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Groundwater Assessment

Redevelopment of Former Brick Pit, Kirrawee

for Henroth Investments Pty Limited
October 2010

J1418.13R-rev0

CMJA

C. M. Jewell & Associates Pty Ltd

Groundwater Assessment – Redevelopment of Former Brick Pit, Kirrawee
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Principal

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1.0 INTRODUCTION

1.1 Background

This Groundwater Assessment Report has been prepared in support of an application for Concept Plan approval under Part 3A of the Environmental Planning and Assessment Act at 566-594 Princes Highway, Kirrawee (as shown on Figure 1), otherwise known as the former Kirrawee Brick Pit (Reference MP 10_0076). The application seeks approval for a mixed use development comprising residential, retail and commercial uses and building envelopes of between 5 and 15 storeys. The proposal also involves basement car parking and includes commuter parking, landscaping, services and the provision of a major new public park. Specifically, this report addresses requirements related to groundwater, pit dewatering, and associated contamination issues, as detailed in the Director General's Requirements (DGR) issued by the Department of Planning on 24 August 2010 and outlined below.

The proposal to redevelop the former Kirrawee Brick Pit will include construction of basement car-parking within the existing pit. As the pit is currently flooded, dewatering will be required, and as the proposed development extends below the local water table, long-term management of groundwater inflow will also be necessary.

The DGR included the following

> **Plans and documents to accompany the Application.**
>
> The following plans, architectural drawings, diagrams and relevant documentation shall be submitted;
>
> 10. Site Contamination Assessment / Human Health Risk Assessment / documentation that demonstrates that the land is or can be made suitable for the intended purpose within the project delivery timeframe.
>
> 12. Groundwater Assessment – identifying groundwater issues and potential degradation to the groundwater source that may be encountered during excavation. The assessment should identify contingency measures to manage any potential impacts.
>
> **10. Drainage and Stormwater Management**
>
> - The EA shall address drainage/groundwater/flooding issues associated with the development/site, including stormwater, drainage infrastructure and incorporation of Water Sensitive Urban Design measures.
> - An urban design integrating ‘best practice’ stormwater management principles to minimise the generation of stormwater from the development and maximise opportunities for reuse on-site.
> - Measures to ensure that water quality in the ornamental lake/compensatory pond is continuously maintained to a standard suitable for wildlife known to drink from the existing water body and to a standard compatible with public safety and amenity.
> - Measures to ensure that stormwater flows from the site including any discharges from the ornamental lake/compensatory pond are controlled and appropriately treated to ensure that there will be no short-term or long-term detrimental impacts to the receiving waters or environment.
> - A methodology to dewater the brick pit in preparation for construction of the development that specifically addresses the following issues:
>   - Measures to protect against possible environmental impacts associated with dewatering the brick pit;
>   - Opportunities to reuse the water for beneficial purposes in preference to disposal;
>   - Analysis of water quality and risk to the receiving environment;
>   - Impact of dewatering the brick pit on wildlife habitat;
>   - Affect of withdrawing the water from the brick pit on the groundwater resource; and

  - Stability of the empty impoundment and potential for bank failure, particularly the influence on Flora Street.

11. **Contamination, Human Health Risk Assessment and Geotechnical Issues.**
    - Contamination and geotechnical issues associated with the proposal should be identified and addressed in accordance with SEPP55.

In order to address data and information gaps, Mr Daniel Maurici of Henroth Investments Pty Limited (Henroth) had previously commissioned C. M. Jewell & Associates Pty Ltd (CMJA) to carry out a review of available data and a site investigation and to prepare plans for dewatering and long-term groundwater management. That work was carried out in December 2008 and January 2009, and has now been reviewed and revised as necessary to address the DGR.

This report is a Groundwater Assessment Report that specifically addresses the DGR. It is supported by the Hydrogeological Data Report (ref. J1418.9R-rev0, October 2010) which presents the results of the detailed groundwater, pit water and pit floor sediment sampling program carried out by CMJA, as well as a summary of relevant data obtained from other sources.

It is also complemented by a Dewatering Plan (ref. J1418.10R-rev0, October 2010) and a Long-Term Groundwater Management Plan (ref. J1418.11R-rev0, October 2010) that have been prepared to facilitate operations on site during redevelopment, and which have been submitted under separate covers.

1.2 Objective

The objective of this report is to address the relevant parts of the DGR, as set out in Section 1.1.

1.3 Scope of Work

The scope of work conducted to meet the assessment objective included: the collection of groundwater samples from each of the wells at the site; vertical water quality profiling of the water in the quarry lake; collection of water samples from the water in the quarry lake; collection of sediment samples from the floor of the lake; assessment of the environmental condition of Dents and Oyster Gully Creeks; assessment of the quality and fitness of the analytical data sets generated during the investigation; and finally the preparation of this report and a number of accompanying reports.

Details regarding the scope of work carried out during each stage of the fieldwork are provided below whilst (in-depth) descriptions of the field procedures during each stage are presented in Appendix J of the Hydrogeological Data Report; reference should be made to Figure 2 of this report for sample locations, whilst results of the investigation are presented later in the relevant sections of this report.

Groundwater Sampling

- *Manual measurement of standing water levels at monitoring wells GW1, GW2, GW3, BH1 and BH4.*
- *Purging of groundwater from each of these groundwater monitoring wells, and the subsequent collection of groundwater samples from each monitoring well.*

  A duplicate sample – identified as GW:D – was also collected from monitoring well GW3.
- *Monitoring of physio-chemical parameters including pH, electrical conductivity, temperature, dissolved oxygen and redox potential during the purging of each monitoring well.*
- *Submission of the samples for laboratory analysis.*

Each sample submitted was analysed for major anion and cation concentrations (i.e. chloride, sulphate, bicarbonate, carbonate, magnesium, calcium, potassium and sodium), dissolved concentrations of heavy metals (which included iron and manganese), total petroleum hydrocarbons (TPH), and benzene, toluene, ethylbenzene and xylene (BTEX compounds), volatile halogenated compounds (VHC), dissolved organic carbon (DOC) and a range of nutrients and ecological toxicants (including boron, nitrate, nitrite, total nitrogen, ammonia and reactive and total phosphorus).

Pit Water Profiling and Sampling

- *Vertical profiling of the water in the quarry lake at seven locations.*

  Profiling was carried out by taking and recording measurements of pH, electrical conductivity, temperature, dissolved oxygen, oxidation–reduction potential and turbidity at 0.5-metre intervals until the quarry floor was encountered; these parameters were also measured at the floor of the quarry lake at a number of sampling locations.

- *Assessment of the water column profiles and selection of two sampling depths for each location.*

- *Collection of two water samples from each of the water profiling locations.*

  Water samples were collected using a peristaltic pump with one sample collected from the upper portion of the water column, and one from the lower portion; two duplicate samples – identified as BP:D1 and BP:D2 – were also collected from sample location BP:02 at depths of 1.5 and 3.5 metres respectively.

- *Submission of the samples for laboratory analysis.*

  Each sample submitted was analysed for major anion and cation concentrations, dissolved concentrations of heavy metals (namely arsenic, cadmium, chromium, copper, lead, manganese, iron, mercury, nickel and zinc), TPH, oil and grease, DOC, biological oxygen demand (BOD), and a range of nutrients and ecological toxicants (including boron, nitrate, nitrite, total nitrogen, ammonia and total and reactive phosphorus).

Pit Floor Sediment Sampling

- *Collection of sediment samples from the floor of the quarry lake at two depths.*

  Samples were collected from the same locations chosen during the water sampling program, and were collected using a sediment hand-coring device from depths of 0.05 and 0.15 metre. Two duplicate samples – identified as BP:SD1 and BP:SD2 – were also collected from sample location BP:02, the first from 0.05 metre depth, and the second 0.15 metre.

- *Submission of the samples for laboratory analysis.*

  Each sample submitted was analysed for heavy metals (namely arsenic, cadmium, chromium, copper, lead, manganese, mercury, nickel and zinc), semi-volatile fractions of TPH, polycyclic aromatic hydrocarbons (PAH), organochlorine pesticides (OCP), total phosphorus and total organic carbon (TOC).

Description of Surface Water Drainage Systems

- *Visual assessment and characterisation of the geological, geomorphological and environmental characteristics of both Dents and Oyster Gully creeks at a number of locations along their alignment.*

Features documented included the cultural, topographic and geological settings, channel and embankment features – such as height, gradient and condition, vegetation condition, and finally the nature and type of any refuse in the area.

- *Monitoring of physio-chemical parameters of pH, electrical conductivity, temperature and dissolved oxygen at each profiling location.*
- *Estimation and measurement of baseflow in both systems at each of the profiling locations.*

1.4 Report Format

Section 2 of this report provides basic identification information and a description of the site and surrounding area. A description of the geology and physical hydrogeology of the site and surrounding area is set out in Section 3, whilst groundwater chemistry is described in Section 4. Section 5 and Section 6 provide information on the chemical character of the quarry lake, and the sediments on the floor of the quarry lake.

In Section 7, the program proposed for dewatering of the quarry lake is briefly described, while the approach proposed for water disposal is outlined in Section 8.

Section 9 identifies potential impacts of the proposed dewatering and water disposal operations; the impact of these operations is assessed in Section 10. Section 11 sets out proposed mitigation and contingency measures.

Section 12 contains some brief concluding remarks and references to companion documents.

1.5 Limitations and Intellectual Property Matters

This report has been prepared by C. M. Jewell & Associates Pty Limited for the use of the client identified in Section 1.1, for the specific purpose described in that section. The project objective and scope of work outlined in Sections 1.2 and 1.3 were developed for that purpose, taking into consideration client requirements.

The work has been carried out, and this report prepared, utilising the standards of skill and care normally expected of professional scientists practising in the fields of hydrogeology and contaminated land management in Australia. The level of confidence of the conclusions reached is governed, as in all such work, by the scope of the investigation carried out and by the availability and quality of existing data. Where limitations or uncertainties in conclusions are known, they are identified in this report. However, no liability can be accepted for failure to identify conditions or issues which arise in the future and which could not reasonably have been assessed or predicted using the adopted scope of investigation and the data derived from that investigation. An information sheet – 'Important Information about your Environmental Site Assessment' – is provided with this report. The report should be read in conjunction with that information sheet.

Where data collected by others have been used to support the conclusions of this report, those data have been subjected to reasonable scrutiny but have essentially, and necessarily, been used in good faith. Liability cannot be accepted for errors in data collected by others.

This report, the original data contained in the report, and its findings and conclusions remain the intellectual property of C. M. Jewell & Associates Pty Ltd. A licence to use the report for the specific purpose identified in Section 1.1 is granted to the persons identified in that section on the condition of receipt of full payment for the services involved in the preparation of the report.

This report should not be used by other persons or for other purposes than those identified in Section 1.1, and should not be reproduced except in full and with the permission of C. M. Jewell & Associates Pty Ltd.

2.0 SITE INFORMATION

This section provides a brief summary of hydrogeological conditions on the site. For further detail, and a full list of information sources, reference should be made to the Hydrogeological Data Report.

2.1 Site Identification

The site is located between the Princes Highway, which forms the northern boundary of the site, and Flora Street, Kirrawee. It is bounded to the east by a number of industrial units, and to the west by Oak Road.

The site address is 566-594 Princes Highway, Kirrawee, and the land title designation is Lots 1 and 2 in DP589977 and Lot 1 in DP179075.

2.2 Site Description

The site is roughly rectangular and measures approximately 250 metres east-west by 170 metres north-south, and has an area of 4.25 hectares. As shown on Figure 2, the former quarry occupies most of the southern half of the site, whilst the northern portion of the site consists of a series of shallow slopes and terraces that fall towards the Princes Highway.

2.3 Current Site Use

The site is currently disused. The former quarry pit is filled with water, and the remainder of the site is heavily overgrown with vegetation, including many species of exotic weeds.

2.4 Surrounding Area

Land use in the area surrounding the site is predominantly low-density residential, with commercial and light industrial use immediately to the east of the site and also to the north of the Princes Highway, and a small commercial area to the south-east. There is commercial (retail) development to the south-west, and light industry to the south. The Sutherland–Cronulla railway lies one block to the south, and there are a number of recreational open space areas nearby.

2.5 Topography and Drainage

The site is located on the northern flanks of the Woronora Plateau, about 30 kilometres south of Sydney. The site lies on the crest of a ridge that divides the lower Woronora River and Hacking River drainage systems.

Most of the surface of the site – excluding the area of the brick pit itself – dips gently to the east in line with the structural inclination of the region. The elevation in the south-western corner of the site – which is also the highest point of the site – is about 105 metres above Australian Height Datum (AHD), and that part of the site lies along the crest of a locally prominent ridgeline; this ridgeline generally follows the direction of the Princes Highway and forms the major surface water divide in the area. From the south-western corner, the site gently slopes to the east and south-east, with the elevation in the south-eastern corner measured at 94 metres AHD.

The height of the pit walls range from over 15 metres along the western face of the quarry, to a little over 3 metres in the south-eastern corner of the site. The quarry walls vary in slope between near vertical to 20 degrees, with the steepest faces along the southern boundary of the former quarry where some remedial works, including rock bolting and shotcrete application, have been carried out to ensure the stability of these walls.

3.0 GEOLOGY AND HYDROGEOLOGY

3.1 Geology

A detailed description of regional and local geology is provided in the Hydrogeological Data Report.

The site is situated on one of the 'claystone, siltstone and laminite' (shale) lenses that occur within the Hawkesbury Sandstone on the Woronora Plateau. These lenses are usually mid to dark-grey, lensoidal in shape, and either grade into the overlying sandstone or have sharp boundaries. They vary in thickness from a few millimetres to more than 10 metres and may be laterally continuous for several hundreds of metres.

Geological conditions on site have been documented by URS Australia Pty Limited (URS). URS drilled four geotechnical boreholes to depths of 15 metres, logged the core for geological and geotechnical purposes, and carried out pit wall geotechnical mapping. From this work, URS then defined the geological and geotechnical units encountered during its investigations, and compiled a geotechnical cross-section across the northern part of the site. The cross-section and borehole logs from these investigations are included in the Hydrogeological Data Report whilst geological units are summarised in Table 1.

TABLE 1
Geological Units as Defined by URS

Unit No.	Geological Description	Approximate Thickness (m)	Rock Mass Classification
1	FILL: silty CLAY and sandy CLAY with assorted fragments, orange brown, low plasticity, firm to very stiff, fragments include concrete and bricks.	1.0 to 2.5	-
2	RESIDUAL SOIL: silty CLAY, red-brown and grey, low to medium plasticity, stiff to hard occasional sub-angular to angular shale fragments.	1.0 to 7.0	-
3a	EXTREMELY TO DISTINCTLY WEATHERED SHALE: extremely low to very low strength, light and dark-brown grey, laminated, fractured to fragmented, some residual clay zones, local siltstone towards the base.	3.0 to 7.0	Class V-IV shale
3b	SLIGHTLY WEATHERED SHALE: medium strength, dark grey, thinly laminated, poorly developed bedding, fractured, localised fragmented zones and low strength although stronger where iron staining is present.	3.0 to 4.5	Class III shale
4a	EXTREMELY TO DISTINCTLY WEATHERED SANDSTONE: low to medium strength, orange brown, massive to faintly cross-bedded, fine to medium-grained, fragmented to slightly fractured.	2.0 to 3.0	Class IV sandstone
4b	SLIGHTLY WEATHERED SANDSTONE: medium to high strength, light-grey brown, massive to faintly cross-bedded, fine to medium-grained, fractured to slightly fractured.	Greater than 2.0	Class III sandstone

In the northern portion of the site, bedding dips very gently from west to east at about 2 degrees, which is consistent with the regional trend inferred from the Wollongong–Port Hacking geological map sheet; this was confirmed during site reconnaissance works carried out by CMJA.

The depth to and thickness of some of these units, and also their degree of weathering, vary across the site; this is most evident in the declining thickness of the weathered profile from west to east. A thicker soil horizon is also evident along the western batters of the quarry lake compared to those along the eastern batter.

Reference to the Wollongong–Port Hacking geological map sheet indicates that there are no regionally significant geological structures in the area, something that is confirmed by the URS and Australian Water Technologies (AWT) observations. Rather, discontinuities in the bedrock are dominated by jointing and bedding plane partings. URS identified two prominent sub-vertical joint sets – which it referred to as Set 1 and Set 2 – and a weak and ill-defined third set. These sets were mapped along the exposed cuttings along the southern face of the pit and were described as follows.

> Set 1 (major set): strikes north-north-west and is sub-vertical in orientation; URS also noted that the strike of this set is roughly perpendicular to the east-west alignment of the southern wall of the former quarry.
>
> Set 2 (secondary set): strikes east-south-east and is sub-vertical in orientation; the strike of this set is sub-parallel to oblique to the southern wall of the former quarry.
>
> Set 3 (weak set): randomly orientated, and variably dipping; was also encountered along well-exposed sections of the western pit wall, although no other description of its occurrence was provided.

Spacings between joints in each of the above sets are typically between 0.5 and 1.0 metre, but are quite variable.

URS also provided the following geotechnical description of the shale horizons exposed in the walls of the pit.

> Slope stability in exposed rock cuts is controlled by the presence of planes of weakness consisting of a combination of bedding plane partings and jointing that results in various modes of instability. The bedding plane is sub-horizontally orientated and thinly to very thinly spaced apart (with partings varying between 2 to 20 centimetres) and may be persistent for tens of metres or more.

3.2 Hydrogeology

3.2.1 Aquifer Type

Groundwater in the vicinity of the site flows predominantly within the numerous discontinuities, such as joints, bedding plane partings and miscellaneous fractures, which form a fractured rock aquifer within the shale; minor flows associated with weathered horizons and lithological contrasts may also occur within the shale and siltstone layers as well (i.e. primary porosity flows), however these are likely to be restricted to the western half of the site.

3.2.2 Aquifer Hydraulic Properties

Borehole yields obtained from shale and siltstone units in the Sydney Basin are usually very low, and are commonly between 0.1 and 0.5 litre per second (L/s).

In general, the highest hydraulic conductivities within such aquifers tend to be found in the shallow parts of the aquifer. The principal exceptions to this occur where there is lithologically controlled porosity or fracturing caused by the deepest structural features such as faults; however these features are rare in this area, with jointing the main feature contributing to aquifer transmissivity.

As part of its investigation into groundwater quality in the area, Douglas Partners Pty Ltd (Douglas 2009) carried out small-scale pumping tests in monitoring wells GW1, GW2 and GW3 in order to estimate the hydraulic conductivity of the shale and siltstone formations. Pumping tests were carried out using a submersible pump, and the water level was monitored during recovery using an electric dip meter.

Table 2 below presents the results of analysis of Douglas’s test data carried out by CMJA.

TABLE 2
Calculated Aquifer Hydraulic Properties

Monitoring Well	Test Type	Analytical Solution	Saturated Aquifer Thickness* (m^{α})	Transmissivity$^{\beta}$ (m^2/s^{χ})	Hydraulic Conductivity (m/s^{ε})
GW1	Pumping	Theis (recovery)	9.19	2.5×10^{-5}	2.7×10^{-6}
		Bouwer - Rice	9.19	1.5×10^{-5}	1.6×10^{-6}
GW2	Pumping	Theis (recovery)	11.11	1.5×10^{-5}	1.4×10^{-6}
		Bouwer - Rice	11.11	1.4×10^{-5}	1.3×10^{-6}
GW3	Pumping	Theis (recovery)	5.81	3.7×10^{-5}	6.4×10^{-6}
		Bouwer - Rice	5.81	2.0×10^{-5}	3.4×10^{-6}

Notes:
* estimated from borehole logs
α metres
β transmissivity is the rate at which water of a prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient.
χ metres squared per second
ε metres per second

It is noted that the initial change in water level was not ‘instantaneous’ (as assumed in the derivation of the Bouwer-Rice (1976) slug test interpretation method). However, the agreement between values derived using pumping test and slug test approaches indicate that these values are indeed reasonable.

Hydraulic test results indicate that the hydraulic conductivity of the shale interbed varies between about 1.3×10^{-6} and 6.4×10^{-6} metres per second (m/s^{-1}), which is about 0.1 to 0.5 metres per day (m/day^{-1}), whilst values of transmissivity vary between about 1.4×10^{-5} and 3.7×10^{-5} metres squared per day (m^2/day^{-1}). No values of storativity were derived.

3.2.3 Groundwater Levels and Flow Directions

Within the fractured rock aquifer, the water table is not as precisely defined as it is within granular aquifer materials; it is generally described as the depth to which interconnecting joints, voids and fractures are water-filled. Consequently, features such as the connectivity of a series of fractures, both within and between differing geological units, will greatly influence the aquifer’s characteristics. The interconnected fractures act as an equivalent porous medium in distributing water pressure throughout the fractured rock aquifer; the depth of saturation measured in a set of fractures will therefore reflect the prevailing water pressure in the vicinity of the measurement, and cannot be assumed to be representative of the entire aquifer.

Standing water levels have been measured during a number of monitoring events since May 1999. During each event, water levels were measured from each of the groundwater monitoring wells installed by AWT – namely GW1, GW2 and GW3, whilst during the November 2001 and December 2008 monitoring events, water levels were also measured in the two wells installed by URS in boreholes BH1 and BH4. An overview of the elevation of the water table as measured in each of the wells is presented below in Table 3.

TABLE 3
Summary of Groundwater Elevation Measurements
(m AHD$^{\alpha}$)

Date	Consultant	Groundwater Monitoring Well				
		GW1	GW2	GW3	BH01	BH04
May 1999	AWT	94.1	91.8	91.2	-	-
October 2001	AWT	93.6	91.9	90.5	-	-
November 2001	URS	93.6	-$^{\delta}$	90.1	93.8	91.5
October 2006	URS	94.51	92.20	91.14	-	-
December 2008	Douglas	94.17	92.33	91.60	-	-
December 2008	CMJA	94.17	92.43	91.60	93.44	91.73

Notes: $^{\alpha}$ metres above Australian Height Datum
$^{\beta}$ not measured

From Table 3, it can be seen that the elevation of the water table is greatest in the north-western corner of the site (i.e. in monitoring well GW1), and falls gently with distance to the east. When the above information is plotted, it shows that the groundwater flow direction coincides with both the local topographic expression and the regional inclination of the Hawkesbury Sandstone, with groundwater flowing from the north-western corner of the site to the east and south-east. This flow pattern has been observed by AWT and URS, both of whom concluded that groundwater from the site generally flows to the east and south-east, with changes in the flow direction expected in close proximity to the quarry lake. Both URS and AWT also consider the groundwater and the water in the quarry lake to be hydraulically connected, with the water level in the quarry lake – which acts as a near constant head source – expected to influence groundwater levels immediately downgradient of the site; during the December 2008 monitoring event, the water level in the quarry lake was measured to be 91.70 metres AHD, which was slightly higher (about 0.1 metre) than the elevation of the water table in GW3 (i.e. in the south-eastern corner of the site).

During periods of extended drought, it is recognised that the water table may decline to depths greater than anticipated, particularly if evaporation from the quarry lake exceeds infiltration. Furthermore, given the nature of the underlying profile, one or more perched groundwater tables may be present between the ground surface and the underlying aquifer, particularly in the north-western corner of the site where the aquifer is relatively deep and the weathered zone apparently very complex.

The regional groundwater flow direction is considered to be primarily controlled by three factors: the location of recharge areas; the regional topography; and the structural orientation of the aquifer. It is therefore considered that groundwater within the Hawkesbury Sandstone would flow to the east and north-east of the site, consistent with the assumed structural orientation of the region, whilst perched and ‘shallow’ groundwater flow would be controlled by the local topography and would therefore be expected to flow to the east and south-east of the site, towards Savilles Creek, Dents Creek and several of their tributaries on the urban fringe.

3.2.4 Aquifer Recharge and Discharge

A review of topographical and geological mapping indicates that the site is part of the local groundwater recharge zone. The primary source of groundwater recharge in the area is the infiltration of soil-water (derived from excess precipitation) through the subsoil and unsaturated rock to the water table; some infiltration from the quarry lake is also expected, particularly around the eastern margin of the quarry lake.

Discharge from the aquifers is thought to occur primarily through natural flow from springs, both perennial and ephemeral, and baseflow into perennial watercourses.

3.2.5 Local Groundwater Use

CMJA undertook a ‘desktop’ review of records held by the Department of Water and Energy (DWE), covering boreholes within 2 kilometres of the centre of the site. Seven registered boreholes were identified during the search, the closest being GW103885 located about 150 metres east of the site. The bore was drilled for monitoring purposes and screened between the ground surface and 6 metres depth.

Table 4 collates the borehole summary worksheets for the bores located during the search, whilst borehole locations are shown on Figure 3; borehole summary worksheets for each of these bores are also reproduced in Appendix C of the Hydrogeological Data Report.

TABLE 4
Summary Data for Groundwater Bores within a 2-Kilometre Radius of the Site

Borehole ID[δ]	Total Depth (m)	WBZ[*] (m)	SWL[†] (m)	Geology	Salinity (mg/L)[α]	Yield (L/s)[β]
GW016096	76.5	7.3 – 9.1 45.7 – 45.7	2.7	Clay and sandstone Sandstone / shale contact		0.03 0.03
GW018433	198.1			Shale and sandstone		
GW101858	3.5		2.0	Clayey sand	12.0	
GW103885	9.0			Clay and shale		
GW107901	3.0			Clay and sandstone		
GW107902	4.0			Sandstone		
GW108343	75.0					

Notes: δ DIPNR borehole registration reference number
* Water-bearing zones
† Standing water level
α milligrams per litre
β litres per second
φ parts per million

Based on the information provided on the borehole summary worksheets, it does not appear that groundwater in the area is extracted for any purpose, with most of the bores identified during the search installed for groundwater quality monitoring purposes only.

4.0 GROUNDWATER CHEMISTRY

4.1 Description of Available Data

Four rounds of groundwater sampling have been carried out at the site since 1999: two by AWT during June 1999 and January 2001, one by Douglas in December 2008, and one by CMJA, also in December of 2008. During each round, groundwater samples were collected from each of the three monitoring wells installed by AWT in 1999 (which are identified as GW1 to GW3), whilst during the final sampling event groundwater samples were also collected from monitoring wells BH01 and BH04, both of which were installed by URS (in October 2006) presumably for geotechnical purposes only; to CMJA's knowledge, groundwater samples have only been collected from monitoring wells BH01 and BH04 on one occasion, namely during the assessment carried out by CMJA at the end of 2008.

An overview of the sampling and analysis schedules carried out during each round of sampling is provided in Table 5.

TABLE 5
Summary of Groundwater Quality Sampling Events

Date	Consultant	Number of Samples	Sample Identifiers	Analytical Schedule
1999	AWT	3[α]	GW1 to GW3[β]	pH, electrical conductivity, heavy metals[χ] (including selenium), TPH, BTEX, PAH, OCP, OPP and PCB
2001	AWT	3[α]	GW1 to GW3	Heavy metals[χ] (including selenium)
2008	Douglas	3[φ]	GW1 to GW3	Heavy metals, TPH, BTEX, PAH, OCP, VOC and hardness
2008	CMJA	5	GW1, GW2, GW3, BH01[λ] and BH04[λ]	Heavy metals (including iron and manganese), major anions[ϕ], major cations[γ], nitrate[η], ammonia[η], phosphate, DOC, TPH, BTEX and VOC

Notes:
[α] results presented in AWT's report titled '*Final Report – Stage 2 Environmental Site Investigation – Kirrawee Brick pit, 566-594 Princes Highway, Kirrawee*', dated January 2002 (AWT Report No. 2002/0002)
[β] groundwater monitoring wells installed by AWT in May 1999 and documented in AWT's report titled '*Final Report – Stage 2 Environmental Site Investigation – Kirrawee Brick pit, 566-594 Princes Highway, Kirrawee*'
[χ] arsenic, cadmium, chromium (III), copper, lead, mercury, nickel and zinc
[φ] results reported in Douglas's report titled 'Draft Report on Kirrawee Brick Pit – Water Quality Assessment, Flora Street, Kirrawee' dated January 2009; Douglas project No. 45949
[ϕ] includes chloride, sulphate, carbonate and bicarbonate
[γ] includes sodium, potassium, calcium and magnesium
[η] reported as milligrams per litre of nitrogen
[λ] groundwater monitoring wells installed by URS in October 2006 and documented in URS's report titled '*Supplementary Geotechnical Investigations; Former Kirrawee Brick Pit; 566-594 Princes Highway, Kirrawee, NSW*' dated 20 November 2006

4.2 Groundwater Geochemistry

As mentioned above, groundwater samples were collected from each of the monitoring wells at the site during the CMJA monitoring event, and submitted for laboratory analysis. Samples were analysed for a range of common contaminants (including heavy metals, TPH, BTEX, VHC), water quality descriptors (major anions and cations), nutrients (namely nitrate, nitrite, ammonia and phosphorus) and dissolved organic carbon (DOC), whilst measurements of dissolved oxygen, electrical conductivity, pH, oxidation–reduction potential and temperature were recorded during purging. A discussion regarding the results of the groundwater sampling program is presented in the following sections, whilst copies of the analytical summary tables and accompanying laboratory certificates are provided in Appendix D of the Hydrogeological Data Report; sample locations are shown on Figure 2.

4.2.1 Physio-Chemical Parameters

Measurements of physio-chemical parameters (i.e. pH, electrical conductivity, oxidation–reduction potential, dissolved oxygen and temperature) varied greatly between wells, with only weak correlations noted.

In GW1, pH is relatively low (i.e. about 4.2 pH units), the electrical conductivity moderately low (1517 microsiemens per centimetre - µS/cm), and dissolved oxygen 0.64 parts per million (ppm). Measurements of field parameters at BH1, which is located some 40 metres east of GW1 along the northern boundary of the site, show that the groundwater in this well has a pH of 4.5, electrical conductivity of 361 µS/cm, and a dissolved oxygen content of 1.63 ppm. Measurements of oxidation–reduction potential in these wells also indicated that the groundwater was moderately oxidised, varying between 186 and 206 millivolts (mV) when converted to Eh.

Physio-chemical parameters measured in GW2 – which was also installed on the northern boundary of the site – show a similar trend to those measurements from GW1 and BH1. Measurements of pH (5.7 pH units) and electrical conductivity (569 µS/cm) and also the major ion concentrations are generally similar. Markedly lower measurements of Eh (26 mV) and dissolved oxygen (0.42 ppm) tend to indicate that the groundwater in this area was more stagnant that that in GW1 and BH1.

Measurements of physio-chemical parameters for the groundwater purged from GW3 indicate that the groundwater system is connected to the water in the quarry lake. Measurements of Eh (-68 mV) and dissolved oxygen (0.36 ppm) – which were the lowest measurements of all of the wells – appear to be similar to those at equivalent depths in the quarry lake (i.e. at depths of about 5 to 6 metres). The pH in this well was 6.14 – which was the closest to a neutral pH measured in any of the wells, and which is also similar to the relatively neutral pH at the base of the quarry lake – whilst measurements of electrical conductivity also indicate some mixing with water from the quarry lake.

From AWT's analytical summary tables, presented in Appendix E of the Hydrogeological Data Report, it can be seen that the electrical conductivity of the groundwater purged from GW3 has declined during each sampling event, from 2363 and 2230 µS/cm in June 1999 and January 2001 respectively, to 1675 µS/cm at the end of 2008. Based on the location of the well and knowledge of the installation of groundwater monitoring wells, it is thought that the decrease in electrical conductivity observed in this well could be due to the replacement of groundwater in the shale with water of lower salinity from the quarry lake.

Measurements of field parameters in BH4 – which is not thought to have been purged or sampled prior to this event – may not be representative of the conditions in the aquifer. These measurements were made from the water column in the well, and not from the water drawn into the well during micro-purging (as evidenced by the high concentrations of dissolved oxygen as well as measurements of Eh), as the inflow from the formation during purging was extremely low. Because of this, a grab sample was collected and the well was allowed to recover; the very high pH in the well indicates contamination by cement products.

4.2.2 Major Ions

In all of the samples collected, sodium is the dominant cation, whilst the dominant anion appears to vary depending on the location of the groundwater monitoring wells and the groundwater flow system encountered. The proportions of major ions are shown as Piper and Schoeller diagrams on Figure 4.

In monitoring wells GW1 and BH1 – which are located in the north-western corner of the site in close proximity to the local groundwater divide – chloride is the dominant anion.

In monitoring well GW2, sulphate is the dominant anion.

In monitoring well GW3, there is no one particular dominant anion, rather chloride and bicarbonate are the dominant anions.

The major ion chemistry for GW3 – as well as the depth and position of the well – indicates that this well receives significant groundwater recharge from the water within the quarry lake, something which is supported by the similar concentrations of bicarbonate in the water samples collected from the lake itself.

In monitoring well BH4, carbonate is the dominant anion, as the pH was 12.

4.2.3 Heavy Metals

Historically, elevated concentrations of copper, lead, zinc – and to a lesser extent mercury and cadmium – have been identified in groundwater samples obtained from GW1 and GW2. On completion of its Stage 2 Environmental Site Assessment in 2001, AWT noted that some variations in metal concentrations were evident between monitoring events in these wells, and noted that higher concentrations of the respective analytes were more frequently observed in GW1.

The following concentrations measured in samples obtained by Douglas in 2008 were in excess of the trigger values set for the protection of 95% of species in fresh water as listed in Table 3.4.1 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (2000).

- Copper (0.015 μg/L), lead (0.029 μg/L) and zinc (0.031 μg/L) in the sample collected from monitoring well GW1.
- Zinc (0.056 μg/L) in the sample collected from GW2.
- Copper (0.028 μg/L), lead (0.029 μg/L) and zinc (0.036 μg/L) in the sample collected from BH1.
- Copper (0.035 μg/L), cadmium (0.035 μg/L) and lead (0.030 μg/L) in the sample collected from BH4.

No exceedances of these trigger values were identified in GW3 during either this event or the previous sampling events carried out by AWT.

In CMJA’s opinion these concentrations are typical of urban groundwater in low-permeability formations in the Sydney metropolitan areas. Primarily these concentrations reflect the impact of diffuse urban pollution that has been concentrated during recharge.

The low concentrations of heavy metals and the high concentration of boron in GW3 clearly show the influence of mixing with water derived from the pit on the groundwater chemistry at this location.

Apart from BH04, groundwater from all of the monitoring wells, including GW3, has high concentrations of iron and manganese. These elements are abundant in both shales and sandstones of the Hawkesbury Sandstone system. Their solubility is enhanced by the low pH and reducing conditions that are common in Hawkesbury Sandstone groundwater and prevalent on this site. The absence of iron and manganese from BH04 reflects the high pH in this borehole.

Iron and manganese are thus regarded as naturally occurring components rather than chemical contaminants. However, the high measured concentrations of these metals will be a significant factor in the future management of the site.

4.2.4 Nutrients

The concentrations of nutrients measured in the samples were generally low, with concentrations of nitrate and phosphorus only two or three times their respective practical quantitation limits (PQLs) in most of the samples submitted for analysis. Ammonia – the reduced species of nitrogen – exceeded the concentration of nitrate in all of the samples, with concentrations varying between 0.14 mg/L (in monitoring well GW1) and 1.21 mg/L (in BH4); concentrations of DOC were also low in the samples submitted for analysis, with the highest concentration – 10 mg/L – noted in BH4. These values are typical of urban groundwater and do not indicate the presence of contamination originating from the site.

4.2.5 Organic Contaminants

Organic contaminants were noted in three of the five groundwater monitoring wells at the site, namely GW1 in the north-western corner, BH1 about 40 metres east of GW1, and BH4 in the north-eastern corner of the site.

Concentrations in excess of the respective PQLs included the following.

- Semi-volatile TPH (250 μg/L) and isopropyl benzene (2.9 μg/L) in the sample purged from groundwater monitoring well GW1.
- Semi-volatile TPH (310 mg/L) in the sample purged from monitoring well BH1.
- Total xylene (5.0 mg/L) in the sample purged from monitoring well BH4.

No concentrations of PAH or OCP in excess of the respective PQLs were identified in any of the samples collected during this monitoring event; it is also noted that no TPH, BTEX, PAH, OCP, OPP and PCB were detected during either of the previous monitoring events carried out at the site by AWT.

As BH01 and BH04 were not constructed as groundwater quality monitoring wells, the xylene detected in BH04 may have originated from PVC solvent-cement used to join the lengths of casing in this borehole.

The measured concentration of semi-volatile TPH (i.e. C_{10}-C_{36}) is below the *Airports (Environmental Protections) Regulation 1997* (AGD 2004) level of 600 μg/L that is commonly used to assess the significance of TPH contamination in groundwater.

5.0 QUARRY LAKE WATER CHEMISTRY

5.1 Description of Available Data

Five rounds of pit (quarry lake) water sampling have been carried out at the site since 1999: the first two by AWT in June 1999 and January 2001; one by URS in September 2006; one by Douglas in December 2008; and the final event by CMJA, which was also carried out in December of 2008.

Most of the sampling events have been limited to two or three sampling locations – with samples generally collected from the surface of the lake and about 0.5 metre from the floor of the former quarry.

During the CMJA sampling event, sampling depths were judgmentally selected on the basis of vertical water quality profiling, with vertical profiles of pH, electrical conductivity, oxidation–reduction potential and dissolved oxygen – among other measurements – used to characterise the change in geochemical characteristics with depth; it is noted that vertical profiling was carried out by AWT during both of its phases of sampling; however, these results do not appear to have been used to select sample depths, with samples obtained from standardised depth intervals.

An overview of the sampling and analysis schedules used during each round of sampling is presented in Table 6.

TABLE 6
Summary of Quarry Lake Water Quality Sampling Events

Date	Consultant	Number of Samples	Sample Identifiers	Analytical Schedule
1999	AWT	2^{α}	SW-SUR and SUR-DEP$^{\beta}$	pH, electrical conductivity, heavy metals$^{\chi}$ (including selenium), TPH, BTEX, PAH, OCP, OPP, PCB, total phosphorus and total nitrogen
2001	AWT	2^{α}	SW2 and SW3$^{\psi}$	pH, electrical conductivity, heavy metals$^{\chi}$ (including selenium), OCP, OPP, total phosphorus and total nitrogen
2006	URS	6^{δ}	KW01 to KW03$^{\varepsilon}$	pH, electrical conductivity, oxidation-reduction potential, dissolved oxygen, heavy metals$^{\chi}$, major anions$^{\phi}$, major cations$^{\gamma}$, total suspended solids, total dissolved solids, TPH, BTEX, OCP, OPP, nitrate$^{\eta}$, nitrite$^{\eta}$, nitrate + nitrite$^{\eta}$, ammonia$^{\eta}$, total Kjeldahl nitrogen$^{\eta}$, total phosphorus, TOC, BOD and faecal coliforms
2008	Douglas	3^{φ}	SSW1, SSW2 and SSW3$^{\kappa}$	pH, electrical conductivity, oxidation-reduction potential, dissolved oxygen, heavy metals$^{\chi}$ (including iron), major anions, major cations, total suspended solids, total dissolved solids, TPH, BTEX, PAH, OCP, OPP, PCB, nitrate$^{\eta}$, nitrite$^{\eta}$, nitrate + nitrite$^{\eta}$, ammonia$^{\eta}$, total Kjeldahl nitrogen$^{\eta}$, total phosphorus, TOC, BOD and faecal coliforms
2008	CMJA	14^{ω}	BP:01 to BP:07$^{\lambda}$	Heavy metals$^{\chi}$ (including iron and manganese), major anions, major cations, nitrate$^{\eta}$, ammonia$^{\eta}$, boron, total phosphorus, phosphate, BOD, DOC, TPH and oil and grease

Notes:
$^{\alpha}$ results presented in AWT's report titled 'Final Report – Stage 2 Environmental Site Investigation – Kirrawee Brick pit, 566-594 Princes Highway, Kirrawee', dated January 2002 (AWT Report No. 2002/0002)
$^{\beta}$ samples SW-SUR collected from the surface of the brick pit lake whilst SW-DEP was collected from a depth of 1.8 metres
$^{\chi}$ arsenic, cadmium, chromium (III), copper, lead, mercury, nickel and zinc
$^{\psi}$ samples collected from depths of about 2 metres
$^{\delta}$ results presented in URS's letter report titled 'Water Quality Assessment: Former Kirrawee Brick Pit' dated 16 October 2006; URS project No. 43217575
$^{\varepsilon}$ samples collected from two depths at each location; firstly from the surface and secondly about 0.5 metre above the floor of the former quarry
$^{\phi}$ includes chloride, sulphate, carbonate and bicarbonate
$^{\gamma}$ includes sodium, potassium, calcium and magnesium
$^{\eta}$ reported as milligrams per litre of nitrogen
$^{\varphi}$ results reported in Douglas's report titled 'Draft Report on Kirrawee Brick Pit – Water Quality Assessment, Flora Street, Kirrawee' dated January 2009; Douglas project No. 45949
$^{\kappa}$ samples collected from 'midpoint' depths at each location, namely at depths of 2.5, 1.8 and 2.7 metres respectively
$^{\lambda}$ samples collected from two depths at each location; the first typically in the upper layer identified during vertical profiling, and the second from the lower layer; where this was not possible, the second sample was collected from about 0.5 metre above the floor of the former quarry
$^{\omega}$ two duplicate samples also collected from sample location BP:02; the first from the upper layer identified during vertical profiling, and the second from the lower layer

5.2 Quarry Lake Physio-Chemical Profiles

Vertical physio-chemical profiles of the water in the quarry lake were carried out in order to assess whether it exhibited differing geochemical character with depth (i.e. was stratified), or was essentially uniform throughout its depth.

Profiling was carried out at seven locations – identified as BP:01 to BP:07 – using two configurations, the first consisting of a peristaltic pump, TPS FLMV90 multi-parameter meter and flow cell, and the second an MP Troll 9500 multi-parameter water quality tool lowered through the water column. Both configurations were run concurrently.

During profiling, measurements of pH, electrical conductivity, oxidation–reduction potential (which was measured with a Pt electrode relative to Ag/AgCl electrode), temperature and dissolved oxygen were measured at the surface of the water body (i.e. at a depth of approximately 0.1 metre), and then at 0.5-metre intervals using both configurations; measurements of turbidity were also recorded using the Troll 9500 water quality tool.

Once the floor of the quarry had been reached, the profiles were terminated and new profiles – using the same methodology – run as the units were withdrawn from the quarry lake; no changes were noted in any of the field parameters when the pump inlet and multi-parameter tool were being withdrawn from the quarry lake.

Profiling in the pit has identified that the water in the quarry lake is weakly stratified, with three distinct layers evident; namely a slightly alkaline, well mixed and oxygenated upper layer; a near-neutral (pH) and oxygen-poor lower layer; and a variably mixed transitional layer between the upper and lower layers. The characteristics of each of these layers are further discussed below.

Water in the upper layer – which is thought to be about 3 to 4 metres thick – appears to be well mixed, with only small-scale variations in pH, electrical conductivity, dissolved oxygen and temperature evident both vertically and laterally. As mentioned above, the pH of the water is slightly alkaline (about 8.60 pH units) and is uniform both laterally and vertically throughout the pit.

The electrical conductivity in the upper layer ranged between about 1020 and 1060 μS/cm – although was typically between 1020 and 1035 μS/cm between 0.5 and about 2.5 metres depth, indicating that it is relatively fresh; these values lie in the upper part of the range suitable for potable water.

Between about 3.0 and 4.0 metres, a layer of slightly lower salinity is evident at most sampling locations with the exception of BP:04 – which coincidentally was the deepest measured point in the quarry lake. At this depth, measurements of electrical conductivity fall to about 980 μS/cm before climbing again to about 1030 μS/cm, clearly defining the unit. It is noted, however, that the decline in electrical conductivity is matched by a fall in the temperature of the water body – which is typically of the order of 1.5 to 2.0 degrees Celsius.

The upper layer is well oxygenated, with values of dissolved oxygen typically varying between about 4.0 and 6.0 ppm. Correspondingly, values of oxidation–reduction potential were indicative of well-oxygenated waters, with values varying between about –25 and 75 mV. Measurements as high as 150 mV were noted for the profile at sampling location BP:04 up to a depth of over 4.5 metres; it is noted that although values of oxidation–reduction potential varied between sampling locations, very little variation was noted with depth, highlighting the well-mixed nature of this layer.

Just as the upper is well defined by measurements of physiochemical parameters, so is the lower layer. This layer is characterised by its near-neutral pH, and distinct and well-defined declines in measurements of oxidation–reduction potential, dissolved oxygen and temperature, all of which start to decline at about 3.5 to 4.0 metres depth before stabilising again at 4.5 to 5.0 metres depth; the latter depth is interpreted to be the top of the lowermost layer.

Water in the lower layer – which is thought to be between about 0.5 and 2.0 metres thick where present – exhibits a near-neutral pH with measurements ranging between 7.2 and 7.5 (pH units).

Values of electrical conductivity in the lower layer declined with depth, and again were typical of water having a relatively low salinity. From the vertical profile shown in Figure F2 in Appendix F of the Hydrogeological Data Report, it can be seen that measurements of electrical conductivity generally declined to about 950 μS/cm, which is some 75μS/cm lower than that observed in the upper layer; this however may be attributable to the decline in the temperature of the water.

From Figure F2 of the Hydrogeological Data Report, it can also be seen that measurements of electrical conductivity varied at sampling locations BP:03 and BP:05 (between depths of about 4.5 and 5.5 metres), indicating the presence of a complex system of layered units at these locations. The electrical conductivity at both of these locations, however, as well as that at BP:04 (i.e. each of the deeper sample locations), was observed to stabilise below these depths.

Overall, the conductivity of the water in the quarry lake does not vary significantly with depth. Variations in dissolved oxygen and redox potential are more marked.

Measurements of dissolved oxygen and oxidation–reduction potential in the lower layer indicate that it is oxygen-poor, with measurements of both of these parameters declining markedly from those in the upper layers. Concentrations of dissolved oxygen were typically between 0.3 and 2.0 ppm – some 3.5 to 5.0 ppm lower than that of the upper layer, whilst measurements of oxidation–reduction potential fell to between –100 and –175 mV.

As mentioned above, the other layer identified during profiling was a variably mixed transitional layer between the upper and lower layers. This layer is defined by significantly varying measurements in most of the physio-chemical parameters (due to the mixing of the two of these layers at this depth) as well as a marked increase – and then subsequent decrease – in the turbidity of the interval. Overall, this layer is thought to vary in thickness between about 1.0 and 1.5 metres, and is clearly shown on the plots of measured physio-chemical parameters presented in Appendix F of the Hydrogeological Data Report.

5.3 Sampling and Laboratory Analysis

Fourteen water samples were collected from the quarry lake and submitted for laboratory analysis. Samples were collected from seven sampling locations and from two depths in the lake, analysed for water quality descriptors (namely major anions and cations), common contaminants (such as heavy metals – which included iron and manganese, volatile and semi-volatile fractions of TPH and oil and grease), boron and nutrients (which included nitrate, nitrite, ammonia and phosphate), whilst concentrations of BOD and DOC were also analysed. A discussion regarding the results of the quarry lake water sampling program is presented below, whilst copies of the analytical summary tables and accompanying laboratory certificates are presented in Appendix F of the Hydrogeological Data Report; sample locations are shown on Figure 2. Major ion proportions are shown on the Piper and Schoeller diagrams on Figure 4.

5.3.1 Major Ion Chemistry

In all of the samples submitted for analysis, sodium is the dominant cation and bicarbonate the dominant anion. Water sampling carried out by Douglas – also in December 2008 – also indicated that the water in the pit is sodium-bicarbonate dominant, whilst during the water sampling event carried out by URS in September 2006, bicarbonate was again the dominant anion; during this event, calcium was the only cation requested for analysis.

From the data set, there appears to be little variation in concentration laterally or vertically within the quarry lake, with only slight differences between the concentrations of bicarbonate – and to a lesser degree calcium, magnesium, sodium and chloride – which appear to correlate with the profiling data. This is most evident at locations where samples were collected from depths of 5.5 or 6.0 metres (i.e. at sample locations BP:03, BP:04 and BP:05), correlating with the marked changes in pH, dissolved oxygen and redox potential observed during the physio-chemical profiling program. In these samples, concentrations of bicarbonate, calcium, magnesium and chloride are higher at the base of the quarry lake when compared to those concentrations measured in the upper layer, whilst the concentration of sodium appears to decline marginally; in the case of bicarbonate, concentrations in the deeper samples increase by between 32 and 44 mg/L, reflecting the change in carbonate species with variations in pH with depth.

Concentrations of potassium in the quarry lake are relatively high, indicating a source – most likely the decaying vegetation matter in the sediment on the floor of the quarry – within the lake.

Concentrations of sulphate in the samples are all less than the PQL.

The consistent concentrations of boron in the lake water are notable, and clearly distinguish the lake water from unmixed groundwater.

An assessment of the data set generated during this investigation against the trigger values set for the protection of 95% of species in fresh water – as listed in Table 3.4.1 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (2000) – indicates that the concentration of boron exceeds the trigger value of 370 μg/L in all of the samples submitted for analysis.

The source of the boron is not known, but as boron is released during the aerobic weathering of shale and also during the decay of vegetation, natural sources are likely.

5.3.2 Heavy Metals

Concentrations of heavy metals in the upper layer of the quarry lake are generally low, with the only concentrations in excess of the respective PQLs being manganese (in all the samples) and arsenic in the sample collected from location BP:05. Overall, concentrations of all of the heavy metals were relatively uniform, again indicating that this layer is relatively well mixed with little lateral variation.

Concentrations of heavy metals in the lower layer of the quarry lake are markedly different from those in the overlying layer, with the largest variations evident in the concentrations of iron, manganese, and to a lesser extent arsenic. In the three samples collected from this layer, which as noted above were collected from sample locations BP:03, BP:04 and BP:05, iron and manganese concentrations were as high as 22.0 mg/L and 1.6 mg/L respectively. This change in metal concentration correlates to the marked changes in pH, dissolved oxygen and Eh measurements at this depth, all of which are expected to increase the solubility of these metals.

Heavy metal concentrations measured in the Douglas 2008 investigation are generally similar to those discussed above, with the only point to note being the concentration of (total) iron in each of the three samples collected. Although iron concentrations at these depths were low – varying between 0.18 and 0.20 mg/L – they highlight the observation that iron concentrations increase with depth.

No concentrations of chromium, copper, lead, mercury or nickel in excess of their respective PQLs were identified in any of the samples submitted for analysis by CMJA. Likewise, the following heavy metals were not detected during the quarry lake water sampling events carried out prior to CMJA's involvement at the site.

- Arsenic, cadmium, chromium, copper, lead, nickel and selenium during AWT's sampling event in June 1999.
- Arsenic, cadmium, chromium, copper, lead, nickel, selenium and zinc during AWT's sampling event in January 2001.

- Arsenic, chromium, copper, lead and nickel during URS's sampling event in September 2006.
- Arsenic, cadmium, chromium, copper, lead, mercury, and nickel during Douglas's sampling event in December 2008.

The concentration of cadmium (1.9 µg/L) measured in the deep sample collected from location BP:04 in this investigation was also higher than the trigger level of 0.2 µg/L.

The concentration of zinc (0.017 µg/L) in the deep sample collected from location BP:07 exceeded the trigger value set for the protection of 95% of species in marine waters; these trigger values are listed in listed in Table 3.4.1 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (2000).

5.3.3 Nutrient Chemistry

Concentrations of nutrients in the quarry lake appear to be low, with negligible concentrations of ammonia, nitrate, nitrite and phosphorus evident in the upper 5.0 metres or so of the water column. Below this depth, concentrations of ammonia climb slightly to 0.7 mg/L at sample locations BP:04 and BP:05 – which are thought to be the deepest parts of the quarry lake, reflecting the relatively oxygen-poor conditions at the base of the water column identified during water profiling; concentrations of nitrate and nitrite at these depths were either less than or equal to 0.01 mg/L.

No concentrations of ammonia or nitrate in excess of those trigger values set for the protection of 95% of species in fresh and marine waters – as listed in Table 3.4.1 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (2000) – were identified in any of the sample sets submitted for analysis by CMJA, Douglas, URS or AWT.

5.3.4 Organic Contaminants

No concentrations of the selected organic contaminants above laboratory PQLs were identified by either CMJA or Douglas during their (separate) pit water sampling events; analyses carried out during the CMJA sampling event included TPH (both volatile and semi-volatile fractions) and oil and grease, whilst those requested by Douglas included TPH, BTEX, PAH, OCP, OPP, PCB and VOC.

It is also noted that no concentrations of TPH, BTEX, PAH, OCP, OPP and PCB above laboratory PQLs were detected during any of the previous monitoring events carried out at the site by AWT or URS.

6.0 SEDIMENT CHEMISTRY

6.1 Description of Available Data

Three rounds of sediment (or pit floor) sampling have been carried out at the site since 1999: the first by AWT in June 1999 as part of its Stage 2 Environmental Site Assessment; the second by Environmental Investigation Services Pty Ltd (EIS) in December 2007 – which was reported in January of the following year; and the final event by CMJA in December 2008.

The first two sampling events involved the collection of sediment samples from the pit floor at three and four locations respectively. All samples were collected from the southern half of the pit lake. All of the samples were collected from the surface of the debris on the quarry floor using sediment grab samplers, and neither consultant was able to ascertain the thickness of the sediment, or whether additional layers existed between the sampled layer and the floor of the former quarry. EIS did note in its report that it had planned to obtain samples from several other locations as well as from the floor material itself, however sample recovery was hindered at a number of locations by the presence of weed. This prompted EIS to reduce the analytical schedule to the four samples noted above, and to recommend that if additional sediment samples were required for regulatory purposes, they should be obtained during the dewatering of the pit.

Copies of AWT’s and EIS’s summary tables of analytical results are presented in Appendix I of the Hydrogeological Data Report whilst sample locations for both of these sampling events are shown on Figure 6 of that report.

The final investigation, which was carried out by CMJA at the end of 2008, involved the collection of sediment samples from two depths at seven locations across the floor of the former quarry. The samples were collected with a hand-core sediment sampler on a roughly systematic sampling grid at depths of 0.05 and 0.15 metre; the thickness of the sediment was ascertained at all but one location. On completion of the sampling, the samples were logged for lithological and environmental characteristics, split, and then submitted for laboratory analysis for heavy metals, semi-volatile fractions of TPH, PAH and VOC, as well as total phosphorus and TOC.

Sample locations for CMJA’s investigation are shown on Figure 2 whilst copies of the analytical summary tables are presented in Appendix H of the Hydrogeological Data Report.

An overview of the sampling and analysis schedules carried out during each round of sampling is presented below in Table 7.

TABLE 7
Summary of Pit Floor Sediment Sampling Events

Date	Consultant	Number of Samples	Sample Identifiers	Analytical Schedule
2001	AWT	3[α]	SED1 to SED3[β]	pH, electrical conductivity, heavy metals[χ] (including selenium), sulphate, PAH, OCP, OPP, PCB, herbicides and asbestos
2007[δ]	EIS	4[ε]	SS1 to SS4[β]	Heavy metals[χ] (including chromium VI), TPH, BTEX, PAH, OCP, PCB, TOC and asbestos
2008	CMJA	14	BP:01 to BP07[ϕ]	Heavy metals[χ] (including manganese), semi-volatile TPH[γ], PAH, OCP, total phosphorus and TOC

Notes:
[α] results presented in AWT's report titled 'Final Report – Stage 2 Environmental Site Investigation – Kirrawee Brick pit, 566-594 Princes Highway, Kirrawee', dated January 2002 (AWT Report No. 2002/0002)
[β] samples collected from the surface of the floor of the quarry
[χ] arsenic, cadmium, chromium (III), copper, lead, mercury, nickel and zinc
[δ] fieldwork carried out in December 2007 although reported in January 2008
[ε] results presented in EIS's report titled 'Report to Kirrawee Centre Pty Ltd on Assessment of Former Quarry Sediments' dated January 2008 (EIS Report Reference E21714FJ-RPT)
[ϕ] samples collected from depths of 0.05 and 0.15 metre from the floor of the quarry
[γ] C_{10} – C_{36} fractions of TPH

6.2 Sediment Characteristics

As mentioned above, three sediment-sampling events have been carried out at the site. During the first two events, samples consisting of non-cohesive, dark-grey to black, sandy silt with a very high organic content – predominantly semi-decayed leaf and root matter – were recovered from the floor of the pit, although no samples were collected from below this layer, nor was the thickness of this layer identified.

During the final phase of sampling, which was carried out by CMJA, sediment samples were successfully obtained from two depths (namely 0.05 and 0.15 metre) at seven locations across the floor of the pit, and logged for lithological and environmental characteristics. All samples recovered from 0.05 metre depth consisted of a dark-grey to black sandy silt – which was the same material as that described by AWT and EIS – although at a number of locations minor amounts of coarse aggregate (blue metal) were also evident in the sampling device. Overall, these samples were typically fine-grained, soft, and moderately to poorly sorted, and also exhibited a strong (and characteristic) anoxic organic odour.

Examination of samples collected from 0.15 metre depth indicated that the thickness of the sediment described above was less than 0.15 metre at all but one location, namely BP:04. At all locations, a heavy light-grey clay – which was thought to represent the former floor of the quarry – was encountered at depths of between 0.08 and 0.14 metre, with a relatively sharp contact noted between the two units. The clay was typically very well sorted, soft, and malleable, and exhibited a very high plasticity; occasional pieces of slightly to moderately weathered shale were also recovered in the sediment corer. This unit was interpreted as being weathered shale (i.e. the floor of the former quarry), with the overlying sediment thought to originate primarily from weathered debris from the walls of the pit as well as the surrounding vegetation.

At location BP:04, the former floor of the quarry was not encountered; rather the sediment recovered at 0.15 metre depth was found to consist of a grey fine-grained silty sand. This material was also poorly sorted, with some medium-grained sand and occasional pieces of aggregate and organic debris – primarily consisting of leaves and sticks. The material appeared to be better sorted than the overlying sediment, indicating that this material may have been collected from a former sediment trap on the site as opposed to the relatively clean quarry floor; this assessment is supported by the depth profiling which showed that this was the deepest point in the quarry lake. Several attempts were made to try and core through this material and assess its thickness, however all were unsuccessful with the corer unable to penetrate more than 0.25 metre into the sediment.

Descriptions of each of the samples collected during the final phase of work are provided in Appendix H of the Hydrogeological Data Report.

6.3 Laboratory Analysis of Sediment

Fourteen sediment samples were collected from the floor to the quarry lake and submitted for laboratory analysis. Samples were analysed for a range of common low-solubility contaminants (heavy metals, semi-volatile fractions of TPH, PAH, OCP), whilst concentrations of TOC and total phosphorus were also analysed. A discussion regarding the results of the sediment sampling program is presented below, whilst copies of the analytical summary tables and accompanying laboratory certificates are presented in Appendix H of the Hydrogeological Data Report; sample locations are shown on Figure 2.

The first thing to note from the analytical data set is that the concentrations of heavy metals are generally higher in the surface samples (i.e. those collected from depths of 0.05 metre) than those collected from the weathered shale forming the floor of the former quarry (i.e. those samples collected from 0.15 metre depth). This is most evident at sample locations BP:01, BP:02 and BP:04 where concentrations of manganese and zinc – and to a lesser extent arsenic, chromium and lead – are several orders of magnitude higher in the surface samples.

Generally, concentrations of most of the heavy metals were very low in the samples collected from the weathered shale horizon, with concentrations of manganese and zinc – which were sporadically as high as 150 mg/kg – the only exceptions. Overall, metal concentrations were typical of those noted in shale-derived soils throughout the Sydney area, and, with respect to the proposed development, are not considered to be of concern.

The concentration of heavy metals in sample BP:04; 0.15 confirms that the material sampled was not from the underlying floor of the quarry, but rather from a sediment layer which was distinctly different from those samples collected from 0.05 metre depth. In this sample, concentrations of arsenic, copper and lead were higher than those collected in the overlying sample (i.e. BP:04; 0.05) – contrary to the general trend of decreasing metal concentrations with depth, whilst concentrations of manganese were also much higher than those concentrations measured in the samples collected from the weathered shale.

The following exceedances of the interim urban ecological investigation levels (EILs) – which are presented in Column 5 of the table: ‘Soil Investigation Levels for Urban Development Sites in NSW’, in the NSW Department of Environment and Conservation (DEC) publication *Guidelines for the NSW Site Auditor Scheme* (2006) – were identified from the samples submitted for analysis. Use of EILs and health investigation levels (HILs) is for comparison considered more appropriate than use of Interim Sediment Quality Guidelines (ANZECC 2000), because the quarry lake is to be drained.

- Arsenic (69 mg/kg) and zinc (407 mg/kg) in the sample collected from sampling location BP:01 at a depth of 0.05 metre.
- Zinc (234 mg/kg) in the sample collected from sampling location BP:04 at a depth of 0.05 metre.
- Arsenic (33 mg/kg) in the sample collected from sampling location BP:04 at a depth of 0.15 metre.

- Manganese (608 mg/kg) in the sample collected from sampling location BP:05 at a depth of 0.05 metre.

Overall, concentrations of heavy metals in the samples collected by CMJA were generally consistent with those collected by AWT and EIS. However, concentrations of zinc in all of the samples were significantly lower; the reason for this anomaly is not known.

No concentrations of semi-volatile TPH, PAH or OCP in excess of the PQL were detected in the samples submitted for analysis, and it is also noted that no organic contaminants were detected in the samples collected and submitted for laboratory analysis by AWT or EIS. The PQL for benzo(a)pyrene for sample BP:01; 0.05 was equal to the HIL for residential use with minimal access to soil.

It is also noted that the PQL for benzo(a)pyrene for samples BP:03; 0.05 and BP:05; 0.05 is equal to or exceeds the criteria for *residential use with gardens and accessible soil* and *parks, recreational open space and playing fields*, indicating that further assessment of the suitability of these materials would be required if it was proposed to reuse the material at the site.

7.0 PROPOSED DEWATERING PROGRAM

7.1 Levels

CMJA understands, from Woodhead Masterplan Drawing No. 0300 (21/10/10), that the finished floor level of the basement to be constructed within the pit will be 85.00 metres AHD. This implies a construction working level of about 84.40 metres AHD, which will in turn require that the groundwater and lake level be lowered to an average of about 83.90 metres AHD to allow safe and comfortable working conditions to be maintained during construction.

The current water level in the lake is 91.7 metres AHD, so the water level will need to be lowered by, 7.8 metres.

7.2 Volume of Water in Pit

Currently, the former quarry pit contains approximately 55 megalitres (ML) of water.

7.3 Groundwater Inflow During Dewatering

The rate of groundwater inflow during dewatering operations and subsequent construction work has been assessed using a three-dimensional groundwater flow model (Section 6 and Appendix A of this report). It will depend partly upon the rate at which the pit is dewatered. If, as recommended in this report, dewatering takes place over a period of about seven weeks, at an instantaneous pumping rate of about 15 L/s or 1300 cubic metres per day (m^3/day), then inflow will gradually increase from near zero to a maximum of approximately 2 L/s, then decline to a long-term rate of approximately 90 m^3/day or 1 L/s.

Thus groundwater inflow will make up less than 10 per cent of total pumping during initial dewatering.

7.4 Approach to Dewatering

The preferred approach is to dewater the brick pit over a period of approximately seven weeks, at a nominal pumping rate of 15 L/s or 1300 m^3/d, using pumps mounted on one or two pontoons tethered close to the middle of the lake. Water pressure in the banks would be carefully monitored using a series of piezometers installed prior to the start of pumping, and the pumping rate would be adjusted as necessary. Pumping may also need to be slowed to permit the completion of stabilisation works on the south face as the water level is lowered.

The discharge rate will be continuously monitored using an appropriate magnetic flow meter.

Water quality will be regularly monitored.

A range of measures will be implemented to treat the anoxic layer below 87.2 metres AHD.

8.0 PROPOSED WATER DISPOSAL

8.1 Description of Options

The options available for disposal of water produced during pit dewatering are:

- Disposal to the stormwater system, either directly or by using a feeder line.
- Beneficial use of the water off site.
- Re-use on site.

Disposal to the stormwater system is the most practical option. The proposed pumping rate of 15 L/s is low in comparison to the capacity of all but the smallest stormwater drains, and is highly unlikely to cause overload at any point in the drainage system.

If necessary, flow could be split between the system draining north to Oyster Gully (accessible at the corner of Oak Road and the Princes Highway, at the north-west corner of the site), and the system draining south to Dents Creek, accessible on Flora Street east of the site.

Given the steep gradients of both Oyster Gully and Dents Creek, and their large natural flow range, the proposed discharge would not cause flooding in these waterways.

Some of the water can be made available to off-site users by tanker. Suitable uses would be dust suppression, compaction of soil, fill or road-base material, and irrigation of sports ovals, golf courses or similar open spaces. There are approximately eight such facilities, including a large golf course, within 3 kilometres of the site.

As discussed in the Hydrogeological Data Report, the water is suitable for almost all irrigation purposes. Fill time for a 10,000-litre tanker would be approximately 12 minutes. It is hard to estimate what the take-up of an offer of free water would be, and clearly this would depend to some extent on the time of year and prevailing weather conditions.

Some water could be used on site. Preferentially, this would be the deeper anoxic water, as discussed in Section 11.

8.2 Recommended Approach to Water Disposal

It is recommended that the quarry lake water be discharged to the stormwater system. Water should also be made available free of charge to anyone willing to collect it from the site, and an appropriate tanker filling point should be provided for this purpose.

9.0 POTENTIAL GROUNDWATER ISSUES ASSOCIATED WITH DEWATERING

The following potential issues associated with dewatering have been identified:

- slope stability
- potential impacts associated with water disposal
- anoxic water in the lower section of the pit
- management of long-term groundwater inflows to pit
- management of sediment
- potential degradation of groundwater resources.

9.1 Potential Slope Stability Issues During Dewatering

It has been recognised (URS 2003, 2006) that the slopes of the former brick pit, in particular the south wall, are potentially unstable.

If the water level in the lake were to be drawn down at a rate greater than the drainage rate of the slopes, then the development of excess pore pressures and excess water pressure within joints and bedding-plane fractures would exacerbate the risk of slope failure.

The issue of slope stability during dewatering requires specialist geotechnical review, and has indeed been the subject of such review (Jeffery and Katauskas 2010). Jeffery and Katauskas indicates that progressive stabilisation of the southern face will need to be carried out during dewatering.

9.2 Potential Environmental Impacts Associated with Water Disposal

There are limited options available for disposal of water pumped from the pit. Whilst beneficial use of the water is desirable, and may be possible, at least in part, such use would depend upon the availability and willingness of other parties to accept the water. Such demand is likely to be seasonal and weather-dependent, so alternative means of water disposal must be considered. In practical terms this requires disposal of water to the local stormwater drainage system, which in turn discharges to local creeks. Two potential impacts associated with such disposal have been identified. These are:

- overloading of the stormwater drainage system, with consequent risk of localised flooding; and
- ecological impacts on receiving creeks and other water bodies.

9.3 Anoxic Water in the Lower Section of the Pit

There is potential for the water in the lower part of the flooded brick pit to be anoxic, which may cause odour issues during dewatering, and potential adverse impacts on receiving ecosystems during disposal.

9.4 Management of Sediment

Sediment at the base of the pit may be contaminated or anoxic and may thus require management during dewatering and disposal.

9.5 Long-Term Management of Groundwater Inflows to Pit

Groundwater will continue to seep into the former brick pit following redevelopment; such inflows will require appropriate management.

9.6 Degradation of Groundwater Resources

A potential exists for long term-drainage of groundwater into the pit to adversely affect the availability or quality of groundwater in the area.

10.0 IMPACT ASSESSMENT

10.1 Potential Slope Stability Issues During Dewatering

Jeffery and Katauskas (2010) indicates that progressive stabilisation of the southern face will need to be carried out during dewatering.

With regard to the rate of drainage, the following considerations are relevant.

Excluding the extremely weathered material at the top of the slopes, which is substantially above the current water level, the shale that forms the steeper slopes is characterised by a predominant fracture permeability, low intergranular permeability and low effective porosity. These features promote relatively rapid drainage. Assessment of drainage rate carried out with an equivalent porous medium model will tend to underestimate the real drainage rate, and is therefore conservative. This modelling (Section 6 and Appendix A) indicates that if the water level in the lake is lowered at a rate of less than 150 millimetres per day (mm/day), then excess pressures within 5 metres of the face will be negligible. This implies a dewatering time of about seven weeks.

The modelling provides a guide. Monitoring piezometers installed behind the critical faces would provide reassurance that unacceptable excess pressures do not develop during dewatering. In the event that drainage proved to be slower than predicted, the pumping rate could be reduced.

The need to progressively stabilise the faces during dewatering also indicates that dewatering should be carried out at a rate that permits this work to keep up with the falling water level, and for design changes to be made and implemented if necessary. This requirement is consistent with a dewatering time of seven weeks, or a little longer.

As a guide, if the pit were to be dewatered over a period of seven weeks, the average rate of fall would be 157 mm/day and the required pumping rate would be about 15 L/s. However, for practical as well as geotechnical reasons, the rate of fall of the water level would be slower during the initial part of dewatering, and would be faster at the end of the process, by which time the critical levels adjacent to Flora Street would be fully drained.

10.2 Potential Environmental Impacts Associated with Water Disposal

As indicated in the Hydrogeological Data Report, both Oyster Gully and Dents Creek appear to be heavily impacted by urban influences. Weed encroachment and infestation are significant in Dents Creek, and sewage discharge appears to occur in both creeks. In this area the catchments of both creeks are almost entirely urbanised.

As also indicated in the data report, the bulk of the water in the quarry lake (i.e. the upper 4.5 metres of the lake) is of high quality. Salinity is low, oxygenation high, temperature and pH within an ecologically neutral range, and with the sole exception of boron, no nutrients or toxicants are present in significant concentrations.

Temperature profiles of the quarry lake were run during the summer of 2008-09, and showed an upper layer of well-mixed water at about 25°C and a lower layer with a temperature of about 15°C. These temperatures span seasonal temperatures in local water bodies.

The boron concentration in the lake water (typically 700 μg/L) is above the ANZECC trigger value for 95% species protection (370 μg/L), but only marginally above that for 90% species protection (680 μg/L) and would fall below this value with minimal in-stream dilution. As indicated in the data report, boron is not assessed to be an anthropogenic contaminant, and a natural source, from the shale or decaying vegetation, is considered to be likely.

Examination of the data used for the development of the 95% ANZECC trigger value indicates that this value is driven by the sensitivity of one species of algae (*Chlorella pyrenoidosa*). Most of the freshwater species considered (all fish, crustaceans and macrophytes, and other *Chlorella* species) are much less sensitive to boron. An aquatic ecological assessment would be able to establish whether or not boron-sensitive species are likely to be present in these watercourses.

The background concentration of boron in sea water is 5100 μg/L, and ANZECC recommends the use of this figure as a trigger value for marine waters. Thus, boron concentration will not be an issue below the tidal limit.

Groundwater will contribute less than 10 per cent of the total water volume removed during pit dewatering. Although the groundwater is anoxic and has relatively high concentrations of iron and manganese, the groundwater inflow will mix with oxygenated water in the lake, and most of the iron and manganese will precipitate there. The groundwater does not contain significant concentrations of anthropogenic contaminants.

CMJA considers that natural baseflow in both Oyster Gully and Dents Creek is substantially derived from groundwater in the shale and sandstone of the Hawkesbury Group.

There is thus no reason to expect that any adverse ecological impact due to chemical quality would result from short-term discharge of the quarry lake water to these creek systems.

The proposed discharge of 15 L/s is well within the range of natural flows in the creek systems and is most unlikely to cause scouring, wash-outs or other physical impacts. Additional dry-weather flow may be beneficial to aquatic ecosystems.

10.3 Anoxic Water in the Lower Section of the Pit

As indicated in Section 5.2 of this report and shown in more detail in the profiles included in the Hydrogeological Data Report, the water at the base of the pit (in a layer that varies from 0.5 to 2.0 metres thick) has a low dissolved oxygen concentration and is effectively anoxic. This water would cause adverse impacts if discharged to creeks and other water bodies.

There is also a risk of odour issues arising during dewatering; these will therefore need to be managed.

10.4 Sediments

The sediment present at the base of the quarry has been assessed; results are presented in Section 6 of this report, and in more detail in the Hydrogeological Data Report.

It has been shown that:

- the sediment layer at the base of the flooded brick pit is generally less than 150 mm thick;
- typically, the sediment is a dark grey to black sandy silt with a high organic content that is predominantly partly decayed leaf litter;
- the sediment is anoxic, and has a strong odour;
- the sediment contains relatively high concentrations of total phosphorus (typically 200 to 700 mg/kg);
- the sediment contains generally low concentrations of heavy metals (when compared with both health and ecological investigation levels, which are appropriate for materials to be retained on site);

- concentrations of heavy metals in sediment samples are also generally below the Interim Sediment Quality Guideline (ISQG)-low trigger values (ANZECC 2000), with a few concentrations of arsenic, copper, lead, nickel and zinc lying between ISQG-low and ISQG-high, and no exceedances of ISQG-high values;
- Hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAH) and organochlorine pesticides were not detected at concentrations above the laboratory PQLs.

The results indicate that the sediments could cause odour issues if not appropriately managed, and that disposal to local watercourses should be avoided due to the high nutrient content.

10.5 Long-term Management of Drainage

Groundwater will continue to seep into the former brick pit following redevelopment.

10.5.1 Groundwater Inflow Rates

Table 8 and Figure 5 define the estimates of groundwater flow rates that form the basis for the proposed groundwater management plan, and describe the status of those estimates.

Estimates were derived from a 3-dimensional (MODFLOW 2000) finite difference groundwater flow model of the site and surrounding area (Appendix A).

TABLE 8
Estimated Groundwater Inflow Rates

Time	Inflow (m^3/d)	Source	Assumptions	Status
End of pit dewatering	109	Transient flow model (MODFLOW 2000)	Recharge on site	Conservative
3 months after dewatering	75	Transient flow model	Recharge on site	Conservative
12 months after dewatering	64	Transient flow model	Recharge on site	Conservative
Long-term (10 years)	57	Transient flow model	Recharge on site	Conservative
Long-term average (conservative)	44	Steady-state flow model	No recharge on site, based on fracture hydraulic conductivity	Conservative, used for design purposes
Short-term peak (short duration – up to 1 week)	130	Factored steady-state flow model	Major rainfall events result in rise in groundwater levels sufficient to triple average hydraulic gradient towards pit	Maximum used for design purposes
Long-term average (likely)	32		No recharge on site based on probable lower average hydraulic conductivity	Probable

Figure 5 shows the predicted decline in inflow in the 12 months following completion of dewatering.

Conservative inflow rates are based on the assumption that the hydraulic conductivity values for the shale and weathered sandstone facies that were measured on site apply to the entire groundwater catchment area. Likely inflow rates are based on the assumption that fracture conductivity in the area around the quarry has been enhanced by the effect of blasting and subsequent ground movement, and that at distances greater than 100 metres from the quarry, lower values, more typical of regional values in sandstone and shale facies of the Hawkesbury Sandstone, apply.

10.5.2 Groundwater Chemistry

Table 9 shows the predicted quality of groundwater inflow to the pit for both the short term (up to 2 years following dewatering) and the long term. These data are derived as follows:

- Short-term – average composition of water in pit, assuming that this is in equilibrium with groundwater immediately adjacent to the pit.
- Long-term – average composition of groundwater in on-site monitoring bores, excluding BH04.
- Transition time – particle-tracking model (MODFLOW).

TABLE 9
Estimated Groundwater Quality

Analyte	Short-Term Concentration (mg/L)	Long-Term Concentration (mg/L)
pH	8.5	6.0
Conductivity (µS/cm)	1000	1500
Dissolved oxygen	5	0.4
Temperature (°C)	20	20
Turbidity (NTU)	<10	<10
BOD	5	1
DOC	8	1
Calcium	30	20
Magnesium	35	20
Sodium	125	300
Potassium	27	3
Carbonate/bicarbonate	250	250
Sulphate	<1	200
Chloride	190	300
Nitrate/Nitrite	<0.01	<0.01
Ammonia	<0.01	0.2
Phosphorus	0.04	0.2
Boron	0.7	<0.05
Iron	<0.05	8
Manganese	0.01	1
Arsenic	<0.001	0.001
Cadmium	<0.0001	<0.0001
Chromium	<0.001	<0.001
Copper	<0.001	<0.001
Lead	<0.001	0.03
Mercury	<0.0001	<0.0001
Nickel	<0.001	0.01
Zinc	<0.001	0.05
Monocyclic aromatic hydrocarbons	Below detection limits	Below detection limits
Polycyclic aromatic hydrocarbons	Below detection limits	Below detection limits
Aliphatic hydrocarbons	Below detection limits	Below detection limits
Chlorinated hydrocarbons	Below detection limits	Below detection limits
Organochlorine pesticides	Below detection limits	Below detection limits
Other pesticides	Below detection limits	Below detection limits

Notes:		
	NTU	nephelometric turbidity units
	BOD	biological oxygen demand
	DOC	dissolved organic carbon

10.6 Potential Degradation of Groundwater Resources

10.6.1 Modelling

The groundwater flow system at the site was modelled using the USGS three-dimensional finite-difference flow model MODFLOW 2000. The aquifer system was discretised vertically into three layers, corresponding to the shale, the highly weathered sandstone and the fresh to slightly weathered sandstone units. Laterally, the system was discretised into 132 columns and 100 rows.

An engineering model approach was used, in that measured or judgementally derived boundary conditions and material properties were applied to the system and the validity of these assumptions assessed by sensitivity analysis, rather than using the model calibration approach commonly used in resource studies. The engineering approach is commonly used in pre-development studies simply because time-variant calibration data are usually unavailable for such work.

Lateral constant head boundaries were applied at an elevation of 63 metres AHD, and sensitivity analysis was used to check that these boundaries did not significantly affect model output. Recharge was applied at a constant rate across the urbanised area of the model, with a higher rate applied to the site under pre-development conditions, and to other large open areas.

Material properties were estimated from the on-site measurements provided in the Hydrogeological Data Report.

Both steady state and transient models were run.

Chemical changes were assessed using the particle-tracking feature of MODFLOW, supplemented with some geochemical modelling using the Geochemists Workbench.

A full description of the models and the results of groundwater flow and hydrochemical modelling are set out in Appendix A of this report.

10.6.2 Groundwater Inflow and Aquifer Drawdown

Using a conservative (i.e. high-end) set of assumptions derived from on-site measurements, groundwater flow to the pit for the construction scenario ranged from 109 m^3/day after dewatering to 75 m^3/d three months later, an average of approximately 90 m^3/d or 1.0 L/s; for this scenario, the pit was assumed to have been dewatered to 86.5 metres AHD (the effective pit base, excluding the deepest area), with groundwater recharge occurring across the whole site. For the post-development scenario, which assumed that the site was substantially paved and incorporated a stormwater harvesting system, the steady state groundwater inflow to the pit was estimated to be about 44 m^3/d, which is equivalent to about 0.5 L/s.

Although using less conservative assumptions may be justified by hydrogeological reasoning, and generates lower rates of groundwater inflow, the conservative values should be used for design purposes.

Steady-state drawdown around the pit is shown on Figure 6.

The development of transient drawdown around the pit during dewatering is shown in a series of snapshots in Appendix A.

10.6.3 Salinity Changes

Particle tracking indicates that groundwater flow to the pit is derived predominantly from the west, and that the water quality pumped from the pit will change to that measured in groundwater monitoring wells GW1 and GW2 within two years. More rapid change is likely, however, because it is probable that groundwater of this quality already extends to close to the pit.

10.6.4 Impact Assessment

On the basis of the predicted drawdown pattern and the absence of beneficial use of groundwater in the area, no impact on groundwater resources is anticipated.

Nevertheless, if the water-sharing plan for the Sydney Greater Metropolitan Area groundwater sources is gazetted before the brick pit is dewatered, then an aquifer interference approval may be required.

11.0 MITIGATION AND CONTINGENCY MEASURES

11.1 Potential Slope Stability Issues During Dewatering

The quarry pit will be dewatered slowly, such that the rate of water level decline is no more than 150 mm per day. If dewatering is carried out at this rate, then excess pore pressures within 5 metres of the quarry face will be negligible.

At this rate, dewatering will take approximately seven weeks, which will allow progressive stabilisation of the quarry faces to be carried out. If necessary, the rate of dewatering can be reduced to allow stabilisation work to keep up.

Monitoring piezometers will be installed behind the critical faces and will provide reassurance that unacceptable excess pressures do not develop during dewatering. In the event that drainage proves to be slower than predicted, the pumping rate will be reduced.

11.2 Potential Environmental Impacts Associated with Water Disposal

Two potential impacts associated with such disposal have been identified. These are:

- overloading of the stormwater drainage system, with consequent risk of localised flooding; and
- ecological impacts on receiving creeks and other water bodies.

11.3 Anoxic Water in the Lower Section of the Pit

As discussed earlier, the water in the lower part of the lake – below about 4.5 metres depth, or 87.2 metres AHD – is anoxic, and has high dissolved concentrations of iron and manganese. This water will require careful management to avoid odour issues during dewatering, and potential adverse impacts on receiving ecosystems during disposal.

It will be necessary to monitor the pumping system as this layer is approached, to avoid unnecessary mixing.

Once the anoxic layer is reached, several options are available; these may be used singly or in combination.

- Progressively transfer the water to the deepest part of the lake, where it can be treated by aeration (using an air compressor and diffuser) and by the addition of lime. The iron and manganese will form a floc that will settle out, allowing the clear upper layer to be pumped off. This process can then be repeated.
- As the base of the quarry is not all at the same level, and the anoxic layer is thin in some areas, it may prove more economical to use a waste disposal contractor to remove water from residual ponds once the bulk of the dewatering has been completed.
- As some filling of low areas of the quarry floor is envisaged, at least some of the residual water could be used to assist fill compaction in these areas, thus being absorbed into the fill material.
- Some water can be used for dust suppression on site.

11.4 Management of Sediment

Sediment at the base of the pit may be contaminated or anoxic and may thus require management during dewatering and disposal.

Sediment should not be pumped out of the quarry into the stormwater system.

To minimise sediment entrainment during pumping, minimise suction lift and provide maximum flexibility, it would be appropriate to place pumps on tethered pontoons located close to the centre of the pond, and linked to bank stations using flexible hose and appropriate waterproof cabling. This would remove the need to relocate pump intakes as the water level in the lake is lowered.

Careful monitoring of water depth and the position of the suction intake will provide the most effective means of eliminating sediment uptake during pumping.

Sediment will be exposed at the end of the dewatering period. The area of exposed sediment should be minimised to avoid odour problems; sediment should therefore be progressively consolidated into stockpiles, which should be covered.

The volume of sediment is small, and to the extent possible, this should be reused on site for landscaping purposes. If on-site storage and reuse is not possible, then waste classification and off-site disposal will be required.

11.5 Management of Drainage

Groundwater will continue to seep into the former brick pit following redevelopment; such inflows will require appropriate management. Management options are discussed below.

11.5.1 During Construction

Groundwater will seep into the pit during construction operations. It will be difficult to segregate groundwater seepage from rainfall and overland flow, although if this is possible – for example where groundwater flow occurs through identifiable rock defects – then it may be advantageous to segregate the groundwater as it would generally be of better quality than surface drainage.

In any event, groundwater will form only a small proportion of the water that will need to be managed during construction operations. Water management will be the responsibility of the construction contractor and will be carried out under a sediment and water environmental management plan, as is normal during construction operations.

It is anticipated that water will be collected in sumps and pumped to a settlement pond prior to removal from the site either by pumping to the street stormwater system, or by a liquid waste disposal contractor.

The suitability of collected water for a particular disposal route will be determined by the efficacy of general water management procedures on the site, not by the intrinsic quality of the groundwater inflow.

11.5.2 Long Term

As indicated in Table 8, the anticipated long-term inflow rate of groundwater is low and manageable. As indicated in Table 9 the anticipated chemical quality of inflow in both the long term and the short term is generally good, although iron and manganese concentrations will require careful management.

Two design options are being considered for the sub-surface (basement) component of the development. These are a drained basement and a tanked basement.

Drained Basement

A drained basement design will require long-term collection and disposal of groundwater inflow, but may have a lower construction cost than a full-tanked design.

Once steady-state conditions have been reached, most groundwater inflow will occur around the base of the quarry walls. However, some inflow will occur from bedding planes, joints and other defects at higher levels on the walls, and some upflow will occur through the floor of the pit, beneath the basement.

The most effective means of seepage collection would be to install a perimeter drain around the base of the quarry wall. A slotted agricultural drain laid in a shallow trench and bedded in coarse aggregate with a filter-fabric envelope, with a permeable surface and protective layer, would be effective in collecting both the toe seepage and higher-level seepage flowing down the walls.

A drainage layer – a filter fabric and granular medium, or a modular drainage system – installed beneath the floor slab, could collect up-flow from the quarry floor most effectively. Flow would be directed radially to the perimeter drain, by appropriate grading.

The most challenging aspect of drainage design will be managing clogging by precipitated iron and manganese hydroxides. Iron and manganese are present in the groundwater as reduced (ferrous and manganous) ions. Once the groundwater comes into contact with oxygen in the atmosphere, the redox potential rises substantially; ferric and manganic hydroxides are formed and precipitate. The orange-brown floc that is thus formed can rapidly clog the drainage system.

Two options are available for overcoming this problem. One is to design a system that is always fully submerged, so that the groundwater does not come into contact with the atmosphere until it enters the treatment plant. The second option is to incorporate a cleaning mechanism into the drainage system at the time when it is built (retrofitting would not be possible). Both of these options are feasible.

Alternative Design

An alternative construction design involves a fully tanked or waterproof basement. With this design, once construction is complete, groundwater is allowed to return to its natural level. The waterproof construction effectively prevents seepage into the basement, and collection of only very small volumes will be required.

A fully tanked basement would have to be designed to resist groundwater uplift (buoyancy) pressure, and construction of such a basement would generally be more expensive than for a drained basement.

Treatment and Disposal Options

Collected groundwater will require treatment to remove iron and manganese, prior to disposal. Treatment involves raising the pH by addition of an alkali, aeration, precipitation and settlement of the iron and manganese hydroxides, and then addition of an acid to bring the pH back to a suitable level for disposal to the stormwater system. This could be designed as a batch or continuous process.

Once treated, there is no reason why the relatively small flow of long-drainage could not be discharged to the stormwater system; indeed, this is regularly done in other areas, even when the stormwater system discharges directly to a major waterway.

11.5.3 Regulation And Permitting

Discharge of the treated groundwater drainage to the stormwater system is subject to the approval of Sutherland Shire Council (Council), but would be expected to be incorporated in the approval of the general stormwater management system for the site, as the flow involved is very small in comparison with the peak stormwater flows.

The discharge would also be subject to the general prohibition of pollution of waters prescribed in s120 of the Protection of the Environment Operations Act 1997 (POEO Act).

Pollution of waters is defined in the Act as:

(a) placing in or on, or otherwise introducing into or onto, waters (whether through an act or omission) any matter, whether solid, liquid or gaseous, so that the physical, chemical or biological condition of the waters is changed, or

(b) placing in or on, or otherwise introducing into or onto, the waters (whether through an act or omission) any refuse, litter, debris or other matter, whether solid or liquid or gaseous, so that the change in the condition of the waters or the refuse, litter, debris or other matter, either alone or together with any other refuse, litter, debris or matter present in the waters makes, or is likely to make, the waters unclean, noxious, poisonous or impure, detrimental to the health, safety, welfare or property of persons, undrinkable for farm animals, poisonous or harmful to aquatic life, animals, birds or fish in or around the waters or unsuitable for use in irrigation, or obstructs or interferes with, or is likely to obstruct or interfere with persons in the exercise or enjoyment of any right in relation to the waters, or

(c) placing in or on, or otherwise introducing into or onto, the waters (whether through an act or omission) any matter, whether solid, liquid or gaseous, that is of a prescribed nature, description or class or that does not comply with any standard prescribed in respect of that matter, and, without affecting the generality of the foregoing, includes:

(d) placing any matter (whether solid, liquid or gaseous) in a position where:

  (i) it falls, descends, is washed, is blown or percolates, or

  (ii) it is likely to fall, descend, be washed, be blown or percolate, into any waters, onto the dry bed of any waters, or into any drain, channel or gutter used or designed to receive or pass rainwater, floodwater or any water that is not polluted, or

(e) placing any such matter on the dry bed of any waters, or in any drain, channel or gutter used or designed to receive or pass rainwater, floodwater or any water that is not polluted, if the matter would, had it been placed in any waters, have polluted or have been likely to pollute those waters.

With regard to Part (a) of the definition, as the condition of Dents Creek and Oyster Gully under all flow conditions in all seasons has not been established, it is impossible to be certain that the discharge may not change the condition of the waters in some way. However, with regard to Parts (b) and (c), on the basis of a thorough review of the data presented in the hydrogeological data report, such pollution would not be caused by discharge of groundwater provided that it is treated to remove iron and manganese.

11.6 Degradation of Groundwater Resources

No impact on groundwater resources is likely, and no mitigation measures are required.

12.0 CONCLUSION

This report has provided an assessment of potential groundwater-related issues associated with redevelopment of the Kirrawee brick pit, as needed to address the DGR.

Operational plans for dewatering and long-term management of groundwater drainage have also been prepared. These are:

- Dewatering Plan - Redevelopment of Former Brick Pit, Kirrawee (October 2010), CMJA Report No. J1418.10R-rev0
- Long-Term Groundwater Management Plan –Redevelopment of Former Brick Pit, Kirrawee (October 2010) CMJA Report No. J1418.11R-rev0.

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Important Information About Your Environmental Site Assessment

These notes will help you to interpret your hydrogeological and Environmental Site Assessment (ESA) reports.

Why are ESAs conducted?

An ESA is conducted to assess the environmental condition of a site. It is usually, but not always, carried out in one of the following circumstances.

- As a pre-purchase assessment, on behalf of either purchaser or vendor, when a property is to be sold.
- As a pre-development assessment, if a property or area of land is to be redeveloped, or if its use is to change (for example, from a factory to a residential subdivision) – to meet a requirement for development approval.
- As a pre-development assessment of a 'greenfield' (undeveloped) site - to establish baseline conditions and to assess environmental, geological and hydrological constraints to the proposed development.
- As an audit of the environmental effects of an ongoing operation.

Each type of assessment requires its own specific approach. In all cases, however, the aim is to identify and if possible quantify the risks posed by unrecognised contamination. Such risks may be financial (for example, clean-up costs or limitations on site use), or physical (for example, health risks to site users or the public).

What are the limitations of an ESA?

Although the information provided by an ESA can reduce exposure to these risks, no ESA, however diligently carried out, can eliminate risks altogether. Even a rigorous professional assessment may not detect all contamination on a site. The following paragraphs explain why.

ESA 'findings' are professional estimates

The ground surface conceals a complex 3-dimensional subsurface environment. Subsurface materials, whether placed by geological processes or human activities, are always heterogeneous. Large variations in lithology and hydraulic properties can occur over short distances. Surface observation, and data obtained from boreholes and test pits, can never give us a complete picture of the subsurface.

All data from sampling and laboratory testing must be interpreted by a qualified professional – a geologist, engineer or scientist. They then render an opinion - about overall subsurface conditions, the nature and extent of contamination, its likely impact on the proposed development, and appropriate remediation measures.

Interpretation and professional judgement are thus essential to the assessment process.

Accuracy depends on the scope of work

Site assessment identifies actual subsurface conditions only at those specific points where samples are taken and when they are taken. The accuracy of the entire process depends on sampling frequency and sampling methods - yet the extent of sampling and soil analysis must necessarily be limited.

Sampling generally targets those areas where contamination is considered to be most likely, on the basis of visual observation and the site's history. This approach does maximise the probability of identifying contaminants, but it may not identify contamination in unexpected locations or from unexpected sources.

No professional, no matter how qualified, and no subsurface exploration program, no matter how comprehensive, can reveal what is hidden by earth, rock and time. For example, there may be contaminants in areas not surveyed or sampled; furthermore, they may migrate to areas that showed no signs of contamination at the time of sampling.

Conditions between sample locations can only be inferred – from estimates of geological and hydrogeological conditions, and from the nature and extent of identified contamination. Soil, rock and aquifer conditions are often variable, and so the distribution of contaminants across a site can be difficult to assess. Actual conditions in areas not sampled may differ from predictions.

The accuracy of an assessment is therefore limited by the scope of work undertaken.

Statistical tools can be helpful, but the validity of conclusions still depends entirely on the degree to which the original data reflect site conditions.

Uncertainty is also inevitable when it comes to assessing chemical fate and transport in groundwater and surface water systems, and calculating human health and environmental exposure risks. It is inevitable, too, when estimating remediation performance and time frames.

Your CMJA report includes a statement of the uncertainty associated with this particular project; you should read it carefully.

We can offer solutions

We cannot prevent the unanticipated, but we can minimise its impact. For this reason we recommend that you retain CMJA's services through the remediation and development stages. We can identify differences from predicted conditions, conduct additional tests as required, and recommend solutions for problems encountered on site.

Don't rely on out-of-date information

Subsurface conditions are changed by natural processes and the activity of people. Your ESA report is based on conditions that existed at the time of subsurface exploration. Don't make decisions on the basis of an ESA report whose adequacy may have been affected by time. Speak with CMJA to learn if additional tests are advisable.

If things change, contact us

Every report is based on a unique set of project-specific factors. If any one of these factors changes after the report is produced, its conclusions and recommendations may no longer be appropriate for the site.

Your environmental report should not be used:

- if the nature of the proposed development is changed - for example, if a residential development is proposed instead of a commercial one;
- if the size or configuration of the proposed development is altered;
- if the location or orientation of the proposed structure is modified;
- if there is a change of ownership; or
- for application to an adjacent site.

To help avoid expensive problems, talk to CMJA. We will help you to determine how any factors that have changed since the date of the report may affect its recommendations.

Your ESA report is prepared specifically for you

Every hydrogeological study and ESA report is prepared to meet the specific needs of specific individuals. A report prepared for a consulting civil engineer may not be adequate for a construction contractor, or even for another consulting civil engineer. A report should not be used by anyone other than the client, and it should not be used for any purpose other than that originally intended. Any such proposed use must first be discussed with CMJA.

Beware of misinterpretation

Costly problems can occur if plans are based on misinterpretations of an ESA. These problems can be avoided if CMJA is retained to work with appropriate design professionals. We will explain the relevant findings and review the adequacy of plans and specifications.

Logs and laboratory data should not be separated from the report

Final borehole or test pit logs are developed by CMJA's environmental scientists, engineers or geologists, using field logs (assembled by site personnel) and laboratory evaluation of field samples. Our reports usually include only the final logs, which must not under any circumstances be redrawn for inclusion in other documents.

Similarly, our reports often include field and laboratory data, and laboratory reports. These data should not be reproduced separately from the main report, which provides guidance on their interpretation and limitations.

To reduce the likelihood of misinterpretation, only the complete report should be made available for the use of persons or organisations involved in the project, such as contractors. Consult CMJA before distributing reports, and we will assist with any additional interpretation that is required.

Always read responsibility clauses closely

To avoid misunderstandings, our report includes qualifying statements that explain the level of certainty associated with our findings and recommendations, and responsibility clauses that indicate where our responsibilities to clients and other parties begin and end.

These qualifying statements and responsibility clauses are an important part of your report. Please read them carefully. They are not there to transfer our responsibilities to others but to help all parties understand where individual responsibilities lie.

These notes were prepared by C. M. Jewell & Associates Pty Ltd (CMJA) using guidelines prepared by the National Ground Water Association (NGWA) and other sources.

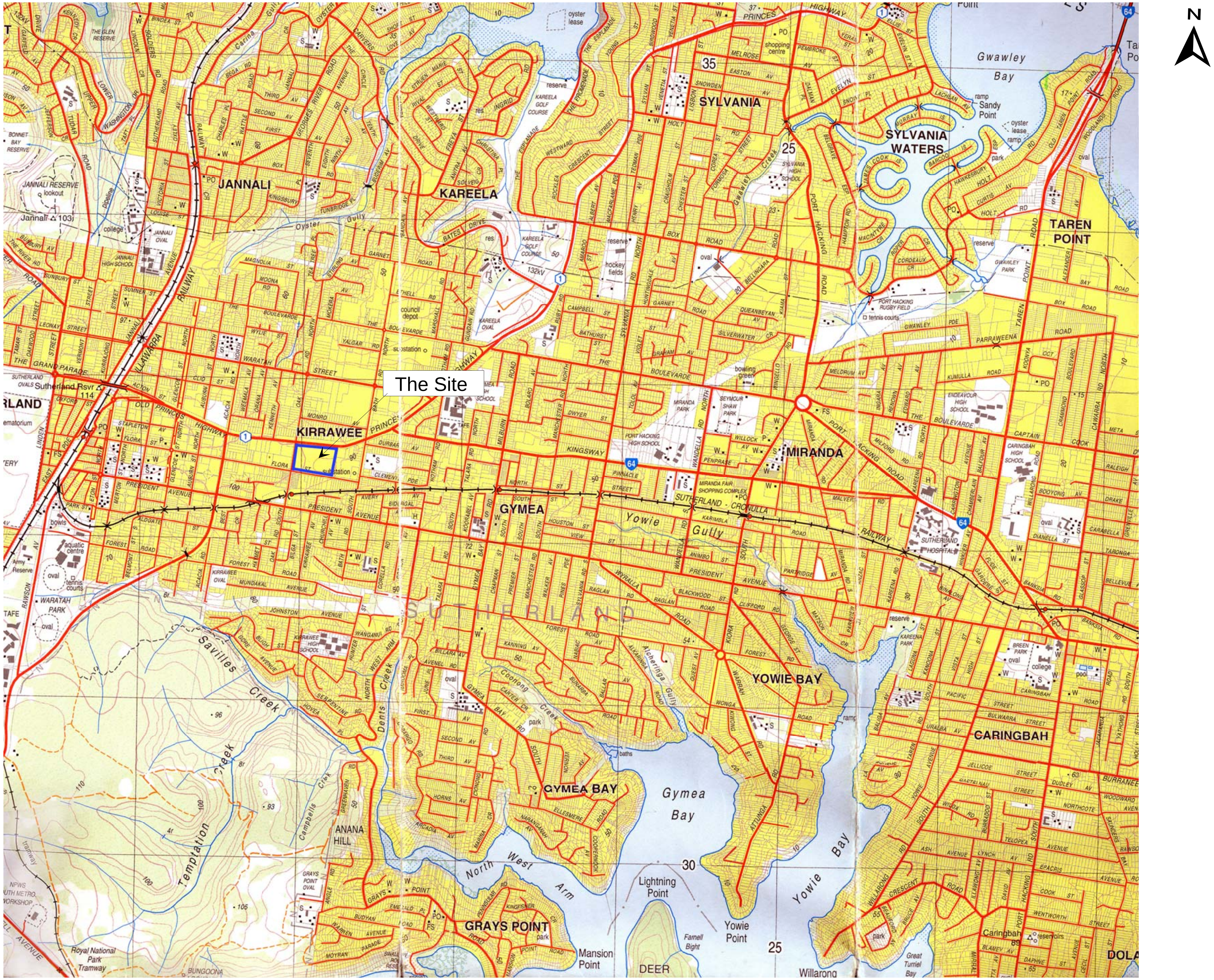

Figure 1

Site Location and Regional Setting

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🔴 Groundwater Sampling Location
🔵 Surface Water Sampling Location

Figure 2

Site Layout and CMJA Investigation Sample Locations, 2008

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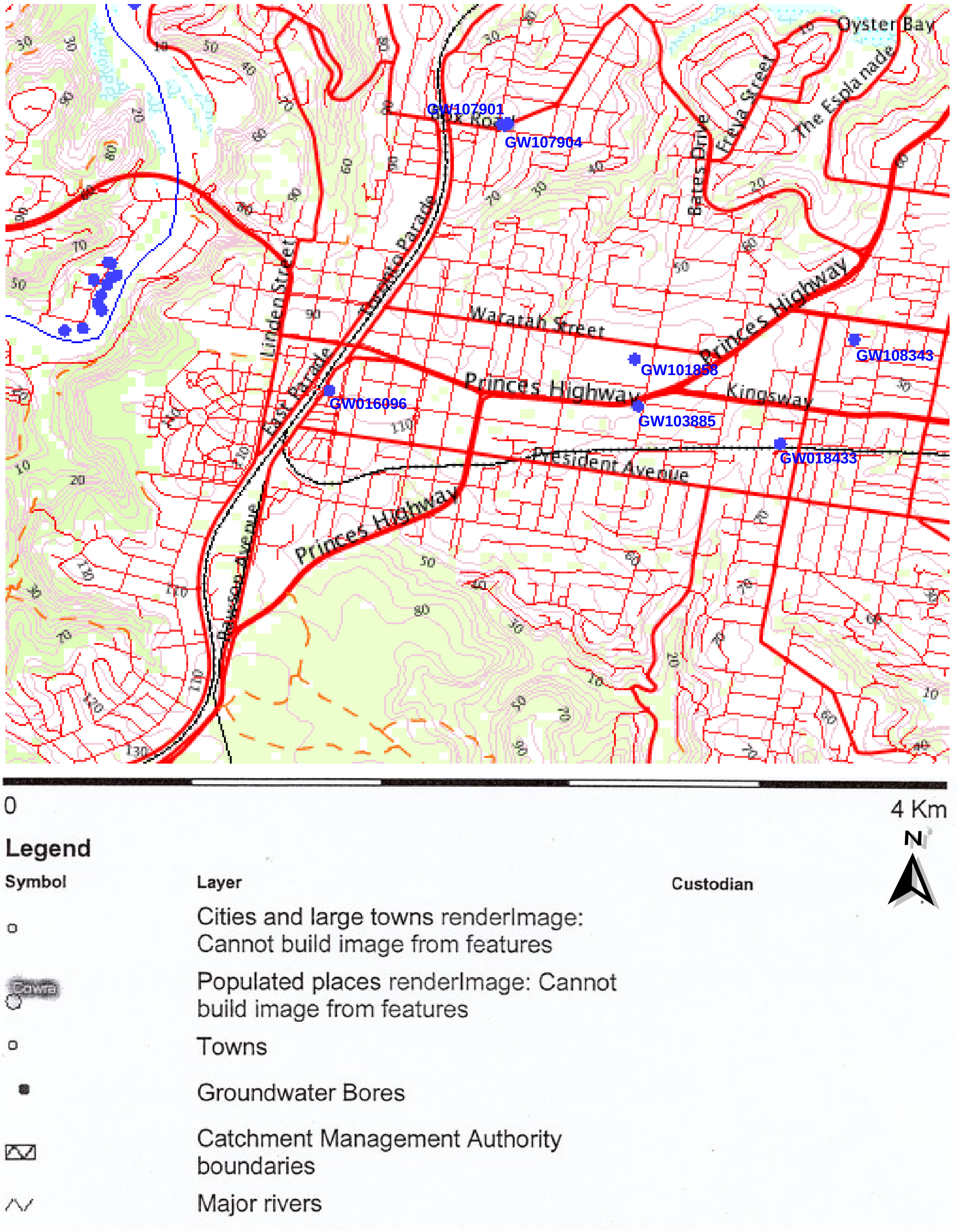

Figure 3

Location of Registered Groundwater Bores Within a 2-Kilometre Radius of the Site

Groundwater Assessment - Redevelopment of Former Brick Pit, Kirrawee

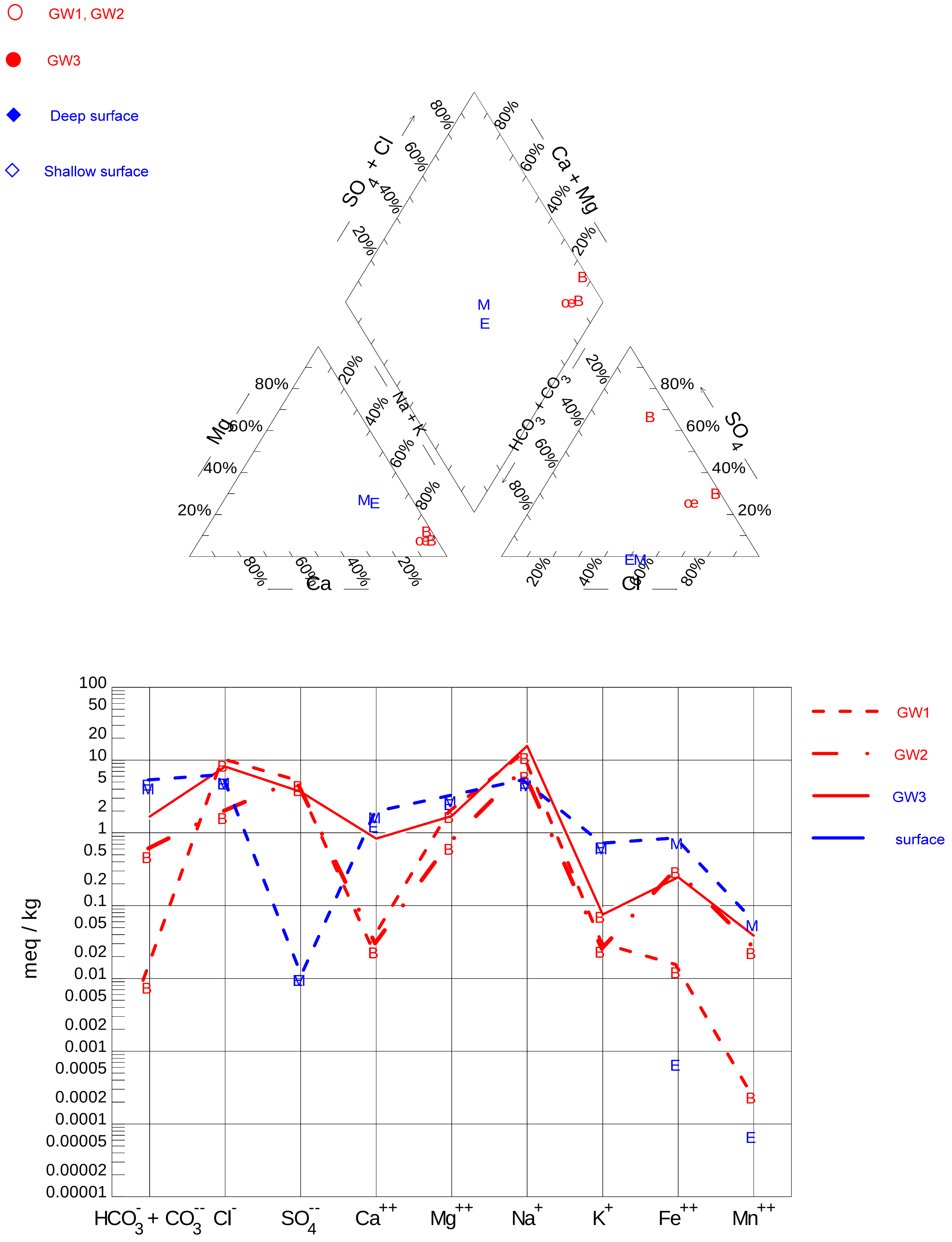

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Figure 4
Piper and Schoeller Diagrams of Major Ion Proportions for Groundwater and Quarry Lake Water Samples

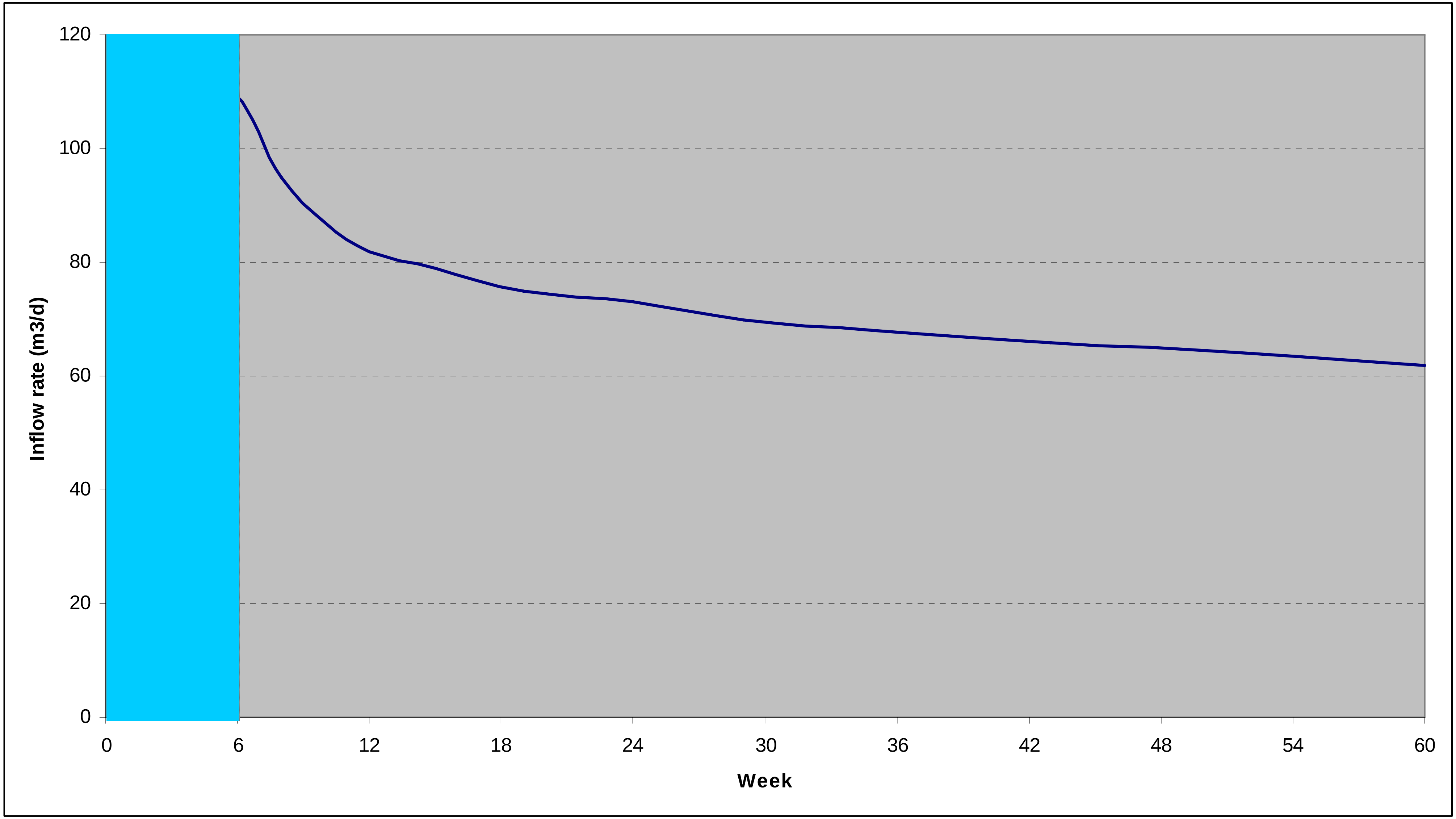

Figure 5

Predicted Groundwater Inflow Rate

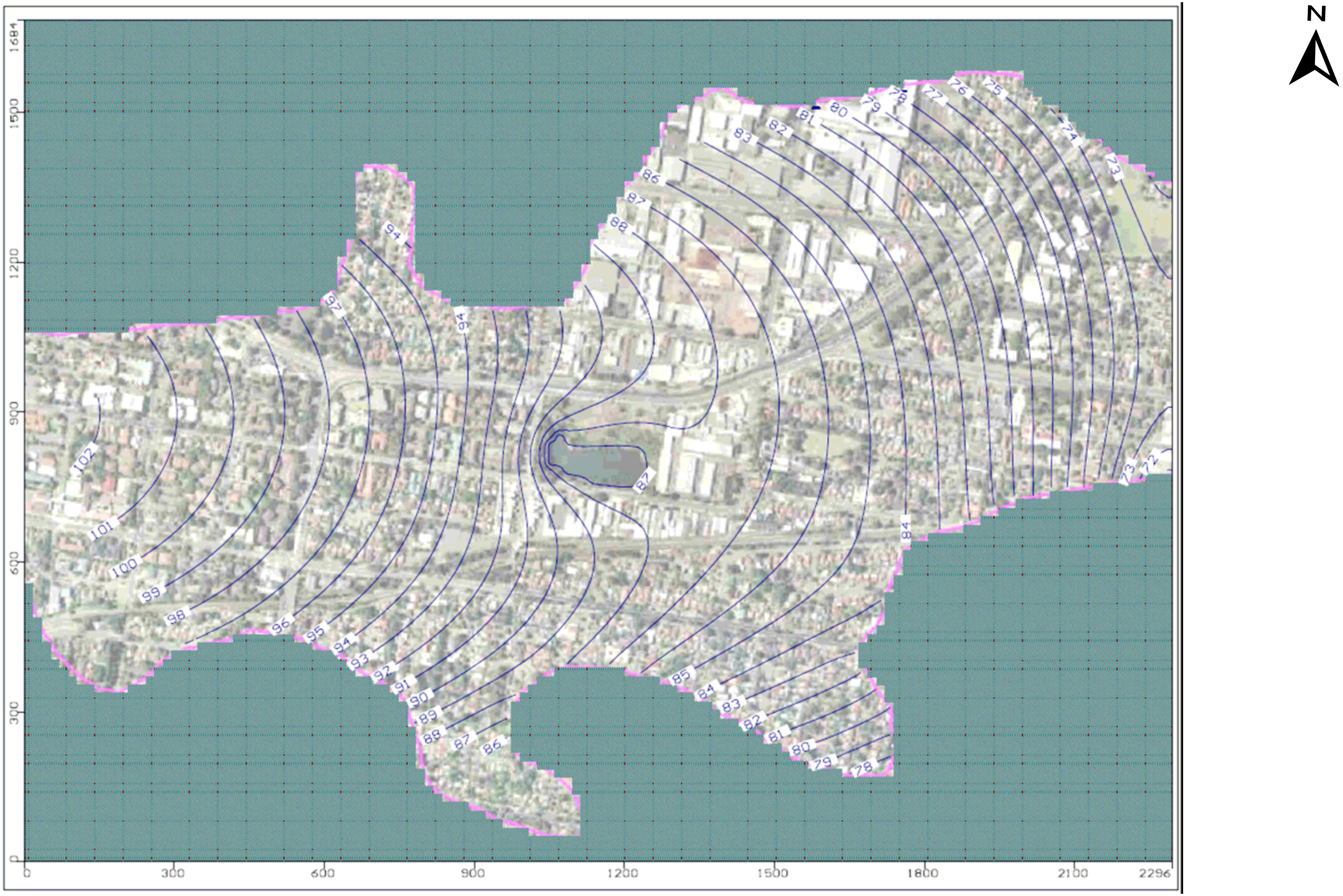

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Figure 6

Steady-State Drawdown around the Pit

APPENDIX A

Groundwater Flow Model

Model Grid
Horizontal Discretisation 132 columns x 100 rows

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Current (quasi-steady-state) groundwater levels
Elevation of water table, m AHD

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Long-term groundwater level around pit
Post construction
Elevation of water table, m AHD

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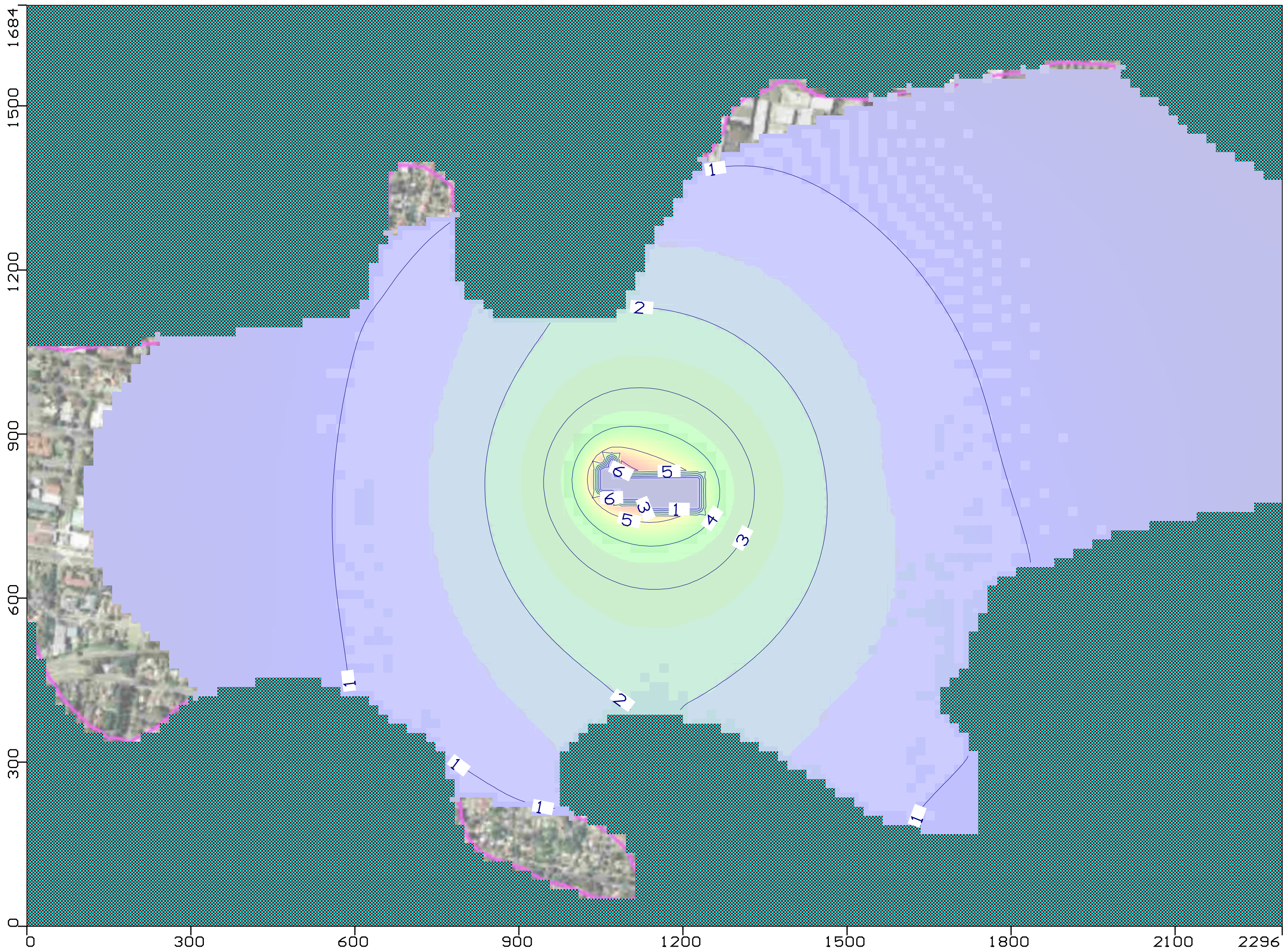
Dewatering and Groundwater Management Assessment



Long-term drawdown around pit
Post construction
Decline in groundwater level, m

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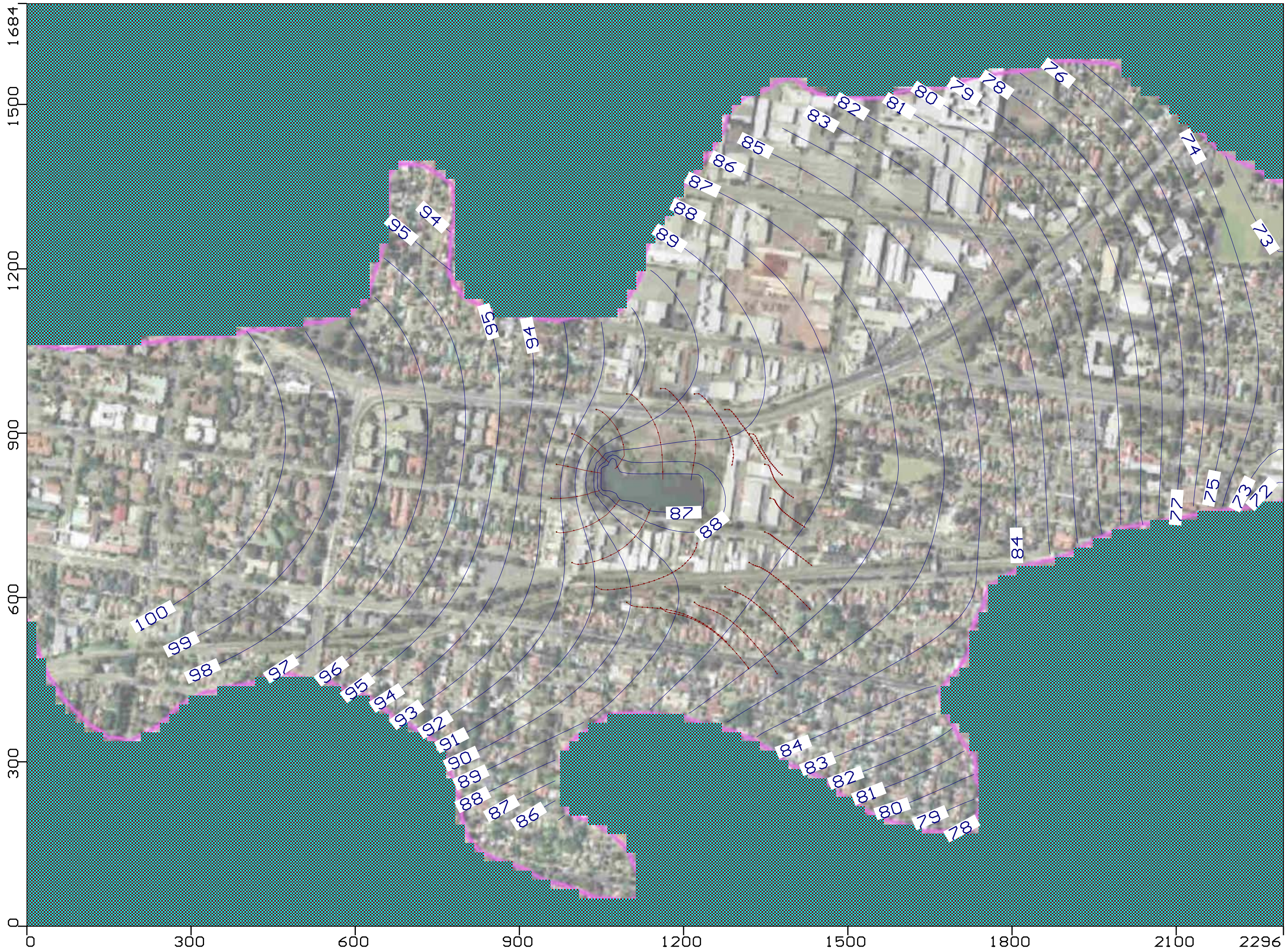

Water levels 12 months following start of dewatering
Contours show the level of the groundwater table in the upper (shale) aquifer in m AHD
Pathlines show groundwater flow directions - each tick represents 30 days travel time

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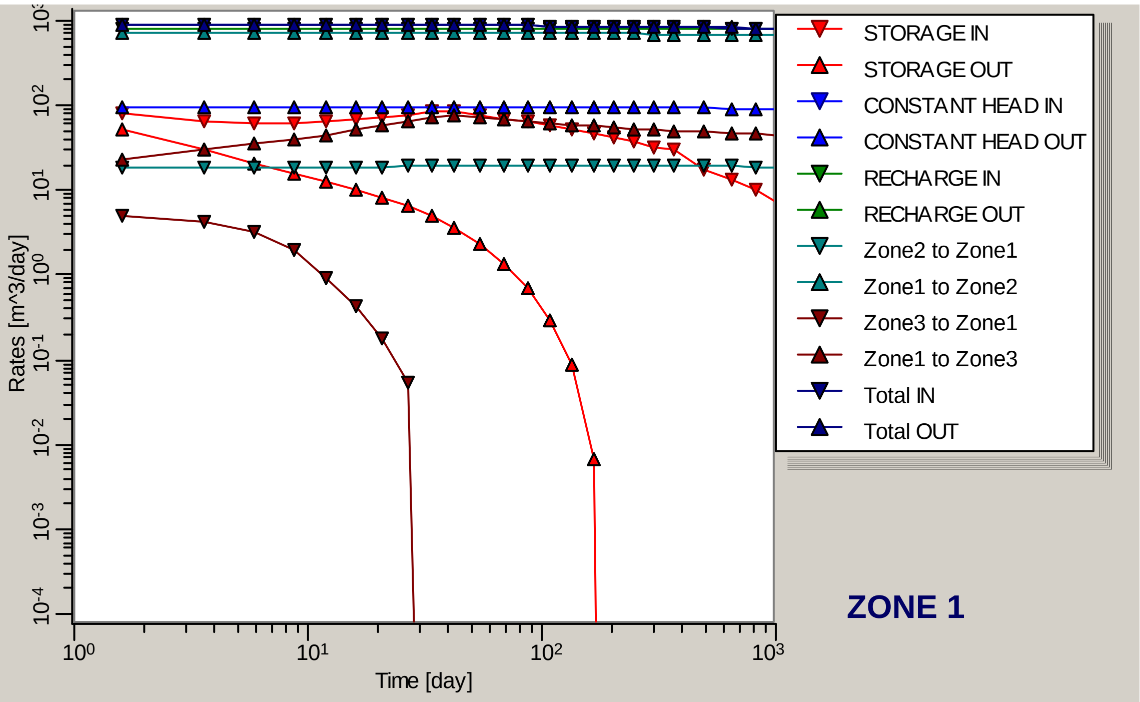
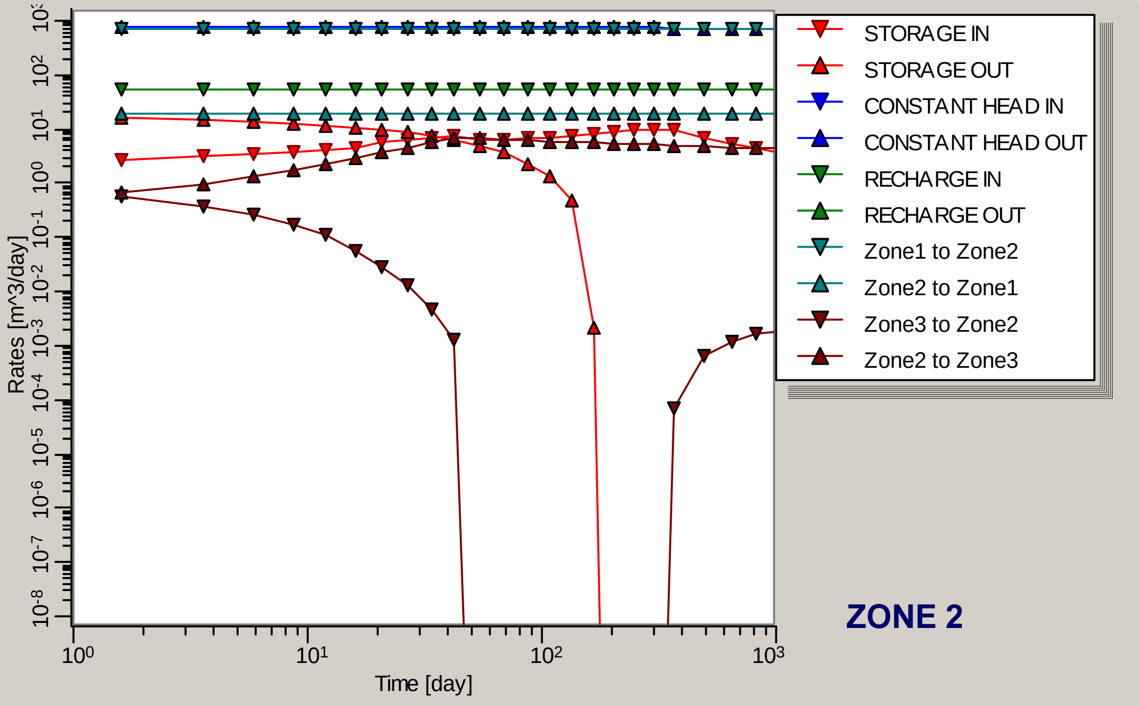
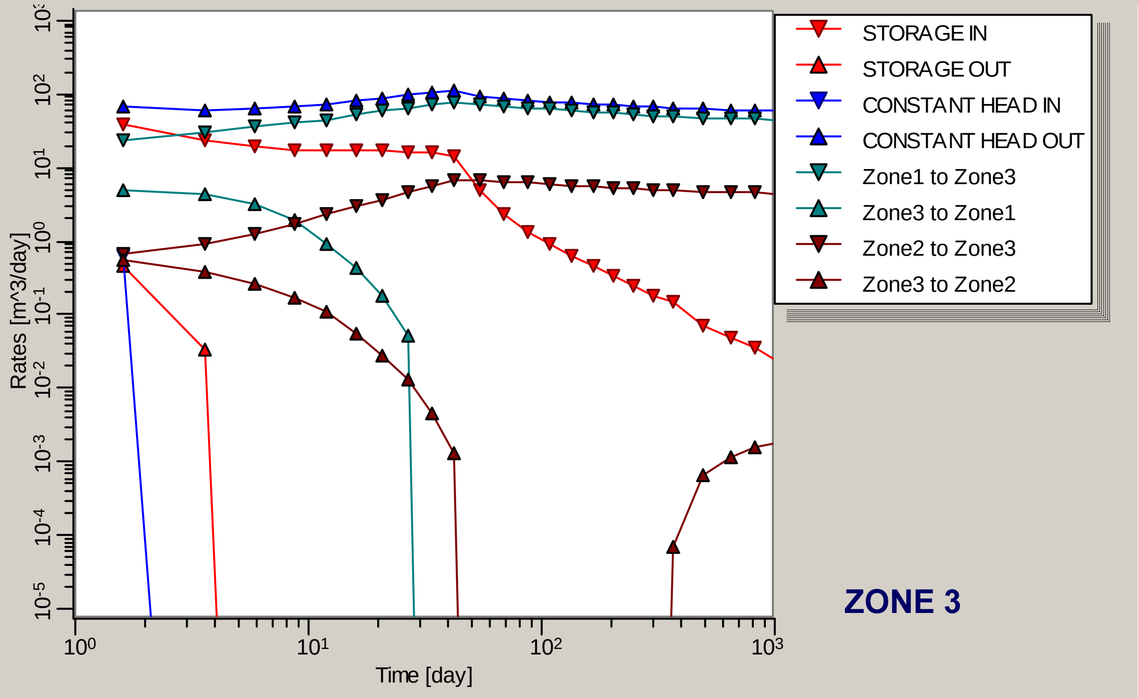


ZONE 1



ZONE 2



ZONE 3