.1.

4 INVESTIGATION LEVELS

4.1 Groundwater, Surface Water and Leachate Samples

The investigation levels for groundwater, surface water and leachate samples used in this assessment are the same as those used in previous reports (Coffey Environments, 2010a and 2010b), and are based on the Australia and New Zealand Environment and Conservation Council (ANZECC) *Guidelines for Fresh and Marine Water Quality 2000* (ANZECC, 2000). The guidelines for protection of marine water ecosystems of the receiving waters have been adopted, since the receiving waters are in an estuarine environment.

The adopted criteria are summarised in the attached results Tables LR1, LR2 and LR3.

4.2 Coalwash, Ash and Soil Samples

The soil sample results for coalwash, ash and natural clay samples were primarily used for comparison to leachate water quality results to compare leachability of the different materials and sources of potential contamination to the groundwater system. Soil investigation levels are included in this assessment and are the same as those used in the previous report (Coffey Environments, 2010a), and are based on the National Environment Protection (Assessment of Site Contamination) Measure 1999 (NEPM) from the National Environment Protection Council (NEPC, 1999).

For assessing contamination levels in soil in urban settings, the NEPC (1999) present health based investigation levels (HILs) for different land uses (e.g. industrial/commercial, residential, recreational etc.) as well as provisional phytotoxicity based investigation levels or ecology based investigation levels (EILs).

There are several proposed land uses for the site including residential, primary school, retirement villages, sporting grounds, tourism, commercial and industrial. The soil investigation levels adopted for the site will depend on the proposed land use. It is considered the following HILs are applicable to the site:

- NEHF A – Residential with gardens and accessible soil (home grown produce contributing less than 10% fruit and vegetable intake, no poultry). Includes childcare centres, preschools, primary schools, townhouses and villas;
- NEHF D – Residential with minimal access to soil including high-rise apartments and flats;
- NEHF E – Parks, recreational open space, playing fields, including secondary schools; and
- NEHF F – Commercial or industrial.

The EILs (for sandy loams with a pH of 6 to 8) are considered suitable to assess potential phytotoxicity of site soils and will be assessed in areas where land use HILs NEHF A, NEHF D, NEHF E and NEHF F apply. Phytotoxicity criteria for the protection of plants are generally not applicable for commercial/industrial sites (NEHF F). Table 3 summarises which soil investigation level will be adopted based on the proposed land use at the various test pit locations.

The adopted criteria are summarised in the attached results Table LR3.

Table 3: Summary of Soil Investigation Levels Adopted for the Site

Area of Site	Coffey Test Pit	Proposed Landuse	Adopted Investigation Levels
Zone 2(A)	CTP87 and CTP88	Environmental reserve, sports ground, tourism, industrial	NEHF E, EILs NEHF F
Zone 3(A)	CTP90, CTP91 and CTP92	Lakeside residential precinct, primary schools, retirement village, commercial	NEHF A, EILs NEHF F
Zone 4(A)	CTP89	Open space, environmental management (no development)	NEHF E, EILs
Zone 4(C)	CTP93 and CTP94	Open space, environmental management (no development)	NEHF E, EILs

4.3 Additional Soil Samples – TOC and CEC

The clay soil sample results for total organic carbon (TOC) and cation exchange capacity (CEC), as well as the nitrogen suite analysis, were primarily used to provide site specific data for transport model parameters (information on the binding capacity of the clay). The additional data was used as part of the assessment of retardation factors in the contaminant transport model.

No adopted criteria were applicable to these analytes summarised in the attached results Table LR4.

5 FIELD AND LABORATORY INVESTIGATIONS

5.1 Previous Field Investigations

Ten groundwater monitoring wells have been previously installed by Coffey: MW01 to MW09 as part of the initial site investigation (Coffey Environments, 2010a) and MW10 as part of a further assessment of groundwater quality (Coffey Environments, 2010b). Existing monitoring well borelogs are attached in Appendix A and well details are summarised in Table 4. Monitoring wells MW06 and MW08 are screened in the ash within Ash Pond 2. Monitoring wells MW03 and MW04 are located within Ash Pond 3 and are screened in the underlying alluvial/estuarine or residual material. The remaining monitoring wells are screened in alluvial/estuarine sediments with one monitoring well MW07 screened in weathered sandstone bedrock of the Berry Siltstone formation. Monitoring well locations are shown in Figure 5.

An additional monitoring well installed by others, TAGM/D3, is also included in Table 4 and Figure 5. Construction details are not known.

5.2 Current Field Investigations

Field investigations were carried out between 22 December 2010 and 18 April 2011 in the full time presence of a Coffey engineering geologist or environmental scientist. Data loggers were installed in five existing monitoring wells on 22 December 2010 and two new monitoring wells on 3 February and 18 February 2011. Monitoring wells MW11 to MW18 were installed between 31 January and 4 February 2011. The location and elevation (ground level and top of casing) of the monitoring wells were surveyed by Landteam on 8 March 2011. Survey details are summarised in Table 5. Aquifer testing was conducted on 17 February, 24 February and 15 March 2011. Groundwater and surface water samples were collected between 15 February and 8 March 2011. Coalwash, ash and soil samples were collected on 18 April 2011 for leachate analyses. Clay soil samples were collected on 23 August 2011 for binding capacity analyses.

The following sections describe the field investigations in more detail.

5.3 Groundwater Monitoring Well Installation

Eight new groundwater monitoring wells, MW11 to MW18, were installed as part of the current groundwater assessment to obtain more data prior to commencement of groundwater modelling. Monitoring well borelogs are attached in Appendix B and well details are summarised in Table 5.

Monitoring wells MW11 to MW13 were installed within Ash Pond 2 in order to obtain ash aquifer properties from pump test analyses. MW14 was installed to the west of Ash Pond 2 to assess groundwater quality down gradient of Ash Pond 2. MW15 was installed adjacent to Duck Creek to assess groundwater quality at the discharge location down gradient of Ash Pond 2. MW16 and MW17 were installed in the wetland area to the east of Ash Pond 3 to assess groundwater quality in this area. MW18 was installed as a background well to the west of Ash Pond 3.

A trailer mounted Gemco drilling rig was used to install all monitoring wells except for MW15, which was installed using a hand auger due to access restrictions. During drilling and hand augering the subsurface conditions were logged and groundwater conditions noted. The drill rig used a 125 mm diameter solid stem auger fitted with a hardened steel V- bit or a diatube in the ash for MW11 to MW13. The lower 3.0 m section of each well was screened (except shallow well MW15 where the lower 1.0 m section was screened) with 50 mm machine slotted, Class 18, threaded PVC. Blank (unslotted) Class 18 PVC was used to case each well to the ground surface. Coarse sand was placed within each well annulus to a level of approximately 0.5 m above the top of the slotted screen, followed by an annular seal of bentonite. Concrete was then placed to the surface. The top of each well was completed with a steel monument.

The eight monitoring wells were then developed using an electric submersible pump following installation.

The approximate locations of MW11 to MW18 are shown in Figure 5.

Table 4: Existing Groundwater Monitoring Well Details (MW01 to MW10 and TAGM/D3)

Well ID	Easting (m MGA)	Northing (m MGA)	Location	Date Completed	Total Well Depth (m bgl)	Screen Interval (m bgl)	Screened Lithology	Diameter and Type of PVC Casing	Elevation Top of PVC Casing (m AHD)	Elevation Ground Surface (m AHD)
MW01	297731.9	6176080.1	Eastern edge of Ash Pond 3	4/3/2010	6.0	3.0 to 6.0	Alluvial/Estuarine (Clay) - connected with bund wall coalwash fill	50mm Class 18	2.82	2.68
MW02	297791.3	6176388.2	Eastern edge of Ash Pond 3	4/3/2010	5.8	2.8 to 5.8	Alluvial/Estuarine (Sand) - connected with bund wall coalwash fill	50mm Class 18	3.05	2.34
MW03	297545.0	6176690.5	Within Ash Pond 3	3/3/2010	5.8	2.8 to 5.8	Alluvial/Residual/ XW Sandstone - connected with ash fill	50mm Class 18	3.98	3.42
MW04	297590.9	6176299.8	Within Ash Pond 3	3/3/2010	6.2	3.2 to 6.2	Alluvial/Estuarine (Clay) - connected with ash fill	50mm Class 18	3.33	3.14
MW05	298381.4	6176516.4	South of Ash Pond 2	5/3/2010	7.5	4.5 to 7.5	Alluvial/Estuarine (Clay)	50mm Class 18	4.7	4.21
MW06	298481.4	6176739.3	Within Ash Pond 2	11/6/2010	7.5	3.0 to 7.5	Fill - Ash	42mm Class 18	10.92	10.28
MW07	298872.6	6176432.4	South of Ash Pond 2	5/3/2010	5.6	2.6 to 5.6	Weathered Sandstone (Berry Siltstone)	50mm Class 18	8.51	8.19
MW08	298837.0	6176677.1	Within Ash Pond 2	10/3/2010	3.6	0.6 to 3.6	Fill - Ash	42mm Class 18	6.51	5.96
MW09	298827.3	6177103.4	East of Ash Pond 1 adjacent to Lake Illawarra	5/3/2010	5.8	2.8 to 5.8	Alluvial/Estuarine (Clay)	50mm Class 18	3.07	2.38
MW10	297882.1	6176850.0	Outside ash ponds	17/8/2010	4.5	1.5 to 4.5	Alluvial/Estuarine (Sandy clay)	50mm Class 18	2.59	1.95
TAGM/D3	297629.8	6175761.6	South east of Ash Pond 3	Unknown	11.2	Unknown	Unknown	50mm	2.2	2.07

Table 5: New Groundwater Monitoring Well Details (MW11 to MW18)

Well ID	Easting (m MGA)	Northing (m MGA)	Location	Date Completed	Total Well Depth (m bgl)	Screen Interval (m bgl)	Screened Lithology	Diameter and Type of PVC Casing	Elevation Top of PVC Casing (m AHD)	Elevation Ground Surface (m AHD)
MW11	298321.8	6177203.7	Within Ash Pond 2	1/2/2011	10.0	7.0 to 10.0	Fill - Ash	50mm Class 18	11.79	11.10
MW12	298322.0	6177206.7	Within Ash Pond 2	1/2/2011	10.0	7.0 to 10.0	Fill - Ash	50mm Class 18	11.87	11.15
MW13	298319.2	6177205.4	Within Ash Pond 2	1/2/2011	7.0	4.0 to 7.0	Fill - Ash	50mm Class 18	11.88	11.11
MW14	298093.4	6176938.4	Outside ash ponds	1/2/2011	4.0	1.0 to 4.0	Alluvial/Estuarine (Sandy clay)	50mm Class 18	2.79	2.07
MW15	298379.1	6176480.3	Adjacent to Duck Creek	4/2/2011	1.5	0.5 to 1.5	Alluvial/Estuarine (Sandy clay)	50mm Class 18	1.36	0.62
MW16	297878.7	6176242.9	Wetland east of Ash Pond 3	31/1/2011	5.5	2.5 to 5.5	Alluvial/Estuarine (Clay)	50mm Class 18	1.92	1.30
MW17	297773.6	6176163.1	Wetland east of Ash Pond 3	31/1/2011	5.0	2.0 to 5.0	Alluvial/Estuarine (Sandy clay)	50mm Class 18	2.16	1.38
MW18	297113.4	6176542.0	Western site boundary	31/1/2011	5.8	2.8 to 5.8	Residual Clay/XW Sandstone	50mm Class 18	5.73	4.89

5.4 Aquifer Testing

Aquifer testing involved using data loggers and manual equipment to take measurements of groundwater levels during the various tests to allow assessment of aquifer properties such as transmissivity and hydraulic conductivity. The aquifer tests conducted included the following:

- Constant discharge test with multiple obervation piezometers within the ash at Ash Pond 2 (pumping of MW11);
- Constant discharge tests at two locations, MW09 adjacent to Lake Illawarra in clay material and MW04 at Ash Pond 3 in natural clay connected with the ash; and
- Slug tests at two locations, MW05 south of Ash Pond 2 in clay material and MW17 in the wetland area east of Ash Pond 3 in natural clay.

The pump test at MW11 was initially conducted on 24 February 2011 using an electric submersible Grundfos MP1 pump, with a maximum discharge rate of approximately 0.5 L/s. Due to higher than anticipated permeability of the ash material, this discharge rate was not sufficient to obtain the required drawdown response in the two observation wells, MW12 and MW13, located approximately 3 m from the pump well MW11.

A second pump test at MW11 was conducted on 15 March 2011 using a centrifugal Grundfos JPB9 pump, with a maximum discharge rate of approximately 2 L/s. A discharge rate of 1 L/s was achieved at a groundwater depth of approximately 4 m below ground level. The higher discharge rate provided sufficient drawdown response to allow analysis of the data for assessing aquifer properties.

The slug tests and constant discharge tests were conducted on 17 February 2011 using an electric submersible monsoon pump, with a maximum discharge rate of approximately 0.1 L/s. The slug tests involved pumping the well dry and measuring water level recovery (rising head tests) and the constant discharge tests involved pumping the well at a constant rate for approximately 30 minutes (as these wells were not pumped dry) and measuring water level recovery.

5.5 Groundwater Sampling

Groundwater sampling was conducted between 15 February and 8 March 2011. Newly installed monitoring wells MW11 to MW18 were allowed to stabilise for at least 7 days prior to sampling being carried out. Six of the eight new monitoring wells were sampled as MW12 and MW13 were within 3 m of MW11 and were therefore not sampled. Sampling of groundwater from existing monitoring wells included MW01 to MW06, MW08 to MW10 and TAGM/D3. Standing water levels were checked using an electronic probe prior to sampling. Existing monitoring well MW07 was dry and therefore not sampled.

Typically two well volumes were removed from all wells during purging, where practicable. The volume was less at five locations (MW06, MW08, MW16, MW17 and MW18) where only one well volume was removed before the wells went dry and did not recover quickly.

Field parameters recorded during the well purging included temperature, pH, electrical conductivity (EC), dissolved oxygen (DO) and reduction oxidation potential (E_r) using a calibrated water quality meter.

The monitoring wells were purged and sampled using similar procedures as described in our previous reports (Coffey Environments, 2010a and 2010b) using dedicated disposable plastic bailers. The groundwater samples were placed into appropriately preserved containers supplied by the contract laboratory. The groundwater samples for heavy metals analysis were filtered in the field with a 0.45µm filter. The groundwater samples were immediately stored in a chilled insulated container.

5.6 Surface Water Sampling

Surface water locations were included in the sampling program to assess potential contaminant concentrations within close proximity to the discharge area west of Ash Pond 2 and at the surface of Ash Pond 3. Surface water sampling was carried out at two locations, designated SW7 and SW8 as follows:

- SW7 was collected in the pond to the west of Ash Pond 2 and in the vicinity of the newly installed monitoring well MW14.
- SW8 was collected in the lake within Ash Pond 3.

Field parameters were measured at each location using a calibrated water quality meter (temperature, pH, EC, DO and E_r). The water sample was collected with a telescopic sampler which was washed with a phosphate free detergent, rinsed with potable water followed by rinsing with distilled water between sampling locations.

The surface water samples were placed into appropriately preserved containers supplied by the contract laboratory. The surface water samples for heavy metals analysis were filtered in the field with a 0.45µm filter. The surface water samples were immediately stored in a chilled insulated container.

5.7 Coalwash, Ash and Soil Sampling

A field program was conducted on 18 April 2011 to further assess the potential sources of contaminants in the groundwater system, particularly for ammonium. Test pits were excavated to a maximum depth of 3.7 m using a backhoe under the supervision of a Coffey environmental scientist. Test pit logs are included in Appendix C and test pit locations are illustrated in Figure 4.

Samples were collected of the ash, coalwash and natural clay material at the locations and depths listed in Table 6.

Table 6: Summary of Coalwash, Ash and Soil Sampling Locations

Area of Site	Coffey Test Pit	Sample Type and Location	Sample Depths (m)
Zone 2(A)	CTP87	Coalwash within the bund wall and access road of Ash Pond 2.	0.5-0.6 m, 1.4-1.6 m
Zone 2(A)	CTP88	Ash within Ash Pond 2, approximately 200 m east of MW06.	0.6-0.8 m, 3.5-3.7 m
Zone 4(A)	CTP89	Coalwash within the bund wall and access road of Ash Pond 3, approximately 10 m north of MW01.	0.5-0.6 m, 1.8-2.0 m
Zone 3(A)	CTP90	Coalwash within the bund wall and access road of Ash Pond 3, approximately 10 m west of MW02.	0.5-0.6 m, 1.8-2.0 m
Zone 3(A)	CTP91	Ash within Ash Pond 3, approximately 10 m north of MW04.	0.6-0.8 m, 1.6-1.8 m
Zone 3(A)	CTP92	Ash within Ash Pond 3, approximately 10 m north west of MW03.	0.6-0.8 m, 1.0-1.1 m
Zone 4(C)	CTP93	Natural clay material, approximately 2 m west of MW15 adjacent to Duck Creek.	0.6-0.7 m
Zone 4(C)	CTP94	Natural clay material, approximately 10 m north of MW17 in the wetland area.	0.4-0.5 m, 0.8-1.0 m

5.8 Additional Soil Sampling

A field program was conducted on 23 August 2011 to collect information on the binding capacity of the clay. The additional data was used as part of the assessment of retardation factors in the contaminant transport model. Four hand auger locations were completed to a maximum depth of 1 m by a Coffey environmental scientist. Logs are included in Appendix D and locations are illustrated in Figure 5.

Samples were collected of the natural clay material at the locations and depths listed in Table 7.

Table 7: Summary of Additional Soil Sampling Locations

Area of Site	Coffey Hand Auger ID	Sample Type and Location	Sample Depths (m)
Zone 3(A)	HA1	Natural clay material, approximately 1 m east of Ash Pond 3 bund wall.	0.8-1.0 m
Zone 4(C)	HA4	Natural clay material, approximately 17 m east of Ash Pond 3 bund wall.	0.8-1.0 m
Zone 4(C)	HA2	Natural clay material, approximately 50 m east of Ash Pond 3 bund wall.	0.8-0.9 m
Zone 4(C)	HA3	Natural clay material, approximately 110 m east of Ash Pond 3 bund wall.	0.6-0.7 m

5.9 Field Quality Control Procedures

The field quality control consisted of the following:

- Sampling was performed generally in accordance with the procedures outlined in Coffey Environments relevant standard operating procedures, which are based on industry accepted protocols for environmental sampling. This was carried out by a trained and experienced environmental scientist or engineering geologist. Sampling staff had undergone Coffey Environments internal training procedures in accordance with the Coffey Environments standard operating procedures and supervised field training;
- Calibration of field instruments in accordance with manufacturer's instructions;
- Collection and analysis of two blind coded duplicate groundwater samples, QC01 (duplicate of primary sample MW05) and QC03 (duplicate of primary sample MW01) for dissolved heavy metals (arsenic, cadmium, chromium, copper, lead, molybdenum, nickel and zinc), ammonium, nitrate, nitrite, total kjeldahl nitrogen (TKN) and total nitrogen;
- Collection and analysis of three blind coded duplicate soil samples, QC1 (duplicate of clay primary sample CTP93/0.6-0.7), QC2 (duplicate of coalwash primary sample CTP89/1.8-2.0) and QC3 (duplicate of ash primary sample CTP91/0.6-0.8) for dissolved heavy metals (arsenic, cadmium, chromium, copper, lead, molybdenum, nickel and zinc), ammonium, nitrate, nitrite, TKN and total nitrogen;
- Collection and analysis of one blind coded duplicate soil sample, QC1 (duplicate of hand auger sample HA1/0.8-1.0) for TOC, CEC, ammonium, nitrate, nitrite, TKN and total nitrogen; and
- Samples were transported in chilled insulated containers to the contract laboratory, SGS Environmental Services Pty Ltd (SGS) in Sydney, which is NATA accredited for the analysis performed, under chain of custody conditions. Copies of the chain of custodies are included in Appendix E.

5.10 Laboratory Analysis

The groundwater, surface water and leachate water samples were tested for dissolved heavy metals (arsenic, cadmium, chromium, copper, lead, molybdenum, nickel and zinc), ammonium, nitrate, nitrite, TKN and total nitrogen.

Leachate analyses were conducted on samples of coalwash, ash and alluvial/estuarine sediments. The Australian Standard Leaching Procedure (ASLP) was conducted using neutral deionised laboratory water.

The solid samples of coalwash, ash and clay soils were also analysed for the same suite of heavy metals and nitrogen compounds.

The additional clay samples were analysed for TOC, CEC, ammonium, nitrate, nitrite, TKN and total nitrogen.

The laboratory results are discussed in Section 6.5 and the laboratory reports are presented in Appendix F.

6 RESULTS

6.1 Groundwater Levels and Flow

Groundwater levels from the gauging round conducted on 12 April 2011 are listed in Table 8. In the alluvial/estuarine sediments, groundwater levels range from 0.36 m AHD at MW15 adjacent to Lake Illawarra, to 1.53 m AHD at TAGM/D3. Groundwater levels within Ash Pond 3 ranged from 2.15 m AHD at MW03 to 2.17 m AHD at MW04 for the natural alluvial/estuarine sediments below.

MW07 screened in weathered sandstone bedrock was dry. Groundwater levels within the ash in Ash Pond 2 ranged from 8.0 m AHD at MW11 to 4.34 m AHD at MW06. In the south eastern saltmarsh inundated area water levels were 0.86 m above ground level, at an elevation of 6.82 m AHD at MW08. This inundated area is bunded and considered as separate to the rest of the Ash Pond 1 and 2 system. Surface water drainage from Ash Pond 1 and 2 is directed towards the inundated area.

Table 8: Monitoring Well Groundwater Levels from 12 April 2011

Well ID	Location	Elevation Top of PVC Casing (mAHD)	Elevation Ground Surface (mAHD)	Groundwater Depth (mbgl)	Groundwater Level (mAHD)
MW01	Eastern edge of Ash Pond 3	2.82	2.68	1.57	1.11
MW02	Eastern edge of Ash Pond 3	3.05	2.34	1.20	1.14
MW03	Within Ash Pond 3	3.98	3.42	1.28	2.15
MW04	Within Ash Pond 3	3.33	3.14	0.98	2.17
MW05	South of Ash Pond 2	4.70	4.21	2.96	1.25
MW06	Within Ash Pond 2	10.92	10.28	5.95	4.34
MW07	South of Ash Pond 2	8.51	8.19	Dry to 5.6m bgl	Dry to 2.6m AHD
MW08	Within Ash Pond 2	6.51	5.96	-0.86[1]	6.82[1]
MW09	East of Ash Pond 1	3.07	2.38	1.44	0.94
MW10	Outside ash ponds	2.59	1.95	0.87	1.08
MW11	Within Ash Pond 2	11.79	11.10	3.10	8.00
MW12	Within Ash Pond 2	11.87	11.15	3.16	7.99
MW13	Within Ash Pond 2	11.88	11.11	3.12	7.99
MW14	Outside ash ponds	2.79	2.07	0.80	1.27
MW15	Adjacent to Duck Creek	1.36	0.62	0.26	0.36
MW16	Wetland east of Ash Pond 3	1.92	1.30	0.64	0.66
MW17	Wetland east of Ash Pond 3	2.16	1.38	0.41	0.98
MW18	Western site boundary	5.73	4.89	1.72	3.17
TAGM/D3	South east of Ash Pond 3	2.20	2.07	0.54	1.53

[1]Above ground water level corresponds to surface water level in the inundated area of Ash Pond 2.

Groundwater level data loggers were installed on 22 December 2010 at five existing monitoring wells across the site (MW01, MW04, MW05, MW08 and MW09). In addition to these locations, two data loggers were installed at new monitoring well locations, one in Ash Pond 2 (MW11) and one in the wetland east of Ash Pond 3 (MW17). All loggers were removed on 9 February 2012. Hydrographs are illustrated in Figure 6.

All monitoring wells show an increase in groundwater level for the rainfall events between 20 and 22 March 2011, where a total of 397 mm was recorded at the Wollongong Airport weather station in Albion Park, approximately 2 km south west of the site. The increase in groundwater levels ranged from approximately 0.8 m at MW11 in Ash Pond 2 to approximately 2.0 m at MW04 in Ash Pond 3. The increase of around 3.5 m at MW08 corresponds to an above ground surface water level in the inundated area of Ash Pond 2. Water levels in this holding pond have remained relatively constant around 7 m AHD since March 2011. Redirected runoff and power station water is piped at a daily rate of approximately 0.1 ML/day to the wetland pond in the north of Ash Pond 2, which drains along with additional surface water runoff from Ash Pond 1 and 2 to the holding pond where MW08 is located.

Based on analysis of groundwater level rises for the main rainfall event in March 2011, groundwater recharge from rainfall is assessed to be between approximately 5% and 10%.

Groundwater flow south of Duck Creek is to the north east towards Duck Creek, to the east towards Lake Illawarra and to the south east towards Macquarie Rivulet. Groundwater flow north of Duck Creek is radial from the elevated Ash Pond 1 and 2 area towards Duck Creek and Lake Illawarra.

The elevated groundwater levels within the ash ponds are above the natural sediment. Groundwater flow from the ash ponds to the surrounding environment is assessed as being predominantly vertical flow through the base of the ponds rather than horizontal flow through the bund walls. No groundwater was observed by Coffey staff as seepage from the bund walls during site visits for the current assessment nor during the previous subsurface investigations in 2010. Most of the bund walls for Ash Pond 1 and 2 are vegetated with a range of species including swamp oaks (*Casuarina glauca* and other tree species) and weeds. It is therefore assessed that if groundwater were to flow horizontally through the bund walls in this area, the groundwater would be consumed by evapotranspiration.

The ash level within Ash Pond 3 is lower than the bund walls, and groundwater levels on the eastern edge of Ash Pond 3 are at an elevation of approximately 1 m AHD (MW01 and MW02), which is at a similar elevation to the surface water in the drainage channel flowing north to Duck Creek. The drainage channel is located approximately 10 m from monitoring wells MW01 and MW02. The lake in the southern part of Ash Pond 3 is connected to the groundwater system in this area. Surface water overflows from the lake are directed to the lake outside the bund wall to the west, which then flows in a series of drainage channels flowing east along the southern Ash Pond 3 boundary, and then north towards Duck Creek along the eastern Ash Pond 3 boundary.

6.2 Aquifer Properties

Movement of groundwater within the ash ponds and the natural alluvial/estuarine sediments is governed by aquifer properties including hydraulic conductivity and effective porosity, and by the hydraulic gradient in the aquifer. These properties are reported in the following sections.

6.2.1 Hydraulic Conductivity

6.2.1.1 Constant Discharge Test with Multiple Observation Piezometers

In order to assess the hydraulic conductivity of the ash material, a pump test was conducted. The pump test comprised groundwater well installation followed by test pumping. One pumping well (MW11) screened between 7 and 10 m depth, and two monitoring wells (MW12 and MW13) were installed within Ash Pond 2. The monitoring wells were used for measuring drawdown in groundwater levels in the ash while pumping from the pumping bore located 3 m away. The monitoring well screens covered the depth intervals 7 to 10 m, and 4 to 7 m. This arrangement was used to obtain drawdown data that, when analysed using specialist pump-testing interpretation software (WTAQ), would provide an estimate for the important quantity of vertical hydraulic conductivity for the ash, in addition to the lateral hydraulic conductivity and specific storage.

The computer code WTAQ (Barlow and Moench, 1999) was used for the analysis, in combination with software that can estimate parameter values in an iterative fashion by matching the model calculated values to actual field observations. WTAQ takes into account vertical heterogeneity (the fact that vertical and horizontal hydraulic conductivities are usually very different) and variable well screen lengths within an aquifer, and so is a powerful program for interpretation of pump test drawdown data.

Figure 7 shows the observed and calculated drawdowns for the pump test. The pumping well has also been used for analysis (in combination with a well loss drawdown component) as an additional check on calculated parameters. The match is considered good, and the conceptual model used by the software is valid. Calculated parameters are well resolved and have small error margins. Calculated aquifer parameters are a hydraulic conductivity of the ash of about 50 m/day, a vertical hydraulic conductivity of about 1 m/day, and a specific storage of about 5×10^{-4} m^{-1}, indicating a more compressive aquifer than is typically seen for sediments.

6.2.1.2 Slug Test and Constant Discharge Single Well Tests

Slug tests were conducted at two locations, MW05 south of Ash Pond 2 in clay material and MW17 in the wetland area east of Ash Pond 3 in natural clay. Constant discharge tests were conducted at two locations, MW09 adjacent to Lake Illawarra in clay material and MW04 at Ash Pond 3 in natural clay connected with the ash. Interpretation graphs are shown in Figure 8.

The slug tests involved pumping the well dry and measuring water level recovery (rising head tests). Slug tests were analysed using the Hvorslev method (Hvorslev, 1951). The constant discharge tests involved pumping the well at a constant rate for approximately 30 minutes (as these wells were not pumped dry) and measuring water level recovery. Recovery data were analysed using the Jacob method (Cooper and Jacob, 1946). Interpretation graphs are shown in Figure 9.

Results for the above tests are detailed in Table 9. The ash material shows the highest permeability, with a horizontal hydraulic conductivity of approximately 50 m/day. The lowest measured permeabilities are for the alluvial/estuarine clay in the wetland area to the east of Ash Pond 3, with a hydraulic conductivity value of approximately 0.04 m/day. Intermediate values around 0.5 m/day were obtained for the sandy clays south and east of Ash Pond 2.

Table 9: Summary of Aquifer Test Results

Monitoring Well	Aquifer Test Type	Hydrogeological Unit	Horizontal Hydraulic Conductivity (m/day)	Comments
MW11-MW13	Pump test	Ash within Ash Pond 2	50	High permeability ash material
MW05	Slug test	Alluvial/estuarine clay	0.5	Higher permeability influenced by sandy clay material
MW17	Slug test	Alluvial/estuarine clay	0.04	Lower permeability wetland clay
MW04	Constant discharge test	Alluvial/estuarine clay connected with ash within Ash Pond 3	2.9	Higher permeability influenced by ash material
MW09	Constant discharge test	Alluvial/estuarine clayey sand and clay	0.4	Higher permeability influenced by sand layer at base of well

6.2.1.3 Previous Piezocone Data

Since groundwater flow from the ash dams was assessed as being predominantly vertical through the base of the ash ponds rather than horizontal, vertical hydraulic conductivity values were previously calculated from horizontal conductivity data (Coffey Environments, 2010c) assessed as part of the initial piezocone investigation works (Coffey Environments, 2010a). The time for 50% pore pressure dissipation was assessed and horizontal conductivity values were calculated using the method by Robertson et al (1997). Piezocone tests tended to fail in higher permeability strata such as coarse ash material. Approximately 50 % of the piezocone dissipation tests were recorded as failures, introducing a bias to the results.

Horizontal hydraulic conductivities measured from the piezocone dissipation tests ranged from 0.0002 m/day in the fine ash material to 0.02 m/day in the coarser ash material. This was similar to the underlying natural sediments, where horizontal hydraulic conductivities ranged from 0.0001 m/day to 0.01 m/day (Coffey Environments, 2010c). These values are up to five orders of magnitude lower compared to the Tallawarra aquifer test data summarised in Table 9. Results from aquifer tests conducted in piezometers or wells more accurately reflect aquifer properties because a greater volume of the aquifer is engaged during such tests. The small scale of the piezocone test method as well as a tendency toward successful tests in lower permeability layers, and test failures in higher permeability materials, as described below, may account for the differences between the data sets.

For the piezocone tests, pore water pressure dissipation times are variable, which is typical for this type of test. Several tests appear to have been conducted in drainage layers (in sand or other higher permeability material) encountered in the ash or underlying alluvial/estuarine sediments, resulting in shorter dissipation test times. These tests were generally not successful for assessing horizontal hydraulic conductivity, therefore the data previously tabulated may have included a greater proportion of the lower permeability material.

Such variations consisting of vertically and laterally discontinuous and irregular lenses are consistent with the visual and laboratory data from test pits and boreholes previously collected at the site (Coffey Environments, 2010a).

6.2.1.4 Reference Values for Ash

Reference values for hydraulic conductivity values of ash material from other published studies are listed in Table 10. The values listed for fly ash (0.0002 and 0.0004 m/day) and the geometric mean for the field testing from South Africa (0.02 m/day) are up to five orders of magnitude lower compared to the Tallawarra aquifer test data. The value for the coarse bottom ash material (15 m/day) is closer to the Tallawarra value of around 50 m/day and illustrates the wide range of hydraulic conductivity possible for the ash material.

Table 10: Reference Values for Ash Hydraulic Conductivity

Report Reference	Study Location	Horizontal Hydraulic Conductivity Values (m/day)				
		Fly Ash (Fine)	Bottom Ash (Coarse)	Average Saturated	Geometric Mean - Lab Testing	Geometric Mean - Field Testing
Muhardi et al, 2010	Tanjung Bin Ash, Malaysia	0.0004	15			
Mudd, 2000	Latrobe Valley, Victoria, Australia			0.3		
Yeheyis, 2008	Ontario, Canada	0.0002				
October et al, 2009	Various locations, South Africa				0.18	0.02

6.2.2 Effective Porosity

The effective porosity of a medium is that porosity which must be used to reproduce observed travel times in tracer experiments. It is lower than the total porosity and, in most instances, is larger than the specific yield. It is also known as the kinematic porosity. Reasonable estimates of effective porosity for the ash and alluvial/estuarine sediments, based on bore logs, are 15% and 25% respectively.

6.2.3 Hydraulic Gradients

Based on the interpreted groundwater contour map presented in the preliminary hydrogeological report (Coffey Environments, 2010c) hydraulic gradients vary from 0.001 in the low lying wetland area east of Ash Pond 3 to steeper gradients of around 0.05 in the elevated Ash Pond 1 area towards Lake Illawarra.

6.2.4 Rate of Groundwater Movement

Since groundwater flow from the ash ponds is assessed as being predominantly vertical through the base of the ash ponds rather than horizontal, vertical hydraulic conductivity values are used to assess the rate of groundwater movement from the ash ponds. Based on an average vertical hydraulic conductivity of 1 m/day, an average effective porosity of 15% and a hydraulic gradient of 0.05 (see Section 6.2.3), the rate of vertical groundwater movement within the ash is around 0.3 m/day or 110 m/year.

Once groundwater reaches the base of the ash ponds, entry of the groundwater into the underlying alluvial/estuarine clay sediments is controlled by the lower permeability of the clay compared to the ash material. Based on an average horizontal hydraulic conductivity of 0.1 m/day, an average effective porosity of 25% and a hydraulic gradient of 0.001 (see Section 6.2.3), the rate of horizontal groundwater movement within the clay is around 0.0004 m/day or 0.2 m/year.

Groundwater discharge from the ash ponds is therefore limited by the aquifer properties of the alluvial/estuarine sediments.

Calculated rates of groundwater movement are highly variable depending on the adopted aquifer properties, gradients and local conditions considered.

6.3 Water Sampling

6.3.1 Observations

The following observations were made during sample collection:

- The surface water samples were slightly cloudy;
- Typically, the groundwater samples were slightly cloudy to turbid;
- The colour of the groundwater at MW01, MW02, MW04, MW05, MW09, MW10, MW17, MW18 and TAGM/D3 was generally brown to orange brown;
- The colour of the groundwater at MW03, MW06, MW08, MW11, MW14, MW15 and MW16 was generally grey to grey brown;
- No visual evidence of oily sheens or hydrocarbon odours were apparent during sampling;
- Slight organic odours were noted at the groundwater monitoring well locations MW01, MW02, MW09 and MW16; and
- Moderate decaying organic matter odour was noted at the well locations MW14 and MW15. Frogs were also noted within and outside the well MW15 adjacent to Duck Creek.

6.3.2 Field Quality Parameters – Groundwater

Groundwater quality parameters measured in the field are presented in Table LR1 and summarised below.

- DO measurements ranged between 0.9 mg/L (MW08) and 5.6 mg/L (MW17);
- E_r measurements ranged between reducing conditions, -150 mV (TAGM/D3) and oxidising conditions, +245 mV (MW09);
- EC measurements ranged between brackish conditions, 4.08 mS/cm (MW18) and saline conditions, 46.80 mS/cm (MW06);
- pH measurements ranged between acidic conditions with a pH of 4.2 (MW03 and MW09) and slightly alkaline conditions with a pH of 8.2 (MW11); and
- Temperature measurements ranged between 18.1°C (MW05) and 22.6°C (MW01 and MW04).

6.3.3 Field Quality Parameters – Surface Water

Surface water quality parameters measured in the field are presented in Table LR1 and summarised below.

- DO measurements ranged between 8.0 mg/L (SW7) and 6.9 mg/L (SW8);
- E_r measurements ranged between -56 mV (SW7) and +20 mV (SW8);
- EC measurements indicated brackish water and ranged between 5.85 mS/cm (SW8) and 6.04 mS/cm (SW7);
- pH measurements indicated slightly alkaline conditions and ranged between 8.1 (SW7) and 8.8 (SW8); and
- Temperature measurements ranged between 26.6°C (SW7) and 32.3°C (SW8).

6.4 Coalwash, Ash and Soil Sampling

6.4.1 Observations

The following observations were made during sample collection:

- The coalwash samples were generally fine to coarse grained gravels, black, with no odours noted;
- The ash samples were generally sandy silts, grey, with no odours noted; and
- The alluvial/estuarine sediment samples were generally sandy clays, dark brown or grey, with moderate organic odours noted.

6.5 Laboratory Results

The laboratory results are summarised in attached Tables LR1 to LR4. The laboratory certificates are included in Appendix F.

6.5.1 Data Validation

The data were assessed against predetermined Data Quality Objectives (DQOs) and Data Quality Indicators (DQIs) (completeness, comparability, representativeness, precision, and accuracy) for both field and laboratory procedures and results. Two data validation reports have been prepared and are included in Appendix G.

Based on the assessment, it is considered that the data collected for this assessment are adequate and meet the DQOs and DQIs.

6.5.2 Major Ions

The results for the major cations and anions are summarised in Table LR1 and are illustrated in a trilinear piper plot presented in Figure 10. The piper plot shows that the dominant water type for all groundwater samples is sodium chloride, irrespective of whether the groundwater is from the alluvial/estuarine sediments, residual sediments or connected with ash or coalwash material. Typical values for seawater were also plotted and included in Figure 10 to illustrate the similarities in composition between the groundwater and seawater. Considering the coastal site location, the seawater signature for the estuarine alluvial sediments is considered reasonable. The seawater signature of the ash and coalwash may be due to mixing with alluvial/estuarine groundwater (at low elevations), and evaporative concentration of rainfall salts (at higher elevations in the ash). The signature of rainwater is typically very similar to the seawater signature.

6.5.3 Comparison of Laboratory Results to Groundwater, Surface Water and Leachate Water Investigation Levels

The laboratory results are summarised and compared to the adopted investigation levels in Table LR1. Concentrations of various heavy metals (arsenic, chromium, copper, lead, molybdenum, nickel and zinc), ammonium and total nitrogen exceed the adopted investigation levels at background locations, within the ash ponds and downslope of the ash ponds.

Table LR2 includes results from our previous assessments for comparison purposes. Results show generally similar concentrations, with the exception of a decrease in ammonium at MW01 from 12 mg/L in August 2010, to 2.2 mg/L in February 2011. Since the sampling procedures are the same between these sampling events, the likely reason for the change in concentration is not clear. The August 2010 sampling round did not include total kjeldahl nitrogen (TKN), and the differences may include an increase in organic nitrogen and a subsequent decrease in ammonium concentrations.

Table LR3 includes results for the leachate analyses conducted on solid samples of coalwash, ash and alluvial/estuarine sediments. The Australian Standard Leaching Procedure (ASLP) was conducted using neutral deionised laboratory water. The results indicate that concentrations of arsenic consistently exceed the adopted investigation level for leachate from the ash material and concentrations of molybdenum exceed the investigation level for the clay sediment south of Ash Pond 2. Leachate results are discussed further in Section 7.2.

6.5.4 Comparison of Laboratory Results to Soil Investigation Levels

Table LR3 includes results for the soil samples of coalwash, ash and clay soils analysed for the same suite of heavy metals and nitrogen compounds as the leachate tests. The results show that the heavy metals concentrations are below the investigation levels.

Table LR4 includes results for the additional clay samples analysed for TOC, CEC, ammonium, nitrate, nitrite, TKN and total nitrogen.

There are no nutrient guidelines as part of the NEPM guidelines (NEPC, 1999), and other agricultural guidelines depend on crop types, soil and fertiliser application, which are not considered applicable for this assessment. Soil results for the nutrient suite are discussed further in Section 7.2.

There are no guidelines for TOC and CEC, these analytes were used to assess the binding capacity of the clay.

7 HYDROGEOLOGICAL CONCEPTUAL MODEL

In order to understand the spatial and temporal variability of groundwater quality, it is important to have a conceptual model of the groundwater flowpath and the travel time from the contaminant source to the sampling point. Along the flowline, chemicals may become sorbed which retards their transport compared to the velocity of water. Furthermore, physical processes such as diffusion and dispersion cause mixing and smoothen concentration changes.

The following sections outline the hydrogeological conceptual model for the site that was used as a basis for the numerical groundwater modelling assessment. A schematic diagram summarising the main components of the conceptual model is shown in Figure 11.

7.1 Flow Mechanisms

7.1.1 Groundwater Recharge

Groundwater recharge to the aquifer can occur via the following processes:

- Direct rainfall infiltration;
- Runoff from the hills to the north and west reporting to the alluvial/estuarine aquifer; and
- Recharge from bedrock.

The upper layers of the underlying bedrock may provide minor groundwater recharge in dryer times. Depending on overall sediment thickness (and the closure of rock apertures and their weathering), the upper bedrock layers are expected to have lower overall permeability compared with the alluvial/estuarine aquifer.

Based on analysis of groundwater level rises for the main rainfall event in March 2011 (Figure 6), aquifer recharge estimates range between approximately 5% and 10%.

7.1.2 Groundwater Discharge

Discharge of groundwater from the aquifer will occur via the following processes:

- Lateral flow to Lake Illawarra and other surface water bodies including Duck Creek, Wollingurry Creek and drainage channels;
- Evapotranspiration by vegetation with sufficient root depth;
- Evaporation from ponded water; and
- Leakage to bedrock.

The upper layers of the underlying bedrock may accept groundwater leakage from the alluvial/estuarine aquifer in wetter times. Depending on overall sediment thickness (and the closure of rock apertures and their weathering), the upper bedrock layers are expected to have lower overall permeability compared with the alluvial/estuarine aquifer.

7.1.3 Groundwater Flow Volumes

Based on adopted aquifer parameters outlined in Section 6.2.4, the vertical groundwater velocity for the ash material is around 0.3 m/day or around 110 m/year and the horizontal velocity for the alluvial/estuarine clay is around 0.0004 m/day or around 0.2 m/year. Therefore the controlling influence on movement of groundwater from the ash mounds into the wider environment is controlled by the lower permeability of the alluvial/estuarine sediments.

Potential groundwater flux from the ash ponds was previously assessed based on a lower vertical hydraulic conductivity of the ash (0.0007 m/day) estimated from piezocone results (Coffey Environments, 2010c). Due to the limiting factors of the dissipation test from piezocone testing (as discussed earlier), a pump test with multiple observation piezometers in the ash was undertaken to obtain more reliable results. These results showed that the vertical hydraulic conductivity of the ash was likely to be significantly higher than the clay. Since the vertical hydraulic conductivity of the clay is likely to be significantly less than for the ash (1 m/day), the maximum seepage rate through the base of the ash will, in the long term, be controlled by the clay.

Movement of groundwater from the base of the ash ponds to receptors such as Duck Creek will be limited by the aquifer properties of the alluvial/estuarine sediments. These water budgets are discussed further as part of numerical groundwater modelling results in Section 10.2.

To compare the magnitudes of groundwater flow from the ash ponds and surface water flows within Duck Creek, the following information was previously reviewed (Coffey Environments, 2010c). The six hour duration 100 year ARI peak flow for Duck Creek at the Lake Illawarra outlet was reported to be 289 m^3/s or around 24,970 ML/day (Bewsher, 2010). For the Duck Creek surface water catchment, average flows of approximately 1 m^3/s or around 86 ML/day are considered reasonable (pers. comm. Bewsher, 2010). Based on numerical groundwater modelling results outlined in Section 10.2, the combined groundwater flow rate out of the ash to the underlying alluvial/estuarine sediments for Ash Ponds 1 to 3 is approximately 0.5 ML/day. The average flow rate for Duck Creek is therefore higher than the groundwater flux from the ash.

7.2 Groundwater Quality and Contaminant Sources

Assessment of groundwater within the ash ponds indicates isolated impact from arsenic (up to 330 µg/L at MW06), chromium (up to 330 µg/L at MW08), molybdenum (up to 110 µg/L at MW06) and nickel (up to 2,400 µg/L at MW08), above background or downslope concentrations. As previously reported, it is likely that the ash ponds are a source of dissolved heavy metals, however concentrations in the receiving surface water environment are generally within background ranges (Coffey Environments, 2010b).

The more complicated groundwater quality issue with respect to assessing a potential source is the elevated concentrations of ammonium found at the site. The pH-pe diagram illustrated in Figure 12 shows that for the pH values recorded at the site (less than pH 8), the ammonium ion (NH_4^+) dominates, rather than ammonia (NH_3). Ammonia only dominates in alkaline conditions where pH values are greater than 9. This is the reason ANZECC (2000) trigger values for ammonia/ammonium are pH dependent (trigger values decrease as pH increases).

The highest ammonium levels recorded on site are south of Ash Pond 2 adjacent to Duck Creek (20 mg/L at MW15), west of Ash Pond 2 (15 mg/L at MW14) and south of Ash Pond 3 (17 mg/L at TAGM/D3). High organic nitrogen content is also a characteristic of the groundwater, with concentrations up to 22 mg/L adjacent to Duck Creek at MW15. Organic nitrogen concentrations are part of the total kjeldahl nitrogen (TKN) results, where:

TKN = organic nitrogen + ammonium + ammonia

Since the highest ammonium concentrations are found outside the ash ponds, this shows either that:

- The dominant source of the ammonium used to be relatively mobile dissolved ammonia (in an unknown form) within the ash during deposition (which ceased in 1989). The ammonia could have leached from the ash quickly, leaving behind elevated concentrations at some distance from the ash ponds, representing the current position of the plume; or
- The dominant source of the ammonium is the coalwash placed in the bund walls of the ash ponds, including the organic material associated with the coalwash material (mixture of soil, shale and coal which has high total organic carbon (TOC) content); or
- The dominant source of the ammonium is related to natural degradation of nitrogen in the clay in a reducing wetland environment with high natural organic matter content (microbial processes, commonly described as the nitrogen cycle).

Available data suggest that the first two sources listed above have both been active in producing ammonium. Ammonium from the ash has migrated through the more permeable, low TOC ash material until it has reached the bund wall. The ammonium has sorbed to any organic material in the bund wall and has eventually overwhelmed the binding sites and then migrated into the clay soil. Cations (positively charged ions) such as ammonium are readily sorbed or exchanged to negatively charged mineral surfaces such as clays (Environment Agency, 2005).

To assess a possible inorganic source of ammonium on site, additional sampling and chemical analysis of coalwash, ash and alluvial/estuarine clay was conducted. Analysis of the solid samples (prior to conducting neutral leachate tests) shows that both the natural clay soil and the coalwash have similar concentrations of TKN (mainly organic nitrogen), with the highest concentration found in the clay (5,300 mg/kg in the wetland east of Ash Pond 3). The highest TKN concentration found in the coalwash was 4,200 mg/kg while the highest concentration found in the ash was 1,100 mg/kg. The highest ammonium concentrations were found in the clay material with results ranging between 4.4 mg/kg and 11 mg/kg. Two samples from the ash within the saturated zone at the base of Ash Pond 3 showed similar concentrations to the clay (6.5 mg/kg and 11 mg/kg). It is considered that these ash samples were influenced by being in contact with the saturated zone and are within 0.1 m of the natural clay sediment.

Neutral leachate analyses were conducted on the solid samples using the Australian Standard Leaching Procedure (ASLP). ASLP is a laboratory procedure that has similarities to a process of accelerated weathering, but is certainly not equivalent to natural weathering.

An interpretation of the leachate results is provided in Table 11. Based on the leachate results, coalwash appears to have elevated TKN concentrations, similar to the clay and ash has the potential to release arsenic as a result of weathering and/or saturation.

Table 11: Summary of Leachate Results

Aspect	Coalwash	Ash	Clay Soil	Comment
pH of final leachate	6.7 to 8.2	6.8 to 8.0	5.0 to 7.3	Weathering processes in clay soils may generate slightly acidic conditions, which could increase mobility of metals from fill material within the groundwater saturated zone.
Metals	As, Cu , Pb, Zn: higher total, lower leachability	As: higher leachability	Cu, Mo, Zn: higher leachability	Potential mobility of arsenic from ash, but low concentrations in leachate.
Ammonium	Low	Low	Higher	Trigger value for ammonia (measured as ammonium) is 0.91 mg/L for marine species and varies with pH. Adopting the marine trigger value (representing pH 8) would be conservative. Thus, ammonium does not appear to be an issue of concern with any of the materials assessed.
Total Nitrogen	Consistent TKN about 10 times trigger value, but generally lower than from clay soil (considering averages)	Consistent low TKN	Variable TKN	The highest leachate result for TKN (mainly organic nitrogen) is from the clay sample to the east of Ash Pond 3 in the wetland (17 mg/L), compared to the highest concentration in the coalwash (4.6 mg/L) or ash (0.42 mg/L).

Additional data was collected from the clay samples adjacent to the Ash Pond 3 bund wall to assess the binding capacity of the clay (results attached in Table LR4). The dominant retardation mechanism for binding ammonium at the Tallawarra site is the cation exchange capacity (CEC) of the clay since the TOC results are low (a maximum value of 0.5% was reported). Therefore the third potential source of ammonium listed previously (natural degradation of nitrogen in the clay) is not applicable at the site as it would require high organic matter content to assist the microbial processes as part of the nitrogen cycle. The samples were collected at progressive distances from the bund wall, approximately 1 m, 17 m, 50 m and 110 m east of the bund wall. The nutrient suite results confirm the limited ammonium migration distance from the bund wall. The highest ammonium concentration was found 1 m from the bund wall (7.2 mg/kg) and the lowest concentration was found 110 m from the bund wall (0.41 mg/kg).

Where oxygenated groundwater migrates through the ammonium rich clay (either from recharge or upgradient groundwater) nitrate will be produced and then has the potential to migrate at the same speed as groundwater through the alluvial/estuarine soil as it is non-retarded. However, since the groundwater in the area is under reducing conditions nitrate migration is not an issue at the site. The dissolved iron concentrations are high indicating that at least a portion of the aquifer is under iron-reducing conditions. This is consistent with conditions typically seen in wetlands or floodplains where rapid denitrification occurs. Therefore there is an absence of nitrate in the groundwater downgradient of the ash ponds.

Under current site conditions it is assessed that ammonium migration is limited. If during the proposed development the bund walls and / or clay is excavated or removed, this may influence the potential mobilisation of nitrogen in the system.

8 NUMERICAL MODEL DEVELOPMENT AND CALIBRATION

8.1 Numerical Model

The numerical simulation was conducted using the 2000 version of the groundwater simulation algorithm MODFLOW, compiled by the United States Geological Survey (Harbaugh et al, 2000). MODFLOW is a three-dimensional, finite difference, block-centred flow algorithm. It is an internationally recognised groundwater simulation algorithm accepted by most water resource authorities in Australia and world-wide. The graphical user interface employed for the algorithm is Groundwater Vistas Version 5, 2006, a commercial package produced by Environmental Simulations in the United States.

8.2 Model Domain

The model domain covers an area of approximately 7 km^2. The domain boundary is shown in Figure 13. The domain extends to the bedrock outcrops to the west and north, Lake Illawarra to the east and Macquarie Rivulet to the south of the site.

The model grid consists of a uniform mesh of 20 m x 20 m cells over the whole model domain.

8.3 Stratigraphy

A layered three-dimensional model was developed. Three active model layers have been used, representing the following hydrogeological units:

- Layer 1: Fill including the ash ponds, bund walls, access roads and the coalwash preload mound at Haywards Bay.
- Layer 2: Alluvial/estuarine sediments - the top of natural ground which includes reclamation fill areas (the former arm of Duck Creek, wetland areas and Wollingurry Creek). In reclamation areas layer 2 has a maximum thickness of 1 m.
- Layer 3: Deeper alluvial/estuarine sediments. The top of bedrock is the base of layer 3.

Ground surface contours were developed for the top of layer 1 and the top of layer 2 in areas outside the fill mounds based on Landteam survey data for the site. Since the model domain covers a greater area than what is covered by the site data, additional data sets were collated and analysed to cover the area south of the site boundary to Macquarie Rivulet. This included satellite NASA data and digitised topographic map data. The current ground level was dissociated into two surfaces – the natural ground level and the top of fill, ash, and bund walls. Natural ground levels underneath these anthropogenic materials were assessed to allow calculation of their thickness. Additional data was also used to check the on-site Coffey data due to natural surfaces recorded below 0 m AHD. This included reviewing historical aerial photos, Haywards Bay data and the Electricity Commission of NSW report from 1981 for Ash Pond 3 with data of the natural ground level.

Model stratigraphic structure contours were developed for the base of layers 1, 2 and 3 based on subsurface data collected by Coffey (2010a, 2010b and the current investigation) and Douglas Partners (2006 and 2007). Information from the various data sets were combined to create the three surfaces required for model input.

Model surface contours for the top of fill layer 1 and the base of layers 1 to 3 are shown in Figures 14 to 17, respectively.

8.4 Boundary Conditions

The boundary conditions at the extremities of the model domain comprise:

- No-flow at bedrock outcrops in the west and north;
- Constant head at Lake Illawarra of 0.15 m AHD in the east; and
- Constant head at Macquarie Rivulet of 0.15 m AHD in the south.

Figures 18 to 20 provide a pictorial representation of these and other boundary conditions as used in the model for layers 1 to 3 respectively.

8.4.1 Lake Illawarra

Constant head cells were assigned to the Lake Illawarra boundary at an elevation of 0.15 m AHD. Water level data for Lake Illawarra was sourced from the Manly Hydraulics Laboratory report 1826 (MHL, 2009). A permanent water level recorder in Lake Illawarra at Koonawarra Bay was the closest available data, located approximately 2 km to the north east of the site. Water levels range from a Mean High Water (MHW) of 0.15 m AHD, a Mean Low Water (MLW) of 0.10 m AHD and a Mean Tide Level (MTL) of 0.13 m AHD. The MHW level was adopted for the model boundary.

8.4.2 Ponds

There are nine ponds on site that are simulated using the river package (which allows a water body to gain or lose water to the groundwater system, based on the prevailing head difference). Pond numbering is as shown on Figures 18 to 20 and pond elevations are detailed in Table 12. Pond water level elevations were estimated from the Landteam survey conducted in October 2010, with the exception of Ponds 2 and 3. Pond 2 water levels are based on the water levels recorded by the water level logger installed within the pond in monitoring well MW08. The water level has remained relatively constant around 6.9 m AHD since April 2011. No elevation data was available for Pond 3, and the level was adjusted, based on limits imposed by other data, as part of model calibration.

Table 12: Model Pond Elevations

Pond Number	Pond Location	Pond Elevation (m AHD)	Model Layer
1	Ash Pond 3 (main lake)	1.8	1
2	Ash Pond 2 (triangle holding pond)	6.9	1
3	Ash Pond 2 (diverted discharge pond)	9.5	1
4	West of Ash Pond 2 (rectangle pond)	1.2	2
5	West of Ash Pond 2 (farm dam)	1.5	2
6	Ash Pond 3 (borrow pit north pond)	2.2	2
7	Ash Pond 3 (borrow pit south pond)	2.2	2
8	Farm dam west of Ash Pond 3	4.0	2
9	West of Ash Pond 3 (overflow pond)	1.9	3

8.4.3 Creeks

Duck Creek is a perennial creek running through the site and was simulated using the MODFLOW river package (see Figures 19 and 20). Data for the Duck Creek bathymetry was sourced from the Duck Creek Flood Study (Cardno Forbes Rigby, 2007).

Adopted parameters for Duck Creek (unchanged for all calibrative and predictive runs) were:

- Water level height above base of channel: lower reach – 1 m, upper reach – 0.4 m.
- River width: lower reach – 20 m, upper reach – 10m.

The Duck Creek riverbed hydraulic conductance, a parameter that controls the seepage to or from the river, was initially estimated by analysis of borelogs for riverbed material from several bores near the river (Hean and Nanson, 1985). It was then calibrated using available hydraulic head information.

Macquarie Rivulet is a perennial creek on the southern model boundary and was simulated using a constant head boundary. This was considered suitable due to the proximity of Lake Illawarra to the lower reach of Macquarie Rivulet, acting as an appropriate discharge boundary for groundwater flow.

8.4.4 Drainage Channels

Ephemeral drainage channels and creeks were simulated using the MODFLOW drain package (see Figures 18 to 20). Drain elevations were set using survey data from Landteam in October 2010, where available. Interpolation between known elevations was conducted for the drainage channels to the east of Ash Pond 1 and 2, and south east of Ash Pond 3.

8.4.5 Rainfall

Aquifer annual rainfall recharge has been applied as a proportion of the average annual rainfall based on data from the Port Kembla Station 68131 located on the coast approximately 12 km to the north east of the site. Climate data has been recorded at this location since 1963. Mean annual rainfall is approximately 1104 mm at Port Kembla.

Two rainfall recharge zones have been adopted as illustrated in Figure 21, representing the effect of variation in upper lithology between Ash Pond 3 and the Haywards Bay coalwash mounds compared to the rest of the model domain. Ash Pond 3 has a limited clay and / or coalwash cap, with ash exposed at the surface in some areas. This acts to increase the likely recharge rate to groundwater in the ash. Similarly, the exposed areas of the Haywards Bay coalwash mound would also allow a slightly higher infiltration rate compared to natural ground conditions. Ash Pond 1 and 2 generally has a thicker capping layer up to a maximum of 0.6 m and has therefore been assigned the same recharge rate as the rest of the model domain.

The two rainfall recharge zones are as follows:

- Zone 1: 3% average annual rainfall (0.034 m/year or 0.00009 m/day); and
- Zone 2: 4% average annual rainfall (0.044 m/year or 0.00012 m/day).

8.4.6 Evapotranspiration

Evapotranspiration (ET) has been applied over the model domain based on pan evaporation data sourced from the University of Wollongong (website), which is located approximately 14 km to the north east of the site. Mean annual evaporation is 1278 mm, which exceeds mean annual rainfall.

Four ET zones have been adopted as illustrated in Figure 22, representing variations in vegetation and lithology as detailed in Table 13.

Table 13: Model ET Zones

ET Zone Number	Vegetation Type	Dominant Lithology	Extinction Depth (m)	ET Rate (m/day and % pan evaporation)
1	Exposed ground	Fill – ash or coalwash	0.5	0.0003, 10% pan
2	Grasses, wetlands, various forests	Natural ground – alluvial/estuarine sediment	1.0	0.002, 80% pan
3	Coastal Swamp Oak and weeds	Fill – ash, coalwash or soil	1.5	0.002, 80% pan
4	Planted Swamp Oak (Ash Pond 2 forest)	Fill – ash	10	0.006, 200% pan

The maximum ET rate adopted for Zone 4 was based on the dense vegetation cover in this area of Ash Pond 2 (planted Swamp Oak forest). The average height of the trees in this area is approximately 25 m. The extinction depth of 10 m was based on a relationship between the height (H) of *Casuarina glauca* species (Swamp Oak) and the maximum vertical depth (MVD) of the tree roots:

MVD = 0.4H (Docker, 2003)

The trees in this area are growing within less dense ash material and it is considered likely that the root systems would extend to the base of the ash in this area. The ET parameters for Zone 4 were also adjusted as part of model calibration.

The adopted ET versus depth function was linear.

8.5 Aquifer Parameters

The initial hydrogeological parameters, including hydraulic conductivity and storage, were determined through literature review and site field assessment. Hydraulic conductivity values based on site field assessment are presented in Table 9.

Model layers contain multiple hydraulic conductivity zones as illustrated in Figures 23 to 25. The zonation represents different lithological and fill units across the site. Hydraulic conductivity data were not available for the reclamation fill, reworked soil and coalwash preload mound fill units. Hydraulic conductivity values typical of these material types (based on material descriptions provided in available borehole logs) were adopted for these units. Hydraulic conductivity values for the various units were adjusted as part of model calibration.

Adopted model aquifer parameters are detailed in Section 8.6.2.

8.6 Model Calibration

8.6.1 Steady State Calibration

The model could not be calibrated using steady state conditions due to the model boundary conditions (elevated groundwater levels in the ash ponds with steep hydraulic gradients and contrasting hydraulic conductivity values between the ash and alluvial/estuarine sediments). The MODFLOW ET package also contributed to model instability when the model was run in steady state. Therefore a transient calibration was conducted.

8.6.2 Transient Calibration

Transient calibration comprised manually varying a number of model parameters on a trial and error basis, over many model runs, to match observed groundwater levels and fluxes (such as river base flow). The transient calibration was particularly useful for calibrating vertical hydraulic conductivity, and necessary for calibrating storage parameters. The hydraulic conductivity of the reclamation fill in the vicinity of monitoring wells MW09, MW05 and MW15 was also targeted for calibration. Due to the lack of subsurface data targeting the nature of the reclamation fill multiple model runs were required to obtain similar groundwater levels recorded in these wells.

The model was calibrated to the groundwater levels observed on 12 April 2011. The observed groundwater levels are shown in Table 14.

Model simulations were conducted considering average daily rainfall infiltration (recharge) rates that did not vary over the simulation period. Daily evapotranspiration rates for the different zones were also constant over the transient calibration period.

The horizontal and vertical hydraulic conductivity values for the stratigraphic units were varied over ranges representative of the respective materials.

The Duck Creek riverbed conductance was also calibrated, based on hydraulic head differences with piezometers close to the river, and estimates of observed river baseflow.

Calibrated model parameters (providing the best model fit to observed groundwater levels) are displayed in Table 15. Table 14 shows the observed and calibrated model groundwater levels. The normalised root mean squared (NRMS) error is 5%. The model water budget error is 0.5%.

Modelled groundwater levels are similar to the observed groundwater levels. The uncertainty in calibrated aquifer properties of some fill units such as the reclamation fill is higher than for other parameters. While recognising these uncertainties, the calibrated model is considered adequately calibrated and suitable for its intended purpose.

Table 14: Observed and Modelled Groundwater Levels

Well ID	Screened Lithology	Observed Groundwater Level (mAHD) 12 April 2011	Modelled Groundwater Level (mAHD)	Residual (m) (Modelled minus Observed)
MW01	Alluvial/Estuarine (Clay) - connected with bund wall coalwash fill	1.11	1.17	-0.06
MW02	Alluvial/Estuarine (Sand) - connected with bund wall coalwash fill	1.14	1.08	0.06
MW03	Alluvial/Residual/ XW Sandstone - connected with ash fill	2.15	2.30	-0.15
MW04	Alluvial/Estuarine (Clay) - connected with ash fill	2.17	2.16	0.01
MW05	Alluvial/Estuarine (Clay)	1.25	1.06	0.19
MW06	Fill - Ash	4.34	4.31	0.03
MW08	Fill - Ash	6.82[1]	6.89[1]	-0.07
MW09	Alluvial/Estuarine (Clay)	0.94	0.92	0.02
MW10	Alluvial/Estuarine (Sandy clay)	1.08	1.00	0.08
MW11	Fill - Ash	8.00	7.96	0.04
MW12	Fill - Ash	7.99	7.99	0.00
MW13	Fill - Ash	7.99	7.95	0.04
MW14	Alluvial/Estuarine (Sandy clay)	1.27	1.30	-0.03
MW15	Alluvial/Estuarine (Sandy clay)	0.36	0.42	-0.06
MW16	Alluvial/Estuarine (Clay)	0.66	0.63	0.03
MW17	Alluvial/Estuarine (Sandy clay)	0.98	0.92	0.06
MW18	Residual Clay/XW Sandstone	3.17	2.99	0.18
TAGM/D3	Unknown	1.53	1.38	0.15

[1]Above ground water level corresponds to surface water level in the inundated area of Ash Pond 2 (pond number 2 on Figure 18).

Table 15: Adopted Model Parameters

Stratigraphic Unit	Model Layer	Hydraulic Conductivity		Storage Parameters	
		Horizontal Hydraulic Conductivity (m/day)	Vertical Hydraulic Conductivity (m/day)	Specific yield (Sy)	Specific storage (Ss)
Fill - ash	1	20	0.01	0.07	0.00001
Fill – bund walls (coalwash and clay)	1	0.3	0.01	0.10	0.00001
Fill – coalwash preload mounds	1	2	0.2	0.12	0.00001
Fill – ash (former watercourses and wetlands)	2	20	2	0.07	0.00001
Fill - reclamation	2	40	2	0.12	0.00001
Fill – reworked soil	2	2	0.2	0.05	0.00001
Alluvial/estuarine sediment	2 and 3	0.3	0.3	0.05	0.00001
Infiltration (Recharge) – see Figure 21					
Zone 1	0.00009 m/day (3% of mean annual rainfall)				
Zone 2	0.00012 m/day (4% of mean annual rainfall)				
Evapotranspiration – see Figure 22 and Table 13					
Zone 1	0.5 m extinction depth, 0.0003 m/day, 10% pan evaporation				
Zone 2	1.0 m extinction depth, 0.002 m/day, 80% pan evaporation				
Zone 3	1.5 m extinction depth, 0.002 m/day, 80% pan evaporation				
Zone 4	10 m extinction depth, 0.006 m/day, 200% pan evaporation				
Duck Creek Riverbed Conductance (m^2/day)					
Upstream (rock bed)	1				
Downstream (sediment bed)	40				

9 TRANSPORT MODEL

9.1 Software

MT3DMS (Zheng and Wang, 1999) was adopted for transport modelling. MT3DMS is a multi-species solute transport model designed for modelling contaminants in groundwater. It is capable of simulating chemical reactions, and has gained widespread industry acceptance for modelling and predicting transport and decay of hydrocarbons, metals and other compounds in aquifers. The model simulates contaminant transport by advection and dispersion, and can consider attenuation through biodegradation and sorption if appropriate. The MT3DMS transport model requires a finite-difference numerical groundwater model (such as MODFLOW) as a platform for transport simulation.

9.2 Modelling Approach

Simulation Times

The approach taken has been to run transient groundwater flow simulations for times up to 5000 years into the future, to conservatively assess the possibilities of contaminant travel times to the SEPP14 north wetland east of Ash Pond 3.

Contaminant release from an instantaneously emplaced source was assumed to have occurred for 20 years prior to reaching the current observed contaminant distribution (as assessed from available data). This serves as the starting case for predictive simulations with and without development. This is a simplified representation of the history of the ash ponds, which were progressively filled between 1955 and 1989. The simplification was considered appropriate based on available historical data, and the objectives of the transport modelling.

Transport simulation output is reported for a range of times from present day to 5000 years in the future.

Contaminant Sources

Based on the results and discussion detailed in Section 7.2 groundwater transport simulation of the two main chemicals of concern, arsenic and ammonium, has been conducted.

The source for arsenic was simulated as the ash, based on laboratory results. Given the relatively large volume of ash and low permeabilities of the natural clay (that controls seepage from the ash), the source arsenic body was assigned as a constant concentration source, as illustrated in Figure 26.

As previously discussed, the dominant source of ammonium is not known with certainty. The available data are unable to distinguish between the ash (by historic leaching) or coalwash material as likely candidates, however the actual source may be some mixture of these and perhaps other soil units. In this study, the source for ammonium was simulated as the coalwash bund walls of the ash ponds based on laboratory results. A constant concentration source was adopted, as illustrated in Figure 27. This means that simulation results represent, at any particular point in the aquifer, the modelled concentration resulting only from migration of ammonium from the bund walls, and does not represent the estimated total concentration at that point.

Constant concentration sources assume that the amount of total contaminant mass in the source is very large compared to its mobilisation / dissolution / desorption rate. This is considered a reasonable assumption based on the lack of historic concentration data.

Both constant concentration sources were assigned as the maximum recorded groundwater concentrations for arsenic (0.3 mg/L) and ammonium (20 mg/L) at the site.

In areas where the source is unsaturated (see Figure 28), the contaminant release process (through mobilisation / leaching by rainfall recharge) was therefore not active. The contaminant release process is instead simulated by assigning a recharge source boundary to simulate downward infiltration and leaching of arsenic or ammonium into the top of natural ground (layer 2 in the model). Multiple recharge zones were adjusted to represent a source of arsenic at 0.3 mg/L or ammonium at 20 mg/L.

Solution Method

All MT3DMS simulations were conducted using the Hybrid Method of Characteristics (HMOC) Solver Package using implicit finite-difference methods to solve the advection terms. This approach is robust, fast, avoids stability constraints, and is considered appropriate for the transport problems being solved.

9.3 Transport Modelling Parameters

The transport parameters adopted are presented in Table 16.

Sorption results in a distribution of a solute between the solution (groundwater where it is dissolved) and the solid phase (where it is held by the solids of the aquifer). This distribution is called partitioning and it is quantitatively described with the distribution coefficient K_d:

(1) $K_d = C_s/C_w$

where C_s is the contaminant concentration associated with the solid

C_w is the contaminant concentration in the surrounding aqueous solution

Leachate results provided sufficient data to assess the distribution coefficient for all material types with the exception of arsenic in the clay soils, for which a representative value was adopted from Kresic (2007).

Based on experience, longitudinal dispersivity in alluvial soils commonly ranges between 1 and 10 m. A value of 5 m was adopted, with transverse and vertical dispersivity set one and two orders of magnitude lower respectively. To assess the sensitivity of the transport model results to these parameters, longitudinal, transverse and vertical dispersivity were doubled to 10 m, 1 m and 0.1 m respectively. Minimal differences were recorded in the contaminant plume migration and therefore the original value of 5 m was used for all predictive model runs.

Table 16: Transport Parameters

Parameter	Setting
Time Stepping	Monthly intervals during development scenarios up to 100 year intervals in the later predictive stages
Time Step Multiplier	1.2
Reaction Type	No Decay
Courant Number	1
Soil Bulk Density including Coalwash (kg/L)	1.6
Ash Bulk Density (kg/L)	1.1
Longitudinal Dispersivity (m)	5
Transverse Dispersivity (m)	0.5
Vertical Dispersivity (m)	0.05
Sorption - Arsenic	Linear Isotherm
Sorption - Ammonium	Langmuir Isotherm
K_d[1] Arsenic – Soil (ml/g)	29
K_d[2] Arsenic – Coalwash (ml/g)	15
K_d[2] Arsenic – Ash (ml/g)	1
K_d[2] Ammonium – Soil (ml/g)	21
K_d[2] Ammonium – Coalwash (ml/g)	10
K_d[2] Ammonium – Ash (ml/g)	1

1. K_d for arsenic from Kresic (2007) and assumes neutral pH conditions.
2. K_d values calculated from laboratory leachate results

10 PREDICTIVE MODELLING

Two predictive scenarios were modelled, one with no development and one with development. Both cases adopted the same calibrated model boundary conditions. The no development scenario adopted an average annual recharge rate that remained unchanged throughout the simulations. The development scenario adopted a staged decrease in recharge over the whole construction area over Ash Pond 3 and Ash Pond 2.

10.1 Proposed Site Development – Modelled Sequences

The proposed development is illustrated as a modified schematic conceptual model in Figure 29. Development which may affect groundwater conditions were incorporated into the predictive modelling and include the following elements:

- Two sewer pump station excavations, one north of Duck Creek and the other in Ash Pond 3;
- Fill earthworks in Ash Pond 3;
- Stormwater drains in Ash Pond 3;
- Removal of trees, mainly in Ash Pond 2 with some in Ash Pond 3; and
- Impermeable surfaces as part of residential, commercial and industrial buildings in Ash Pond 2 and Ash Pond 3.

Details of the proposed Ash Pond 3 development from the BMT WBM report (2010) figure "Southern Precinct - Water Sensitive Urban Design (WSUD) Strategy" is attached for reference in Appendix H. It was assumed that the biofiltration basins in Ash Pond 3 would be lined and remain separate from the groundwater system throughout model simulations. Biofiltration basins were therefore not included in the development predictive model.

The stormwater drains included in model layer 1 are illustrated in Figure 30. Elevations of raised ground surface level and the pipe invert levels of the stormwater drainage pipes were based on the BMT WBM figure marked up by Northrop, attached as Appendix I.

Locations of the two sewer pump station excavations and the areas of land cleared for development are illustrated in Figure 31.

The modelled sequences of the proposed site development are provided in Appendix J, including assumptions made for the purposes of modelling.

10.2 Results

Predictive modelling results for the two scenarios include groundwater levels, water budgets, contaminant loads and contaminant migration. These results are detailed in the following sections.

10.2.1 Groundwater Levels

Modelled groundwater contour levels after 30 years of simulation (15 years in the future - 2027) are illustrated for the no development and development cases in Figures 32 and 33 respectively. The 30 year simulation results are presented as this shows the greatest changes in groundwater levels approximately two years following the end of all development changes. Figure 34 illustrates the drawdown calculated as the difference between the development and no development groundwater levels. This illustrates the central and eastern areas across Ash Pond 3 where groundwater drawdown up to 0.4 m is predicted. The decrease in groundwater levels is related to the decrease in recharge over Ash Pond 3 from the increase in impermeable surfaces. Since the ET rates were low over the majority of Ash Pond 3, the net change is a small decrease in groundwater levels. In the north west of Ash Pond 3, an increase in groundwater levels up to 1.2 m is predicted due to filling of the two borrow ponds in this area. In Ash Pond 2, the removal of trees (simulated by reducing ET to zero) results in the larger impact to groundwater levels compared to a decrease in recharge over the development area. Therefore an increase in groundwater levels of up to 0.6 m in the vicinity of MW06 is predicted.

Modelled hydrographs are presented in Figures 35 and 36 and illustrate the above trends in groundwater levels. The short term influence of the sewer pump station excavation is illustrated in the hydrograph for monitoring well MW02, which is located approximately 60 m south of the modelled excavation.

10.2.2 Water Budgets

The water budgets for the no development and development scenarios are presented in a detailed form as separate boundary conditions (Table 17) and grouped as hydrostratigraphic unit (HSU) zones (Table 18). HSU zones were defined in order to assess the changes in water budgets for the areas of interest: Ash Pond 1 and 2, Ash Pond 3 and the north and south SEPP14 wetlands.

Tables 17 and 18 show a number of trends including the following:

- In Ash Pond 2 an 8% decrease in recharge to the groundwater system is predicted from the triangle holding pond and the diverted discharge pond (Ponds 2 and 3 respectively). The increased groundwater levels in the aquifer act to reduce the head difference between the pond and the aquifer, reducing the amount of seepage from the pond.
- Around Ash Pond 2 a 20% increase in groundwater discharge to the drains in the former Duck Creek arm area and a 12% increase in the drainage channel west of Ash Pond 2 is predicted due to the increased groundwater levels across Ash Pond 2.
- A 12% decrease in rainfall recharge over the Ash Pond 2 area is predicted.
- A 25% decrease in ET discharge over the Ash Pond 2 area is predicted due to the clearing of trees.
- In Ash Pond 3 a 20% decrease in groundwater discharge to the drainage channels on the eastern boundary is predicted due to the decreased groundwater levels across the majority of Ash Pond 3.
- Filling of the two Ash Pond 3 borrow pit ponds (Ponds 6 and 7) results in ceasing groundwater discharge to these ponds. Therefore groundwater levels in this area are predicted to increase by up to 1.2 m.
- A 47% decrease in rainfall recharge over the Ash Pond 3 area is predicted.
- The clearing of trees in the north east of Ash Pond 3 results in reducing ET discharge to zero.
- The invert elevations of the stormwater drain system included in the development for Ash Pond 3 remain above the groundwater level throughout the simulation (for average rainfall conditions). These drains could intercept groundwater in times of high rainfall.

Table 17: Water Budgets Based on Boundary Conditions

Water Budgets - Boundary Conditions (100 year simulation rate)	**No Development (m^3/day)**	**Development (m^3/day)**
Constant Head Reaches		
Lake Illawarra breakwall discharge area	-14	-14
Lake Illawarra rock outcrop	-1	-1
Lake Illawarra Duck Creek entrance	-0.09	-0.09
Lake Illawarra south of Duck Creek	-12	-12
Macquarie Rivulet boundary	-13	-13
Totals - Constant Head Reaches	**-40**	**-40**
River Reaches		
Duck Creek	-128	-138
Pond 1 - Ash Pond 3 main lake	-13	-7
Pond 2 - Ash Pond 2 triangle holding pond	301	266
Pond 3 - Ash Pond 2 diverted discharge pond	616	580
Pond 4 - West of Ash Pond 2 rectangle pond	1	1
Pond 5 - West of Ash Pond 2 farm dam	-5	-5
Pond 6 - Ash Pond 3 borrow pit north pond	-4	0
Pond 7 - Ash Pond 3 borrow pit south pond	-4	0
Pond 8 - Farm dam west of Ash Pond 3	-1	-1
Pond 9 - West of Ash Pond 3 overflow pond	-3	-3
Totals - River Reaches	**760**	**693**
Drain Reaches		
Ash Pond 1-2 drain to triangle pond (model layer 1)	0	0
Former Duck Creek arm area drain (model layer 1)	0	0
Former Duck Creek arm area drain (model layer 2)	-109	-130
Drainage channels east of Ash Pond 1-2	-190	-193
Drainage channel west of Ash Pond 2	-78	-87
Drainage channel near MW10	0	0
Drainage channel from farm dam west of Ash Pond 3 to Duck Creek	-5	-6
Drainage channel adjacent to eastern boundary of Ash Pond 3	-9	-4
Drainage channel 50m further east of Ash Pond 3	-30	-27
Wollingurry Creek (drainage from Ash Pond 3 running east to lake)	-18	-17
Haywards Bay Creek (diverted channel south of Haywards Bay development)	-2	-2
Sewer pump station north of Duck Creek	NA	0
Sewer pump station within Ash Pond 3	NA	0
Stormwater drains Ash Pond 3 development (discharge to biofiltration basin S3)	NA	0
Stormwater drains Ash Pond 3 development (discharge to biofiltration basin S4)	NA	0
Stormwater drains Ash Pond 3 development (discharge to biofiltration basin S5)	NA	0
Totals - Drain Reaches	**-441**	**-467**
Recharge Zones		
Zone 1 - Ash Pond 1 and 2	46	41
Zone 1 - Rest of model domain	190	190
Zone 2 - Ash Pond 3 and coalwash preload mound	88	47
Totals - Recharge Zones	**325**	**277**
ET Zones		
Zone 1 - Exposed ground	0	0
Zone 2 - Grasses, wetlands, various forests	-138	-139
Zone 3 - Coastal Swamp Oak and weeds	-3	0
Zone 4 - Planted Swamp Oak (Ash Pond 2)	-475	-355
Totals - ET Zones	**-617**	**-494**

Negative flows indicate outflow from the model (groundwater discharge).

Positive flows indicate inflow to the model (groundwater recharge).

The sewer pump station drains are not active at the 100 year simulation period and therefore record zero flows at this time.

Table 18: Water Budgets Based on Hydrostratigraphic Units

Water Budgets - Hydrostratigraphic Unit (HSU) Zones (100 year simulation rate)	**No Development**		**Development**	
	Inflow (m^3/day)	**Outflow (m^3/day)**	**Inflow (m^3/day)**	**Outflow (m^3/day)**
Summary of HSU Zone 1 - Ash Pond 1 and 2 (Model Layer 1)				
Flows Within HSU				
Constant Head	0	0	0	0
River	918	0.13	846	0.14
Drain	0	0	0	0
Recharge	53	0	50	0
ET	0	475	0	355
Storage	7.18E-07	8.23E-07	2.97E-08	1.20E-04
Flows Between HSUs				
HSU Zone 5	0.2	495	0.1	541
TOTAL FLOWS	971	971	897	896
Summary of HSU Zone 2 - Ash Pond 3 (Model Layer 1)				
Flows Within HSU				
Constant Head	0	0	0	0
River	4	17	5	12
Drain	0	0	0	0
Recharge	35	0	20	0
ET	0	3	0	0
Storage	1.87E-07	8.43E-08	3.07E-04	1.67E-07
Flows Between HSUs				
HSU Zone 5	8	27	7	27
TOTAL FLOWS	47	47	31	39
Summary of HSU Zone 3 - North Wetland (Model Layer 2 and 3)				
Flows Within HSU				
Constant Head	0	0.08	0	0.08
River	0	0.33	0	0.33
Drain	0	0	0	0
Recharge	8	0	8	0
ET	0	8	0	8
Storage	2.07E-10	2.06E-10	3.85E-17	4.75E-09
Flows Between HSUs				
HSU Zone 5	0.36	0.60	0.36	0.60
TOTAL FLOWS	10	10	10	10
Summary of HSU Zone 4 - South Wetland (Model Layer 2 and 3)				
Flows Within HSU				
Constant Head	0	2	0	2
River	0	0	0	0
Drain	0	0	0	0
Recharge	4	0	4	0
ET	0	3	0	3
Storage	1.17E-08	4.41E-18	2.69E-09	7.09E-18
Flows Between HSUs				
HSU Zone 5	2	0.16	2	0.16
TOTAL FLOWS	6	6	6	6
Summary of HSU Zone 5 - Rest of Model (Layers 1 to 3)				
Flows Within HSU				
Constant Head	0	38	0	38
River	2	146	2	147
Drain	0	441	0	467
Recharge	237	0	224	0
ET	0	127	0	127
Storage	1.34E-04	2.04E-05	4.69E-04	2.45E-05
Flows Between HSUs				
HSU Zone 1 - Ash Pond 1 and 2 (Model Layer 1)	495	0.16	541	0.15
HSU Zone 2 - Ash Pond 3 (Model Layer 1)	27	8	27	7
HSU Zone 3 - North Wetland (Model Layer 2 and 3)	0.6	0.4	0.6	0.4
HSU Zone 4 - South Wetland (Model Layer 2 and 3)	0.2	2.2	0.2	2.2
TOTAL FLOWS	761	763	795	788

10.2.3 Contaminant Loads and Migration

Modelled groundwater arsenic and ammonium concentrations for the no development and development scenarios are illustrated in plan view after 30 years and 100 years simulation in Figures 37 to 44. Modelled arsenic and ammonium concentrations are also presented as chemiographs in Figures 45 to 47.

The contour plots of modelled concentrations illustrate the extent of contaminant migration after 30 years and 100 years simulation. For both arsenic and ammonium there is minimal difference in the extent of migration between the no development and development scenarios. All cases illustrate contaminant migration to the following receptors:

- Lake Illawarra breakwall discharge area (east of Ash Pond 1 and 2);
- Duck Creek, mainly south of Ash Pond 2 but also north and east of Ash Pond 3; and
- Drainage channels east of Ash Pond 3 discharging north to Duck Creek.

The chemiographs for the Ash Pond 1 and 2 area (see Figure 45) illustrate minimal difference in the contaminant concentrations for both arsenic and ammonium. For locations closer to the ash ponds and bund walls the maximum concentrations are reached more rapidly.

For the Ash Pond 3 area (see Figure 46 and Figure 47) differences are apparent between the no development and development scenarios for arsenic and ammonium. Modelled arsenic concentrations are lower in the development case due to the decreased recharge (and lower head difference between inside and outside the ash mound) resulting in less contaminant flux out of the ash. The response illustrated for monitoring well MW02 shows an accrual of contaminant mass around 50 years simulation and the effect of dilution by water flux with less contaminant mass for a further 100 year simulation period.

The modelled response for ammonium adjacent to Ash Pond 3 is also due to the decreased recharge within Ash Pond 3 as well as the source for ammonium being the bund walls rather than the ash. Modelled ammonium concentrations outside the ash mound are higher in the development case because in the no development case, the dilution afforded by ammonium-free seepage flowing east out of the ash mound is reduced (due to lower recharge to the ash).

Further east from Ash Pond 3 the simulation times were extended to 5000 years to assess the possibility of contaminant migration as far as the SEPP14 north wetland. For both arsenic and ammonium the north wetland concentrations remain less than laboratory detection limits and monitoring well MW16 remains less than the ANZECC 2000 trigger values. There are limitations with the extended model simulation time as the contaminant sources may not behave as constant sources over such a timeframe, and the variation in long-term climate is neither simulated nor known. The modelling was conducted more to explore the possible conservative outcome in contaminant migration to this area and to confirm that migration is unlikely to affect the SEPP14 wetlands.

The modelled contaminant loads for separate boundary conditions such as Lake Illawarra, Duck Creek, drainage channels and the various ponds on site are detailed in Table 19. The highest contaminant loads are predicted for the Ash Pond 2 area: drainage channels east of Ash Pond 1 and 2, drains in the former Duck Creek arm area, Duck Creek and the drainage channel west of Ash Pond 2. Lower contaminant loads are modelled for Ash Pond 3 as there is less contaminant mass and lower hydraulic gradients in this discharge area.

Table 19: Contaminant Loads for Arsenic and Ammonium Based on Boundary Conditions

Contaminant Loads - Boundary Conditions (100 year simulation rate)	No Development Arsenic (grams/day)	Development Arsenic (grams/day)	No Development Ammonium (grams/day)	Development Ammonium (grams/day)
Constant Head Reaches				
Lake Illawarra breakwall discharge area	-2	-2	-69	-69
Lake Illawarra rock outcrop	-0.000002	-0.000002	-0.0001	-0.0001
Lake Illawarra Duck Creek entrance	0	0	0	0
Lake Illawarra south of Duck Creek	0	0	0	0
Macquarie Rivulet boundary	0	0	0	0
Totals - Constant Head Reaches	**-2**	**-2**	**-69**	**-69**
River Reaches				
Duck Creek	-28	-31	-626	-627
Pond 1 - Ash Pond 3 main lake	-2	-0.4	-20	-17
Pond 2 - Ash Pond 2 triangle holding pond	-0.00006	-0.00006	-0.00005	-0.00005
Pond 3 - Ash Pond 2 diverted discharge pond	0	0	0	0
Pond 4 - West of Ash Pond 2 rectangle pond	0	0	0	0
Pond 5 - West of Ash Pond 2 farm dam	-1	-1	-89	-91
Pond 6 - Ash Pond 3 borrow pit north pond	-0.1	0	-13	0
Pond 7 - Ash Pond 3 borrow pit south pond	-0.1	0	-13	0
Pond 8 - Farm dam west of Ash Pond 3	-1.24E-11	-5.68E-11	-0.015	-0.062
Pond 9 - West of Ash Pond 3 overflow pond	-0.00008	-0.00007	-6	-8
Totals - River Reaches	**-31**	**-32**	**-767**	**-743**
Drain Reaches				
Ash Pond 1-2 drain to triangle pond (model layer 1)	0	0	0	0
Former Duck Creek arm area drain (model layer 1)	0	0	0	0
Former Duck Creek arm area drain (model layer 2)	-32	-39	-747	-900
Drainage channels east of Ash Pond 1-2	-55	-55	-1428	-1421
Drainage channel west of Ash Pond 2	-23	-25	-939	-992
Drainage channel near MW10	0	0	0	0
Drainage channel from farm dam west of Ash Pond 3 to Duck Creek	0	0	-15	-23
Drainage channel adjacent to eastern boundary of Ash Pond 3	-2	-1	-49	-24
Drainage channel 50m further east of Ash Pond 3	-3	-2	-101	-121
Wollingurry Creek (drainage from Ash Pond 3 running east to lake)	-0.0000021	-0.0000018	-31	-32
Haywards Bay Creek (diverted channel south of Haywards Bay development)	0	0	0	0
Sewer pump station north of Duck Creek	NA	0	NA	0
Sewer pump station within Ash Pond 3	NA	0	NA	0
Stormwater drains Ash Pond 3 development (discharge to biofiltration basin S3)	NA	0	NA	0
Stormwater drains Ash Pond 3 development (discharge to biofiltration basin S4)	NA	0	NA	0
Stormwater drains Ash Pond 3 development (discharge to biofiltration basin S5)	NA	0	NA	0
Totals - Drain Reaches	**-115**	**-122**	**-3309**	**-3513**
ET Total	**-0.01**	**-0.01**	**-0.61**	**-0.59**

Negative numbers indicate outflow of contaminant load from the model.

Table 20: Duck Creek Contaminant Load Summary

	No Development Arsenic (grams/day)	Development Arsenic (grams/day)	No Development Ammonium (grams/day)	Development Ammonium (grams/day)
Direct to creek	-28	-31	-626	-627
Discharge to creek via drainage channels	-60	-66	-1857	-2068
Duck Creek Totals (grams/day)	**-88**	**-97**	**-2482**	**-2695**

Table 21: Lake Illawarra Contaminant Load Summary

	No Development Arsenic (grams/day)	Development Arsenic (grams/day)	No Development Ammonium (grams/day)	Development Ammonium (grams/day)
Direct to lake	-2	-2	-69	-69
Discharge to lake via drainage channels (breakwall discharge area)	-55	-55	-1428	-1421
Drainage from Ash Pond 3 running east to lake (Wollingurry Creek)	-0.000002	-0.000002	-31	-32
Lake Illawarra Totals (grams/day)	**-57**	**-58**	**-1528**	**-1522**

10.2.4 Dilution Calculations

The modelled contaminant loads are summarised for the key receptors of Duck Creek and Lake Illawarra in Tables 20 and 21 respectively. The data in these tables has been used to assess the likely overall concentrations of the two contaminants in Duck Creek and Lake Illawarra due to the contaminant loads discharged from the Tallawarra site.

Dilution calculations were conducted by defining the water reticulation system linking Duck Creek, Lake Illawarra, and other streams. Flows for Lake Illawarra including tidal volumes recorded at the lake entrance were sourced from the Manly Hydraulics Laboratory report 1826 (MHL, 2009). A summary of the calculations is attached for reference in Appendix K. The results for arsenic and ammonium are illustrated in Figure 48.

There is minimal difference in arsenic concentrations between the no development and development results. Duck Creek arsenic concentrations reach a maximum of 0.0042 mg/L, which is just above the ANZECC trigger value of 0.0023 mg/L. Lake Illawarra arsenic concentrations remain less than laboratory detection limits.

There are no differences in ammonium concentrations between the no development and development results. Both Duck Creek and Lake Illawarra ammonium concentrations remain below the ANZECC trigger value of 0.91 mg/L (at pH 8).

The dilution calculations involved a number of assumptions including the following:

- Average surface water flux to Lake Illawarra is estimated using adopted runoff coefficients;
- Average groundwater flux to Lake Illawarra is estimated from model results;
- No sources of contaminants other than the Tallawarra site;
- No changes to the contaminant fluxes from the Tallawarra site;
- No accumulation of contaminants in the lake sediments;
- Complete mixing of waters occurs over a tidal cycle, within the estuarine part of Duck Creek, and within Lake Illawarra;
- Water expelled to the ocean from Lake Illawarra over a tidal cycle is assumed to be totally transported away, and not return, maintaining an adopted zero concentration for incoming sea water; and
- No chemical reactions for ammonium are considered in the mass of contaminant reported.

Background contaminant concentrations for Duck Creek and Lake Illawarra have been previously reported by Coffey (2010b). Sample results for upstream Duck Creek show low arsenic and ammonium concentrations (0.002 mg/L and 0.1 mg/L respectively), which is similar or slightly lower than the modelled concentrations in Figure 48 (up to 0.0042 mg/L and 0.1 mg/L respectively). Sample results for Lake Illawarra north of the site show slightly higher arsenic and ammonium concentrations (0.008 mg/L and 0.23 mg/L respectively), which is higher than the modelled concentrations in Figure 48 (up to 0.000008 mg/L and 0.0002 mg/L respectively).

Arsenic and ammonium concentrations within Lake Illawarra are likely to be influenced by sources in addition to the Tallawarra site.

11 CONCLUSIONS

The objective of this assessment by Coffey was to conduct a more detailed and quantitative hydrogeological assessment at the site including numerical groundwater modelling. The assessment provides more information for the groundwater dependent ecosystem (GDE) study and risk assessment by Eco Logical Australia, including assessing groundwater levels and quality in areas away from the ash ponds such as the wetland area to the east of Ash Pond 3.

This modelling report presents additional hydrogeological data collected since December 2010 (groundwater levels, quality and permeability data) and the results of numerical groundwater flow and transport modelling.

Based on the results of the current assessment, the following conclusions are made:

- Groundwater flow from the ash ponds to the surrounding environment is assessed as being predominantly vertical through the base of the ponds rather than horizontal through the bund walls.
- In the long term the maximum seepage rate from the ash ponds to the underlying alluvial/estuarine sediments is limited by the vertical hydraulic conductivity of the clay. Once in the clay, lateral movement of groundwater from the ash to receptors such as Duck Creek and Lake Illawarra is largely controlled by the lateral hydraulic conductivity (and effective porosity) of the alluvial/estuarine sediments.
- Based on numerical modelling results, the combined groundwater flow rate out of the ash to the underlying alluvial/estuarine sediments for Ash Ponds 1 to 3 is approximately 0.5 ML/day. The average streamflow in Duck Creek (around 86 ML/day) is therefore higher than the groundwater flux from the ash.
- Under current site conditions it is assessed that ammonium migration is limited. If during the proposed development the bund walls and / or clay is excavated or removed, this may influence the potential mobilisation of nitrogen in the system.
- The source for arsenic was simulated as the ash based on laboratory results. Given the low permeabilities of the clay, the source arsenic body was assigned as a constant concentration source at the maximum recorded groundwater concentration for arsenic (0.3 mg/L) at the site.
- The available data do not allow the unambiguous identification of the dominant source of ammonium in groundwater. The ash (by historic leaching) or coalwash material are likely candidates, however the actual source may be some mixture of these and perhaps other soil units. For modelling purposes, the source for ammonium was simulated as the coalwash bund walls of the ash ponds based on laboratory results. A constant concentration source was adopted assigning the maximum recorded groundwater concentration for ammonium (20 mg/L) at the site.
- Groundwater drawdown of up to 0.4 m is predicted in the central and eastern development areas across Ash Pond 3. The decrease in groundwater levels is related to the decrease in recharge over Ash Pond 3 (increase in impermeable surfaces).
- In the north west of Ash Pond 3, an increase in groundwater levels of up to 1.2 m is predicted due to filling of the two borrow pit ponds in this area.

- In Ash Pond 2, the removal of trees results in a larger impact to groundwater levels compared to a decrease in recharge over the development area. Therefore an increase in groundwater levels up to 0.6 m in the vicinity of MW06 is predicted.
- Around Ash Pond 2 a 20% increase in groundwater discharge to the drains in the former Duck Creek arm area and a 12% increase in the drainage channel west of Ash Pond 2 is predicted due to the increased groundwater levels across Ash Pond 2.
- A 12% decrease in rainfall recharge over the Ash Pond 2 area is predicted.
- A 25% decrease in evapotranspiration (ET) discharge over the Ash Pond 2 area is predicted due to the clearing of trees.
- In Ash Pond 3 a 20% decrease in groundwater discharge to the drainage channels on the eastern boundary is predicted due to the decreased groundwater levels across the majority of Ash Pond 3.
- A 47% decrease in rainfall recharge over Ash Pond 3 area is predicted.
- The invert elevations of the stormwater drains included in the development for Ash Pond 3 remain above the groundwater level throughout the simulation (for average rainfall conditions). These drains may intercept groundwater in times of high rainfall.
- For both arsenic and ammonium, modelled contaminant migration after 30 years and 100 years simulation shows there is minimal difference in the extent of migration between the no development and development scenarios. All cases illustrate contaminant migration to the following main receptors:
    - Lake Illawarra breakwall discharge area (east of Ash Pond 1 and 2);
    - Duck Creek, mainly south of Ash Pond 2 but also north and east of Ash Pond 3; and
    - Drainage channels east of Ash Pond 3 discharging north to Duck Creek.
- Model simulation times were extended to 5000 years to assess the possibility of contaminant migration as far as the SEPP14 north wetland. For both arsenic and ammonium the north wetland concentrations remain less than laboratory detection limits and closer to Ash Pond 3 monitoring well MW16 remains less than the ANZECC 2000 trigger values.
- The highest contaminant loads are predicted for the Ash Pond 2 area. Lower contaminant loads are modelled for Ash Pond 3 as there is less contaminant mass and lower hydraulic gradients in the Ash Pond 3 discharge area.
- Dilution calculations conducted using the modelled arsenic and ammonium mass loads for Lake Illawarra and Duck Creek indicate minimal differences between the no development and development scenarios. Modelled concentrations taking into account the mixing volumes results in low concentrations that are less than ANZECC trigger values with the exception of arsenic concentrations in Duck Creek (approximately double the trigger value, up to 0.0042 mg/L).
- Previous background sample results (Coffey Environments, 2010b) for Lake Illawarra north of the site show higher arsenic and ammonium concentrations compared to the modelled dilution values.
- Arsenic and ammonium concentrations within Lake Illawarra are likely to be influenced by sources in addition to the Tallawarra site.

12 RECOMMENDATIONS

Based on the outcomes of the current assessment, the following recommendations are made:

- During construction works it is recommended to limit excavation of the ash pond bund walls in order to prevent preferential pathways for contaminant migration. If during the proposed development the bund walls and / or clay is excavated or removed, this may influence the potential mobilisation of nitrogen in the system as well as other contaminants.
- It is recommended that prior to and during the construction program targeted surface water sampling sites are selected to assess the quality of discharge water in the vicinity of receptors – Duck Creek and Lake Illawarra. This would include channels directly adjacent to the ash ponds and allows monitoring of potential changes to water quality during the construction period.
- Short term dewatering licence requirements will need to be considered prior to excavations for the sewer pump stations and consultation with the NSW Office of Water is recommended.
- It is recommended that groundwater inflow and drawdown are monitored during construction activities and dewatering pumping options revised accordingly as necessary.
- The proposed sewer pump station excavation within Ash Pond 3 may require further specific Acid Sulfate Soil (ASS) assessment. It is recommended that monitoring bores be established in the vicinity of this excavation to monitor groundwater levels during construction and a contingency plan developed to respond to development of adverse impacts (for example re-injection of groundwater with increased pH levels if required).

13 LIMITATIONS

The findings contained in this report are the result of discrete/specific methodologies used in accordance with normal practices and standards. To the best of our knowledge, they represent a reasonable interpretation of the general condition at the areas of the site assessed at the time the investigations were carried out.

Under no circumstances, however, can it be considered that these findings represent the actual state of the site at all points.

It should be noted that the modelling results reported here are specific to the modelled conditions. The model assumptions and limitations include the following:

- In the absence of aquifer testing data for certain model zones, the model adopts conditions and parameter values representative of the stratigraphic materials present. Should subsurface conditions be found to differ from the representation made here, the impacts of contaminant migration may vary significantly from those reported.
- The excavation schedule and stormwater drainage network used in this assessment was based on information provided by Northrop (see Section 10.1)
- The staged decrease in recharge assigned to the Ash Pond 3 development area does not take into account future additional water sources from residential gardens.
- It was assumed that the biofiltration basins in Ash Pond 3 would be lined and remain separate from the groundwater system throughout model simulations. Biofiltration basins were therefore not included in the development predictive model.
- For modelling purposes, the contaminant source is introduced instantaneously and contaminant migration is assumed to occur for 20 years to achieve the current observed contaminant distribution. This serves as the starting condition for predictive simulations with and without development. This is a simplified representation of the history of the ash ponds, which were progressively filled between 1955 and 1989. The simplification was considered appropriate for the objectives of the transport modelling.
- Contaminant loads reported for ephemeral drainage channels are simplistic. Unsaturated zone processes (evaporation and rainfall recharge) are not included in the modelling.
- There are limitations with the extended model simulation time as the contaminant sources may not behave as constant sources over timeframes of thousands of years, and the variation in long-term climate is neither simulated nor known. The modelling was conducted more to explore the possible conservative outcome in contaminant migration and to confirm migration does not affect the SEPP14 wetlands.

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Important information about your **Coffey** Environmental Report

Uncertainties as to what lies below the ground on potentially contaminated sites can lead to remediation costs blow outs, reduction in the value of the land and to delays in the redevelopment of land. These uncertainties are an inherent part of dealing with land contamination. The following notes have been prepared by Coffey to help you interpret and understand the limitations of your report.

Your report has been written for a specific purpose

Your report has been developed on the basis of a specific purpose as understood by Coffey and applies only to the site or area investigated. For example, the purpose of your report may be:

- To assess the environmental effects of an on-going operation.
- To provide due diligence on behalf of a property vendor.
- To provide due diligence on behalf of a property purchaser.
- To provide information related to redevelopment of the site due to a proposed change in use, for example, industrial use to a residential use.
- To assess the existing baseline environmental, and sometimes geological and hydrological conditions or constraints of a site prior to an activity which may alter the sites environmental, geological or hydrological condition.

For each purpose, a specific approach to the assessment of potential soil and groundwater contamination is required. In most cases, a key objective is to identify, and if possible, quantify risks that both recognised and unrecognised contamination pose to the proposed activity. Such risks may be both financial (for example, clean up costs or limitations to the site use) and physical (for example, potential health risks to users of the site or the general public).

Scope of Investigations

The work was conducted, and the report has been prepared, in response to specific instructions from the client to whom this report is addressed, within practical time and budgetary constraints, and in reliance on certain data and information made available to Coffey. The analyses, evaluations, opinions and conclusions presented in this report are based on those instructions, requirements, data or information, and they could change if such instructions etc. are in fact inaccurate or incomplete.

Subsurface conditions can change

Subsurface conditions are created by natural processes and the activity of man and may change with time. For example, groundwater levels can vary with time, fill may be placed on a site and pollutants may migrate with time. Because a report is based on conditions which existed at the time of the subsurface exploration, decisions should not be based on a report whose adequacy may have been affected by time. Consult Coffey to be advised how time may have impacted on the project and/or on the property.

Interpretation of factual data

Environmental site assessments identify actual subsurface conditions only at those points where samples are taken and when they are taken. Data derived from indirect field measurements and sometimes other reports on the site are interpreted by geologists, engineers or scientists to provide an opinion about overall site conditions, their likely impact with respect to the report purpose and recommended actions. Actual conditions may differ from those inferred to exist, because no professional, no matter how well qualified, can reveal what is hidden by earth, rock and time. The actual interface between materials may be far more gradual or abrupt than assumed based on the facts obtained. Nothing can be done to change the actual site conditions which exist, but steps can be taken to reduce the impact of unexpected conditions. For this reason, parties involved with land acquisition, management and/or redevelopment should retain the services of Coffey through the development and use of the site to identify variances, conduct additional tests if required, and recommend solutions to unexpected conditions or other problems encountered on site.

Important information about your **Coffey** Environmental Report

Your report will only give preliminary recommendations

Your report is based on the assumption that the site conditions as revealed through selective point sampling are indicative of actual conditions throughout an area. This assumption cannot be substantiated until project implementation has commenced and therefore your report recommendations can only be regarded as preliminary. Only Coffey, who prepared the report, is fully familiar with the background information needed to assess whether or not the report's recommendations are valid and whether or not changes should be considered with redevelopment or on-going use of the site. If another party undertakes the implementation of the recommendations of this report there is a risk that the report will be misinterpreted and Coffey cannot be held responsible for such misinterpretation.

Your report is prepared for specific purposes and persons

To avoid misuse of the information contained in your report it is recommended that you confer with Coffey before passing your report on to another party who may not be familiar with the background and the purpose of the report. In particular, a due diligence report for a property vendor may not be suitable for satisfying the needs of a purchaser. Your report should not be applied for any purpose other than that originally specified at the time the report was issued.

Interpretation by other professionals

Costly problems can occur when other professionals develop their plans based on misinterpretations of a report. To help avoid misinterpretations, retain Coffey to work with other professionals who are affected by the report. Have Coffey explain the report implications to professionals affected by them and then review plans and specifications produced to see how they have incorporated the report findings.

Data should not be separated from the report

The report as a whole presents the findings of the site assessment and the report should not be copied in part or altered in any way. Logs, figures, laboratory data, drawings, etc. are customarily included in our reports and are developed by scientists, engineers or geologists based on their interpretation of field logs (assembled by field personnel), field testing and laboratory evaluation of field samples. This information should not under any circumstances be redrawn for inclusion in other documents or separated from the report in any way.

Contact Coffey for additional assistance

Coffey is familiar with a variety of techniques and approaches that can be used to help reduce risks for all parties to land development and land use. It is common that not all approaches will be necessarily dealt with in your environmental site assessment report due to concepts proposed at that time. As a project progresses through planning and design toward construction and/or maintenance, speak with Coffey to develop alternative approaches to problems that may be of genuine benefit both in time and cost.

Responsibility

Environmental reporting relies on interpretation of factual information based on judgement and opinion and has a level of uncertainty attached to it, which is far less exact than other design disciplines. This has often resulted in claims being lodged against consultants, which are unfounded. To help prevent this problem, a number of clauses have been developed for use in contracts, reports and other documents. Responsibility clauses do not transfer appropriate liabilities from Coffey to other parties but are included to identify where Coffey's responsibilities begin and end. Their use is intended to help all parties involved to recognise their individual responsibilities. Read all documents from Coffey closely and do not hesitate to ask any questions you may have.

Tables

TABLE LR1:

SUMMARY OF LABORATORY RESULTS FOR GROUNDWATER AND SURFACE WATER SAMPLES

Major Ions, Heavy Metals, Ammonium, Nitrite, Nitrate, Total Kjeldahl Nitrogen and Field Measurements

(All results in µg/L, unless otherwise stated)

Sample ID		MW01	QC03	MW02	MW03	MW04	MW05	QC01	MW06	MW08	MW09	MW10	MW11	MW14	MW15	MW16	MW17	MW18	TAGM/D3	SW7	SW8
Material		Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Surface Water	Surface Water
Unit Screened or Surface Water Location	THRESHOLD CONCENTRATIONS	Alluvial/ Estuarine (Clay) - connected with bund wall coalwash fill	Duplicate of MW01	Alluvial/ Estuarine (Sand) - connected with bund wall coalwash fill	Alluvial/ Residual/ XW Sandstone - connected with ash fill	Alluvial/ Estuarine (Clay) - connected with ash fill	Alluvial/ Estuarine (Clay)	Duplicate of MW05	Fill (Ash)	Fill (Ash)	Alluvial/ Estuarine (Clay)	Alluvial/ Estuarine (Sandy clay)	Fill (Ash)	Alluvial/ Estuarine (Sandy clay)	Alluvial/ Estuarine (Sandy clay)	Alluvial/ Estuarine (Clay)	Alluvial/ Estuarine (Sandy clay)	Residual Clay/XW Sandstone	Alluvial/ Estuarine?	Pond near MW14 west of Ash Pond 2	Lake within Ash Pond 3
Date Sampled		16/02/11	16/02/11	16/02/11	16/02/11	16/02/11	15/02/11	15/02/11	24/02/11	24/02/11	15/02/11	08/03/11	16/02/11	16/02/11	16/02/11	16/02/11	16/02/11	16/02/11	16/02/11	15/02/11	16/02/11
MAJOR CATIONS																					
Calcium (mg/L)		110	-	210	20	280	380	-	480	330	420	440	84	1100	460	330	390	61	27	-	-
Magnesium (mg/L)		130	-	320	270	290	1100	-	1300	910	1500	270	120	1100	1300	840	740	150	110	-	-
Potassium (mg/L)		49	-	170	1.9	82	380	-	590	330	64	25	67	250	520	230	190	1.1	90	-	-
Sodium (mg/L)		640	-	3400	2300	2000	8800	-	10000	7200	6700	1000	1200	5500	10000	4100	3300	1000	1600	-	-
Iron (mg/L)		31	-	6.2	140	93	210	-	16	220	94	84	0.03	6.3	60	0.04	170	<0.02	1.3	-	-
MAJOR ANIONS																					
Bicarbonate Alkalinity as $CaCO_3$ (mg/L)		320	-	810	<2	600	240	-	550	54	<2	250	290	1616	1005	1714	160	480	1614	-	-
Carbonate Alkalinity as $CaCO_3$ (mg/L)		<2	-	<2	<2	<2	<2	-	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-	-
Chloride (mg/L)		1300	-	6100	4900	4500	18000	-	19000	14000	16000	1400	2200	12000	21000	7700	5400	1800	2000	-	-
Sulfate (mg/L)		80	-	830	220	610	2200	-	2700	2400	2200	2100	340	2600	850	2600	4600	79	0.6	-	-
TOTAL CATIONS AND ANIONS		2660	-	11846	7852	8455	31310	-	34636	25444	26978	5569	4301	24172	35195	17514	14950	3571	5443	-	-
HEAVY METALS (DISSOLVED)																					
Arsenic	2.3 [1b]	**7**	**7**	**9**	**4**	**9**	**55**	**49**	**330**	**150**	**52**	**3**	**4**	1	**3**	<4	<2	<1	<1	1	**7**
Cadmium	0.7 [1c]	<0.5	<0.5	<1	<1	<1	<0.5	<0.5	<2	<2	<0.5	<0.1	<0.5	<0.5	<0.5	<2	<1	<0.5	<0.5	<0.5	<0.5
Chromium	27.4 [1d]	<5	<5	<10	<10	<10	<5	<5	<20	**330**	<5	<1	<5	<5	<5	<20	<10	<5	<5	<5	<5
Copper	1.3 [1]	<0.5	<0.5	<1	**6**	<1	**50**	**38**	<2	**7**	**33**	<1	<0.5	<0.5	<0.5	<2	**6**	1	<0.5	<0.5	<0.5
Lead	4.4 [1]	<0.5	<0.5	<1	**11**	<1	**7**	**6**	<2	<2	**9**	<1	**5**	<0.5	<0.5	<2	**8**	1	<0.5	<0.5	<0.5
Molybdenum	23 [1a]	1	2	<2	<2	5	1	<1	**110**	12	<1	<1	**27**	4	2	9	2	2	<1	<1	9
Nickel	7 [1c]	5	5	<10	**52**	**37**	5	6	**66**	**2400**	<5	4	<5	<5	<5	<20	**31**	<5	<5	<5	<5
Zinc	15 [1]	**67**	**52**	**54**	**230**	**88**	**73**	**69**	**49**	**90**	**160**	**57**	**19**	**30**	**40**	**40**	**150**	**67**	**32**	**30**	**43**
NUTRIENTS																					
Ammonium (NH_4^+) as N	140-5960 [3]	2200	2300	910	570	**5200**	**9200**	**10000**	**5600**	**2000**	1300	1500	330	**15000**	**20000**	1600	**8500**	50	**17000**	80	330
Nitrate as N	700 [1e]	<50	<10	<50	<50	<50	<250	<250	<250	<250	<250	<25	<25	<250	<250	<50	<50	39	<25	<25	<25
Nitrite as N		<5	6	<5	<5	<5	<5	<5	50	<5	<5	<5	<5	<5	<5	<5	<5	5	<5	<5	<5
Total Kjeldahl Nitrogen		3400	3600	4600	1200	9000	12000	10500	7200	7600	2600	3800	810	17000	42000	17000	9200	690	17000	4800	6700
Total Nitrogen (by calc.)	300 [2]	**3400**	**3600**	**4600**	**1200**	**9000**	**12000**	**10500**	**7250**	**7600**	**2600**	**3800**	**810**	**17000**	**42000**	**17000**	**9200**	**730**	**17000**	**4800**	**6700**
FIELD MEASUREMENTS																					
Dissolved Oxygen (mg/L)		4.5	4.5	5.0	2.6	2.9	4.0	4.0	2.3	0.9	3.5	1.5	1.9	3.2	4.0	5.5	5.6	4.1	2.9	8.0	6.9
Electrical conductivity (mS/cm)		4.60	4.60	13.10	10.54	11.00	34.60	34.60	46.80	29.70	30.70	7.15	5.00	26.70	40.00	16.84	14.01	4.08	7.23	6.04	5.85
pH (Units)	7.0-8.5 [2]	**6.5**	**6.5**	7.0	**4.2**	**6.6**	**6.1**	**6.1**	7.2	**6.1**	**4.2**	**5.2**	8.2	**6.6**	**6.5**	7.5	**6.6**	7.2	7.3	8.1	8.8
Er Redox (mV)[4]		-100	-100	-140	238	-98	-17	-17	-73	-4	245	73	-52	-89	-90	76	-54	82	-150	-56	20
Eh Redox (mV)[5]		99	99	59	437	101	182	182	126	195	444	272	147	110	109	275	145	281	49	143	219
Temp (^oC)		22.6	22.6	20.1	20.4	22.6	18.1	18.1	19.5	21.8	18.8	19	20.1	19.9	20.0	21.6	19.7	20.6	22.1	26.6	32.3

NOTES:

Bold Concentration exceeds the Threshold Criteria

[1] Based on ANZECC/ARMCANZ (2000), Australian and New Zealand Guidelines For Fresh and Marine Water Quality (Marine water, South Eastern Australia, slightly to moderately disturbed system, 95% of species protected)

[1a] Low reliability trigger values

[1b] Low reliability trigger value for As(III) used

[1c] Recommended 99% protection level used

[1d] Based on the Chromium (III) trigger value

[1e] Based on the freshwater trigger value

[2] ANZECC (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Table 3.3.2 (Estuarine trigger value)

[3] ANZECC (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Table 8.3.7 (Marine trigger values, range is pH dependent as ammonia dominates at pH values > 9)

[4] Er is oxidation reduction potential as measured with a platinum electrode and silver/silver chloride reference electrode (saturated KCl)

[5] Eh is converted oxidation reduction potential relative to the standard hydrogen electrode (Eh = Er + 199 mV).

\- Not Analysed

See original laboratory reports for detection limits

TABLE LR2:

SUMMARY OF LABORATORY RESULTS FOR GROUNDWATER AND SURFACE WATER SAMPLES FOR PREVIOUS AND CURRENT COFFEY INVESTIGATIONS

Heavy Metals, Ammonium, Nitrite, Nitrate, Total Kjeldahl Nitrogen and Field Measurements

(All results in µg/L, unless otherwise stated)

Sample ID	THRESHOLD CONCENTRATIONS	MW01			MW02			MW03			MW04			MW05			MW06			MW08		
Material		Groundwater			Groundwater			Groundwater			Groundwater			Groundwater			Groundwater			Groundwater		
Unit Screened		Alluvial/Estuarine (Clay) - connected with bund wall coalwash fill			Alluvial/Estuarine (Sand) - connected with bund wall coalwash fill			Alluvial/Residual/ XW Sandstone - connected with ash fill			Alluvial/Estuarine (Clay) - connected with ash fill			Alluvial/Estuarine (Clay)			Fill (Ash)			Fill (Ash)		
Date Sampled		25-Jun-10	25-Aug-10	16-Feb-11	25-Jun-10	25-Aug-10	16-Feb-11	25-Jun-10	24-Aug-10	16-Feb-11	25-Jun-10	24-Aug-10	16-Feb-11	24-Jun-10	24/08/2010	16-Feb-11	24-Jun-10	25-Aug-10	24-Feb-11	24-Jun-10	25-Aug-10	24-Feb-11
HEAVY METALS (DISSOLVED)																						
Arsenic	2.3 [1b]	<10	**4**	**7**	<10	**10**	**9**	<10	**4**	**4**	<10	**5**	**9**	**23**	**13**	**55**	**190**	**110**	**330**	**73**	**30**	**150**
Cadmium	0.7 [1c]	<1	-	<0.5	<1	-	<1	<1	-	<1	<1	-	<1	<1	-	<0.5	<1	-	<2	<1	-	<2
Chromium	27.4 [1d]	<10	-	<5	<10	-	<10	<10	-	<10	<10	-	<10	<10	-	<5	<10	-	<20	<10	-	**330**
Copper	1.3 [1]	<10	<1	<0.5	<10	<1	<1	<10	<1	**6**	<10	**3**	<1	**32**	**12**	**50**	**29**	<1	<2	**29**	**2**	**7**
Lead	4.4 [1]	<10	-	<0.5	<10	-	<1	<10	-	**11**	<10	-	<1	<10	-	**7**	<10	-	<2	<10	-	<2
Molybdenum	23 [1a]	-	-	1	-	-	<2	-	-	<2	-	-	5	-	-	1	-	-	**110**	-	-	12
Nickel	7 [1c]	<10	5	5	<10	4	<10	**44**	**45**	**52**	<10	**11**	**37**	**13**	**12**	5	**26**	**76**	**66**	**200**	**87**	**2400**
Zinc	15 [1]	**94**	**57***	**67**	**63**	**53**	**54**	**130**	**170**	**230**	**110**	**69**	**88**	**100**	**87**	**73**	**140**	**61**	**49**	**130**	**81**	**90**
NUTRIENTS																						
Ammonium (NH_4^+) as N	140-5960 [3]	**11000**	**12000**	2200	870	950	910	330	390	570	**6500**	**7300**	**5200**	**10000**	**12000**	**9200**	**6300**	**6700**	**5600**	1600	1300	**2000**
Nitrate as N	700 [1e]	-	70*	<50	-	<100	<50	-	<50	<50	-	<50	<50	-	<250	<250	-	<250	<250	-	450	<250
Nitrite as N		-	30*	<5	-	<5	<5	-	<5	<5	-	<5	<5	-	<5	<5	-	120	50	-	42	<5
Total Kjeldahl Nitrogen		-	-	3400	-	-	4600	-	-	1200	-	-	9000	-	-	12000	-	-	7200	-	-	7600
Total Nitrogen (by calc.)	300 [2]	-	-	**3400**	-	-	**4600**	-	-	**1200**	-	-	**9000**	-	-	**12000**	-	-	**7250**	-	-	**7600**
FIELD MEASUREMENTS																						
Dissolved Oxygen (mg/L)		2.6	5.4	4.5	3.0	4.9	5.0	2.1	4.9	2.6	2.0	4.7	2.9	3.9	4.4	4.0	3.7	6.4	2.3	4.6	8.1	0.9
Electrical conductivity (mS/cm)		8.07	23.80	4.60	17.65	18.76	13.10	9.92	11.12	10.54	12.07	12.11	11.00	46.20	48.60	34.60	31.80	53.80	46.80	26.40	26.00	29.70
pH (Units)	7.0-8.5 [2]	7.3	7.1	**6.5**	7.2	7.1	7.0	**5.2**	**4.8**	**4.2**	**6.4**	**6.4**	**6.6**	**6.5**	**6.6**	**6.1**	**6.8**	7.0	7.2	**6.8**	**6.4**	**6.1**
Er Redox (mV)[4]		-116	-63	-100	-96	-104	-140	108	126	238	-59	-89	-98	-73	-68	-17	3	-40	-73	-17	-42	-4
Eh Redox (mV)[5]		83	136	99	103	95	59	307	325	437	140	110	101	126	131	182	202	159	126	182	157	195
Temp (°C)		20.8	19.0	22.6	20.0	17.0	20.1	20.5	19.0	20.4	20.7	18.2	22.6	18.3	17.4	18.1	15.3	13.5	19.5	18.5	14.1	21.8

Sample ID	THRESHOLD CONCENTRATIONS	MW09			MW10		MW11	MW14	MW15	MW16	MW17	MW18	TAGM/1	TAGM/3	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
Material		Groundwater			Groundwater		Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Surface Water	Surface Water	Surface Water	Surface Water	Surface Water	Surface Water	Surface Water	Surface Water
Unit Screened		Alluvial/Estuarine (Clay)			Alluvial/Estuarine (Sandy clay)		Fill (Ash)	Alluvial/Estuarine (Sandy clay)	Alluvial/Estuarine (Sandy clay)	Alluvial/Estuarine (Clay)	Alluvial/Estuarine (Sandy clay)	Residual Clay/XW Sandstone	Alluvial?	Alluvial/Estuarine?	-	-	-	-	-	-	-	-
Date Sampled		24-Jun-10	25-Aug-10	15-Feb-11	24-Aug-10	08-Mar-11	16-Feb-11	16-Feb-11	16-Feb-11	16-Feb-11	16-Feb-11	16-Feb-11	24-Aug-10	16-Feb-11	24-Aug-10	24-Aug-10	24-Aug-10	24-Aug-10	25-Aug-10	25-Aug-10	15-Feb-11	16-Feb-11
HEAVY METALS (DISSOLVED)																						
Arsenic	2.3 [1b]	**17**	**21**	**52**	**3**	**3**	**4**	1	**3**	<4	<2	<1	2	<1	2	**7**	**7**	**7**	**8**	**8**	1	**7**
Cadmium	0.7 [1c]	<1	-	<0.5	-	<0.1	<0.5	<0.5	<0.5	<2	<1	<0.5	-	<0.5	-	-	-	-	-	-	<0.5	<0.5
Chromium	27.4 [1d]	<10	-	<5	-	<1	<5	<5	<5	<20	<10	<5	-	<5	-	-	-	-	-	-	<5	<5
Copper	1.3 [1]	**35**	**6**	**33**	<1	<1	<0.5	<0.5	<0.5	<2	**6**	1	**67**	<0.5	**2**	<1	<1	<1	<1	<1	<0.5	<0.5
Lead	4.4 [1]	**21**	-	**9**	-	<1	**5**	<0.5	<0.5	<2	**8**	1	-	<0.5	-	-	-	-	-	-	<0.5	<0.5
Molybdenum	23 [1a]	-	-	<1	-	<1	**27**	4	2	9	2	2	-	<1	-	-	-	-	-	-	<1	9
Nickel	7 [1c]	**59***	**49**	<5	**14**	4	<5	<5	<5	<20	**31**	<5	**14**	<5	5	**11**	**10**	**11**	**11**	**11**	<5	<5
Zinc	15 [1]	**170**	**270**	**160**	**47**	**57**	**19**	**30**	**40**	**40**	**150**	**67**	**490**	**32**	**76**	**25**	**41**	**37**	**29**	**20**	**30**	**43**
NUTRIENTS																						
Ammonium (NH_4^+) as N	140-5960 [3]	1200	1300	1300	430	1500	330	**15000**	**20000**	1600	**8500**	50	11	**17000**	100	340	250	250	230	200	80	330
Nitrate as N	700 [1e]	-	<250	<250	<25	<25	<25	<250	<250	**<50**	**<50**	39	**12000**	<25	8	<250	<250	<250	<250	<250	<25	<25
Nitrite as N		-	<5	<5	<5	<5	<5	<5	<5	<5	<5	5	670	<5	<5	<5	<5	<5	<5	<5	<5	<5
Total Kjeldahl Nitrogen		-	-	2600	-	3800	810	17000	42000	17000	9200	690	-	17000	-	-	-	-	-	-	4800	6700
Total Nitrogen (by calc.)	300 [2]	-	-	**2600**	-	**3800**	**810**	**17000**	**42000**	**17000**	**9200**	**730**	-	**17000**	-	-	-	-	-	-	**4800**	**6700**
FIELD MEASUREMENTS																						
Dissolved Oxygen (mg/L)		6.2	5.5	3.5	5.6	1.5	1.9	3.2	4.0	5.5	5.6	4.1	0.9	2.9	8.9	7.9	7.5	8.3	9.6	10.7	8.0	6.9
Electrical conductivity (mS/cm)		37.50	40.30	30.70	7.49	7.15	5.00	26.70	40.00	16.84	14.01	4.08	0.55	7.23	11.00	44.80	45.20	46.70	50.10	51.80	6.04	5.85
pH (Units)	7.0-8.5 [2]	**4.2**	**4.1**	**4.2**	**6.4**	**5.2**	8.2	**6.6**	**6.5**	7.5	**6.6**	7.2	**5.4**	7.3	7.6	8.2	8.2	8.2	8.3	**6.5**	8.1	8.8
Er Redox (mV)[4]		199	228	245	-29	73	-52	-89	-90	76	-54	82	29	-150	52	77	60	20	152	161	-56	20
Eh Redox (mV)[5]		398	427	444	170	272	147	110	109	275	145	281	228	49	251	276	259	219	351	360	143	219
Temp (°C)		18.7	12.2	18.8	15.0	19	20.1	19.9	20.0	21.6	19.7	20.6	15.3	22.1	14.7	16.7	15.1	14.4	19.8	19.0	26.6	32.3

NOTES:

Bold Concentration exceeds the Threshold Criteria

[1] Based on ANZECC/ARMCANZ (2000), Australian and New Zealand Guidelines For Fresh and Marine Water Quality (Marine water, South Eastern Australia, slightly to moderately disturbed system, 95% of species protected)

[1a] Low reliability trigger values

[1b] Low reliability trigger value for As(III) used

[1c] Recommended 99% protection level used

[1d] Based on the Chromium (III) trigger value

[1e] Based on the freshwater trigger value

[2] ANZECC (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Table 3.3.2 (Estuarine trigger value)

[3] ANZECC (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Table 8.3.7 (Marine trigger values, range is pH dependent as ammonia dominates at pH values > 9)

[4] Er is oxidation reduction potential as measured with a platinum electrode and silver/silver chloride reference electrode (saturated KCl)

[5] Eh is converted oxidation reduction potential relative to the standard hydrogen electrode (Eh = Er + 199 mV).

\- Not Analysed

See original laboratory reports for detection limits

* Field or laboratory duplicate sample which was higher than the primary sample concentration

TABLE LR3:
SUMMARY OF LABORATORY RESULTS FOR COALWASH, ASH AND SOIL SAMPLES
Heavy Metals, Ammonium, Nitrite, Nitrate and Total Kjeldahl Nitrogen
Soil and Leachate Water Results

Sample ID			THRESHOLD CONCENTRATIONS					CTP87/ 0.5-0.6	CTP87/ 1.4-1.6	CTP89/ 0.5-0.6	CTP89/ 1.8-2.0	QC2 (Duplicate of CTP89/ 1.8-2.0)	CTP90/ 0.5-0.6	CTP90/ 1.8-2.0	CTP88/ 0.6-0.8	CTP88/ 3.5-3.7	CTP91/ 0.6-0.8	QC3 (Duplicate of CTP91/ 0.6-0.8)	CTP91/ 1.6-1.8	CTP92/ 0.6-0.8	CTP92/ 1.0-1.1	CTP93/ 0.6-0.7	QC1 (Duplicate of CTP93/ 0.6-0.7)	CTP94/ 0.4-0.5	CTP94/ 0.8-1.0
Material								Coalwash	Coalwash	Coalwash	Coalwash	Coalwash	Coalwash	Coalwash	Ash	Ash	Ash	Ash	Ash	Ash	Ash	Soil (Clay)	Soil (Clay)	Soil (Clay)	Soil (Clay)
Depth (m)			ANZECC	HIL	HIL	HIL	EIL	0.5-0.6	1.4-1.6	0.5-0.6	1.8-2.0	1.8-2.0	0.5-0.6	1.8-2.0	0.6-0.8	3.5-3.7	0.6-0.8	0.6-0.8	1.6-1.8	0.6-0.8	1.0-1.1	0.6-0.7	0.6-0.7	0.4-0.5	0.8-1.0
Date Sampled	**Units**	**LOR**	(2000)	(NEHF A)	(NEHF E)	(NEHF F)		18/04/11	18/04/11	18/04/11	18/04/11	18/04/11	18/04/11	18/04/11	18/04/11	18/04/11	18/04/11	18/04/11	18/04/11	18/04/11	18/04/11	18/04/11	18/04/11	18/04/11	18/04/11
Soil Results																									
HEAVY METALS																									
Arsenic	mg/kg	<3		100 [1]	200 [1]	500 [1]	20 [1]	9	12	5	<3	<3	15	<3	6	9	<3	<3	4	5	<3	<3	<3	5	<3
Cadmium	mg/kg	<0.3		20 [1]	40 [1]	100 [1]	3 [1]	0.7	0.5	0.4	0.5	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Chromium	mg/kg	<0.3		120,000 [1a]	240,000 [1a]	600,000 [1a]	400 [1a]	1.8	1.8	50	1.7	1.4	1.8	1.4	5.4	4.1	4.5	4.4	5.3	5.3	5.3	5	5.5	22	14
Copper	mg/kg	<0.5		1,000 [1]	2,000 [1]	5,000 [1]	100 [1]	17	21	22	21	22	23	19	9.1	5.2	5.7	5.7	6.8	6.5	5.8	9.2	7.8	46	12
Lead	mg/kg	<1		300 [1]	600 [1]	1,500 [1]	600 [1]	22	23	15	15	15	14	17	4	3	3	3	4	4	3	4	3	47	5
Molybdenum	mg/kg	<1						1.4	1.2	1.7	1.6	<1	1.1	<1	<1	<1	<1	<1	1.2	<1	<1	2.2	1.8	2.3	1.2
Nickel	mg/kg	<0.5		600 [1]	600 [1]	3,000 [1]	60 [1]	5.9	6.1	32	8.2	8.3	8.4	8.1	6.3	6.2	3.8	3.9	4	4.4	3.8	0.8	0.94	15	2.2
Zinc	mg/kg	<0.5		7,000 [1]	14,000 [1]	35,000 [1]	200 [1]	66	65	39	45	60	60	29	13	15	11	12	12	12	11	3.4	4	39	10
NUTRIENTS																									
Ammonium (NH_4^+) as N	mg/kg	<0.15						0.84	0.37	0.73	0.54	0.55	0.55	0.48	0.4	1.6	<0.15	0.15	11	0.54	6.5	11	6.7	4.4	11
Nitrate as N	mg/kg	<0.025						0.16	0.24	0.081	0.11	0.11	0.069	0.13	0.33	<0.025	0.06	0.062	0.037	<0.125	<0.125	<0.050	<0.050	0.17	<0.025
Nitrite as N	mg/kg	<0.025						0.03	0.03	0.03	0.03	0.03	0.04	0.03	<0.025	0.08	<0.025	0.04	0.07	0.06	0.05	0.04	0.05	0.04	0.04
Total Kjeldahl Nitrogen	mg/kg	<40						2800	1900	4200	2300	3100	3300	2400	1100	790	550	300	490	280	300	420	600	5300	450
Total Nitrogen (by calc.)	mg/kg	<20						2800	1900	4200	2300	3100	3300	2400	1100	790	550	300	490	280	300	420	600	5300	450
Leachate Results (ASLP[5])																									
pH of Final Leachate	pH units	<0						7.7	6.8	7.0	6.8	8.2	6.7	6.7	6.9	6.8	7.9	7.7	8.0	7.8	7.2	7.3	7.3	5.0	5.0
HEAVY METALS (ASLP)																									
Arsenic	μg/L	<1	2.3 [2b]					<1	<1	<1	<1	<1	<1	<1	2	**17**	**4**	**3**	**13**	**4**	2	<1	<1	<1	<1
Cadmium	μg/L	<0.1	0.7 [2c]					<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Chromium	μg/L	<1	27.4 [2d]					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Copper	μg/L	<1	1.3 [2]					<1	<1	1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1	1	<1	**3**	1
Lead	μg/L	<1	4.4 [2]					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2	<1
Molybdenum	μg/L	<1	23 [2a]					<1	<1	<1	<1	3	1	<1	<1	3	<1	1	5	15	7	**29**	**24**	<1	<1
Nickel	μg/L	<1	7 [2c]					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	2	<1
Zinc	μg/L	<1	15 [2]					<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	8	4
NUTRIENTS (ASLP)																									
Ammonium (NH_4^+) as N	mg/L	<0.01	0.14-5.96 [4]					0.14	0.12	0.12	0.15	0.13	0.12	0.11	0.12	0.06	0.08	0.09	0.16	0.1	0.25	0.51	0.5	0.21	0.37
Nitrate as N	mg/L	<0.005	0.7 [2e]					0.039	0.033	0.036	0.029	0.017	0.022	0.034	0.031	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.006	0.01	0.025	<0.005
Nitrite as N	mg/L	<0.005						0.006	0.006	0.006	0.006	0.007	0.006	0.006	<0.005	0.007	0.005	0.007	0.007	0.006	0.008	0.02	0.02	0.008	0.007
Total Kjeldahl Nitrogen	mg/L	<0.2						4.6	1.7	2.6	3.7	3.3	3.6	2.6	0.34	<0.2	0.24	0.27	0.42	<0.2	0.3	8.7	5.3	17	0.57
Total Nitrogen (by calc.)	mg/L	<0.2	0.3 [3]					**4.6**	**1.7**	**2.6**	**3.7**	**3.3**	**3.6**	**2.6**	**0.34**	<0.2	0.24	0.27	**0.42**	<0.2	0.3	**8.7**	**5.3**	**17**	**0.57**

NOTES:

Bold Concentration exceeds the Threshold Criteria

[1] Based on National Environment Protection (Assessment of Site Contamination) Measure 1999 (NEPM) from the National Environment Protection Council (NEPC, 1999)

[1a] Based on Chromium III

[2] Based on ANZECC/ARMCANZ (2000), Australian and New Zealand Guidelines For Fresh and Marine Water Quality (Marine water, South Eastern Australia, slightly to moderately disturbed system, 95% of species protected)

[2a] Low reliability trigger values

[2b] Low reliability trigger value for As(III) used

[2c] Recommended 99% protection level used

[2d] Based on the Chromium (III) trigger value

[2e] Based on the freshwater trigger value

[3] ANZECC (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Table 3.3.2 (Estuarine trigger value)

[4] ANZECC (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Table 8.3.7 (Marine trigger values, range is pH dependent as ammonia dominates at pH values > 9)

[5] Australian Standard Leaching Procedure (ASLP) using deionised laboratory water (neutral leachate)

LOR Limits of Reporting

TABLE LR4:
SUMMARY OF LABORATORY RESULTS FOR ADDITIONAL SOIL SAMPLES
Cation Exchange Capacity, Total Organic Carbon, Ammonium, Nitrite, Nitrate and Total Kjeldahl Nitrogen
Soil Results

Sample ID			HA1	QC1 (Duplicate of HA1/0.8-1.0m)	HA4 (10m north of MW17)	HA2	HA3
Material			Soil (Clay)	Soil (Clay)	Soil (Clay)	Soil (Clay)	Soil (Clay)
Distance from edge of Ash Pond 3 bund (m)			1	1	17	50	110
Depth (m)			0.8-1.0	0.8-1.0	0.8-1.0	0.8-0.9	0.6-0.7
Date Sampled	**Units**	**LOR**	23/08/11	23/08/11	23/08/11	23/08/11	23/08/11
Soil Results							
CATION EXCHANGE CAPACITY							
Sodium, Na	mg/kg	2	880	870	740	710	180
Sodium (meq%)	meq%	0.01	3.8	3.8	3.2	3.1	0.78
Exchangeable Sodium	%	1	42	40	37	55	52
Potassium, K	mg/kg	2	260	250	310	170	86
Potassium (meq%)	meq%	0.01	0.66	0.64	0.79	0.43	0.22
Exchangeable Potassium	%	1	7	7	9	8	15
Calcium, Ca	mg/kg	2	300	340	210	99	35
Calcium (meq%)	meq%	0.01	1.5	1.7	1	0.49	0.17
Exchangeable Calcium	%	1	16	18	12	9	12
Magnesium, Mg	mg/kg	2	380	420	440	200	39
Magnesium (meq%)	meq%	0.01	3.1	3.4	3.6	1.6	0.32
Exchangeable Magnesium	%	1	34	36	42	29	21
CEC	meq%	0.01	9.1	9.6	8.7	5.7	1.5
TOTAL ORGANIC CARBON	%	0.05	0.42	0.53	0.43	0.25	0.19
NUTRIENTS							
Ammonium (NH_4^+) as N	mg/kg	0.15	6.4	7.2	5.4	2.3	0.41
Nitrate as N	mg/kg	0.025	0.088	0.15	0.062	<0.050	0.27
Nitrite as N	mg/kg	0.025	0.03	0.03	<0.025	<0.025	<0.025
Total Kjeldahl Nitrogen	mg/kg	40	340	400	400	170	120
Total Nitrogen (by calc.)	mg/kg	20	340	400	400	170	120

NOTES:

LOR Limits of Reporting