Sutton Forest Quarries Pty Ltd

ABN 66 158 999 994

Groundwater Impact Assessment

Specialist Consultant Studies Compendium

Volume 1, Part 2

Prepared by

Larry Cook Consulting Pty Ltd

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Groundwater Impact Assessment

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EXECUTIVE SUMMARY

Larry Cook Consulting Pty Ltd has been commissioned by R.W. Corkery & Co. Pty Limited on behalf of Sutton Forest Quarries Pty Ltd ("the Applicant") to prepare this Groundwater Impact Assessment for the proposed Sutton Forest Sand Quarry ("the Proposal"), Sutton Forest, NSW.

The Applicant proposes to develop and operate a sand quarry on Lot 4 DP253435 ("the Site"). The target resource is friable Hawkesbury Sandstone with sand extraction achieved by ripping, pushing, loading and haul operations. Eight indicative stages (0 to 7) of extraction moving from east to west are proposed over 45 years. However, the development consent currently sought is anticipated to enable extraction of the sand resource until Year 30 which is represented by Extraction Stage 5. Further development of the subsequent stages (Stages 6 and 7) will be subject to an application for development consent in the future. The Site is located near Sutton Forest, approximately 28 km southwest of Berrima in the Southern Highlands and nestled within the headwaters of several first-order watercourses located on the northern, southern and western boundary of the Proposal which flow north, west or northwesterly into the Long Swamp Creek system.

Recovery of friable sandstone would occur within the first years of operation with the extraction of raw feed commencing during the construction of the processing and stockpiling areas. The processing plant is designed to produce up to 260 tph of sand products. Groundwater may be used from time to time for sand washing if surface water supply is insufficient or if commercial water supply arrangements cannot be made.

This Groundwater Impact Assessment provides an assessment of the local and regional hydrogeology centred on the Proposal, and the potential impacts on the groundwater system and environment that may be associated with the Proposal.

The Quarry is located within the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources (the WSP). The groundwater source hosting the Proposal falls under the Nepean Management Zone 1, in the Sydney Basin Nepean Groundwater Source.

The Director-General's requirements for the Proposal stated that a detailed assessment of the Proposal be compiled including:

- potential impacts, including any cumulative impacts on the quality and quantity of existing surface and ground water resources, including the impacts on existing user entitlements, affected licensed water users and basic landholder rights, groundwater-dependent ecosystems;
- an adequate and secure water supply for the Proposal;
- identification of any licensing requirements or other approvals under the Water Act 1912 and/or Water Management Act 2000 and demonstration that the Proposal is consistent with the relevant access and trading rules within the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011;
- a description of the measures that would be implemented to avoid, minimise, mitigate, offset, managed and/or monitor the impacts of the Proposal; and
- an assessment of the potential to intercept and/or impact groundwater and predicted dewatering volumes, water quality and disposal/retention methods. This would need to address the requirements of relevant policy including the Aquifer Interference Policy.

The Proposal is underlain by relatively flat-lying to gently dipping Triassic Hawkesbury Sandstone. The Hawkesbury Sandstone in this part of the Sydney Basin directly and unconformably overlies either the Illawarra Coal Measures or the Shoalhaven Group. The interpreted thickness of the Hawkesbury Sandstone beneath the Proposal is approximately 80 m. The average elevation of the base of the Hawkesbury Sandstone is approximately 623 m AHD. The Hawkesbury Sandstone is interpreted to dip to the northeast in the local area.

The district centred on the Proposal is drained by Long Swamp Creek to the north and west, and Paddys River to the south. A second-order watercourse (Watercourse D) which drains into Long Swamp Creek and Long Swamp is located to the south of the extraction area. A site inspection of Long Swamp Creek by Larry Cook Consulting and a Coffey Geotechnics (Coffey) groundwater consultant calculated the channel flow to be approximately 4.3 ML/day.

An average annual rainfall of 902 mm is adopted for the Proposal by SEEC (2018) in their surface water assessment with an average annual pan evaporation of 1497 mm. The average annual potential evapotranspiration (PET) is estimated by SEEC to be approximately 1167 mm.

Dual porosity water-bearing zones (aquifers) are commonly developed within the Hawkesbury Sandstone in the Southern Highlands at different elevations down to its base, which is the contact with the underlying Permian Illawarra Coal Measures or the Shoalhaven Group. Groundwater is typically acidic and ‘soft’ with low salinity.

Aquifers are found in sub-horizontal relatively porous and stacked layers (beds) of sheeted sandstone with increased primary permeability. These primary aquifers provide the main aquifer storage and are characterised by variable yields. Pervasive sub-vertical, semi-continuous to continuous, rock defects such as fractures and joints with secondary ‘enhanced’ permeabilities constitute a major component of the aquifers’ transmissivity but only a minor component of the aquifers’ storage. Fracture-controlled sandstone aquifers provide relatively moderate to occasionally high yields.

The occurrence of stacked and interbedded, flat-lying massive and sheeted sandstone units indicate that semi-confined to confined hydrogeological conditions exist.

These sandstone-hosted ‘hardrock’ aquifers provide important water supplies in the Southern Highlands including a network of important industrial bores southwest of the Proposal. In addition, ‘shallow’ groundwater is found in the forms of perched water tables and springs which are often collectively referred to as ‘water features’ commonly developed in the greater Southern Tablelands area.

Aquifer recharge is primarily by way of excess precipitation (rainfall), in particular the water that infiltrates the vadose (unsaturated) zone which is not lost through evapotranspiration. The WSP states that 3% of rainfall recharges the aquifer system.

Approximately 50% of the rainfall recharge provides base flow to the watercourses and swamps surrounding the Proposal such as Long Swamp Creek and Long Swamp. The remainder is likely consumed by evapotranspiration and escarpment discharge.

The existence of elevated springs in the local area may indicate that some of this recharge infiltrates down to very shallow sandstone zones, possibly down to the base of the weathered zone where ‘perching’ of shallow groundwater may occur. This water then migrates laterally down gradient and potentially discharges at high elevation as springs. Discharge from beneath remnant basalt occurrences north of Long Swamp Creek may contribute significant water to the local watercourses.

The results of the hydrogeological and surface water investigations indicate that watercourses in the vicinity of the Proposal may be classified as either ephemeral, intermittent or perennial. The first order watercourses close to the Proposal are ephemeral and sections of the receiving system appear to be intermittent. The larger watercourses, such as Long Swamp Creek are permanent watercourses (perennial) as they have year-round base flow from groundwater.

The ephemeral watercourses in this setting are losing / disconnected systems where the flow decreases in a downstream direction due to infiltration through the bed of the watercourse which recharges surrounding sandstone-hosted aquifers with a water table at a lower elevation than the surface of the watercourse. The higher order watercourses in the area such as Long Swamp Creek are considered to be gaining systems whereby underlying aquifers attribute to streamflow as the water table elevation is greater than the channel of the watercourse.

The hydraulic conductivity of sandstone without major structural deformation generally varies from around 0.1 m/day near the surface to around 0.003 m/day at depth which is typical for brittle fractured sedimentary rocks which are subject to large variations in the in-situ stress field due to their developed landforms (cliff lines and steep topography) (Coffey, 2014). Structural deformation generally increases sandstone permeability, and may impart a higher ratio of vertical to horizontal hydraulic conductivity when deformation is largely along sub-vertical features.

Coffey (2016) re-analysed pump test data from a local bore and concluded that lateral anisotropy occurs within the sandstone sequence associated with north-northwest and east-southeast sub-vertical geological defects which are considered common in the southwestern margins of the Sydney Basin.

A number of high priority groundwater dependent ecosystems (GDEs) have been identified by State government mapping in the Southern Highlands as part of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources. Some of these GDEs are known in the area surrounding the Proposal and are collectively labelled the Paddys River Swamps which includes Long Swamp. These are Temperate Highland Peat Swamps developed on sandstone in natural depressions or along watercourses.

A district search for data and information for registered boreholes held by Department of Industry – Crown Lands and Water (CL&W) (formerly the New South Wales Office of Water (NOW)) revealed the existence of 43 registered bores within a 24 km^2 search area centred on the extraction area. Twelve of these registered bores are licensed for industrial, irrigation or both. The majority of the groundwater extraction licences within the search area are for bulk mineral water and attached to properties adjacent to Hanging Rock Road. These properties are situated on the southern side of the Long Swamp Creek valley system area over 1.5 km from the Proposal. Two registered bores are located within Lot 4 DP 253435. One of which (bore GW104765) has an approved irrigation licence for 45 ML.

A network of 14 monitoring bores were constructed within and surrounding the proposed extraction area. The bores were drilled to depths below the design base of the Quarry and all were appropriately constructed as piezometers.

Baseline measurements of water level were collected in the 14 monitoring bores. A numerical computer groundwater model developed by Coffey Geotechnics (Coffey, 2016) showed that the total hydraulic head in the area is characterised by large downward total head gradients which are very typical for steeply dissected topography. Coffey (2016) also concluded that the groundwater flux is controlled by the hydraulic head and hydraulic conductivity fields with its inherent vertical anisotropy.

The results of rising head ‘slug’ tests indicate relatively low rock permeabilities with the tests revealing hydraulic conductivities of between approximately 0.10 and 0.35 m/day, transmissivities of between approximately 0.7 and 2.6 m^2/day and storativities of between 7.0 x 10^{-3} and 2.7 x 10^{-4} (coefficient).

The results of pumping tests carried out in a local production bore, (GW051450) outside of the Proposal were utilised to complement the site aquifer and pump test data. Results include hydraulic conductivities of between approximately 0.71 and 1.60 m/day, transmissivities of between approximately 18.5 and 45.5 m^2/day and a storativity of 5 x 10^{-3} (coefficient). Aquifer testing in the on-site irrigation bore (GW104765) indicated a transmissivity of approximately 30 m^2/day and a storativity of about 1 x 10^{-2} (coefficient). A long-term safe yield for this bore was estimated at 2.1 L/s.

Three samples of drill core collected from the resource drill holes were submitted for laboratory permeability testing. Hydraulic conductivities were calculated using the falling head methods. Laboratory results returned hydraulic conductivities of between approximately 0.07 and 0.87 m/day, which are considered high for Hawkesbury Sandstone as typical values of hydraulic conductivity for the Hawkesbury Sandstone in the Sydney Basin are between approximately 0.005 and 0.01 m/day (Coffey, 2016).

Baseline groundwater quality analysis was carried out by sampling eight monitoring bores, those with sufficient water column. The results indicated that groundwater has low pH and low salinity that is reflected in the concentration of sodium and chloride. The major ion compositions indicates that the groundwater is predominantly of the sodium chloride type with minor amounts of calcium carbonate water.

A numerical groundwater flow model was developed over two years by Coffey to simulate excavation of the Proposal and any potential impacts on the local groundwater system. The results of the numerical computer groundwater model indicate the following:

- The local water table will not be intersected by the expanding extraction area until about the end of Year 3 (Stages 0 and 1).
- Inflows into the pit would commence once extraction occurs below 665 m AHD in Stages 0 and 1 and reach a maximum of approximately 0.2 ML/day in the early part of Stage 6. The total average groundwater inflow to the pit void over 45 years is estimated to be about 0.14 ML/day. This equates to approximately 51 ML per annum.
- The numerical groundwater model predicts that the drawdown radius of influence surrounding the extraction area, arising from the inflow of groundwater into the progressively expanding extraction area is asymmetrical and extends up to approximately 1 km to the south and up to 750 m to the east. The modelled contour of 0.2 m drawdown of the water table (due to extraction operations) extends a maximum of approximately 1 km from the extraction area at the end of Stage 5 (Year 28) and about 1.2 km at the end of Stage 7 (end of extraction operations, Year 45).
- The modelled intercepted baseflow to Long Swamp, Long Swamp Creek and its tributaries due to extraction is a maximum of about 2.6% compared to the calculated long-term average baseflow.
- The maximum modelled drawdown of the water table at the end of extraction operations (Year 45) at each private bore is less than 0.5 m. The maximum modelled drawdown of the water table at Year 45 (end of extraction operations) in the vicinity of the four closest private bores to the extraction area is as follows:
  - GW035166: < 0.3 m
  - GW037967: < 0.3 m
  - GW068897: < 0.5 m
  - GW101872: < 0.3 m

  The amount of predicted drawdown in the four potentially affected bores as a proportion of available drawdown is predicted to be less than 1.5 %.

Given the depths of the four closest bores to the extraction area, their recorded water levels, this drawdown is unlikely to cause significant loss of available groundwater at these locations and is within drawdown limits set in the Aquifer Interference Policy.
Other private bores are unlikely to be influenced by the proposed extraction regime, including the Coca Cola mineral water bores located approximately 2 km south west of the extraction area.

- Placement of fines in the extraction area would predictably impede and possibly reduce direct recharge from rainfall but aid in the recovery (equilibration) of the water table surrounding the extraction area.
- The long-term average groundwater discharge from the backfill in the extraction area is calculated as 0.002 ML/day. This is likely to be consumed by evapotranspiration before being able to discharge as surface water. Where increased discharge occurs (during higher rainfall periods), the discharge will exit the area as watercourse flow.

Potential impacts on Long Swamp (identified as a Temperate Highland Peat Swamp and GDE) from the proposed extraction operations were assessed.

The numerical computer groundwater model predicts a maximum reduction of 0.052 ML/day in baseflow to Long Swamp Creek and Long Swamp over the 45 years of extraction. This equates to a reduction for Long Swamp Creek and Long Swamp of 2.6% of the modelled baseflow which is considered to be a minimal impact and within the range of natural variation in flows for this type of GDE.

In addition, the numerical groundwater model also predicts a maximum drawdown of the water table at the eastern end of Long Swamp of less than 0.1 m at the end of Stage 5, Year 28 with the same prediction at the end of Stage 7, Year 45. This amount of drawdown is not considered significant and within the range of natural variability.

Calculations of the average annual make-up water required to satisfy the water demands of the sand processing operations and dust suppression activities indicate that approximately 33 ML would be required to supplement water captured under harvestable rights. Supplementary water would either be sourced from groundwater or commercial supply arrangements. The numerical groundwater model (Coffey, 2016) incorporated abstraction of 67% annual allocation for all surrounding production bores, including an on-site bore, GW104765 to predict impacts on the local water table associated with the Proposal. Safe yield analyses by Cook (2016) calculated using field data collected from aquifer performance testing at bore GW104765 indicate that the bore is capable of sustaining abstraction rates of 2.1L/second which equates to an annual production volume of 67 ML/year. Therefore, the use of any supplementary groundwater from bore GW104765 would not result in any additional impacts on the groundwater system.

Additional licensed water allocations will be required to account for the average 51 ML/year groundwater inflow into the extraction area predicted by the numerical groundwater model. This additional allocation could be obtained by water dealing in the same groundwater source.

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1. INTRODUCTION

1.1 STATEMENT

Larry Cook Consulting Pty Ltd (Larry Cook Consulting) was commissioned by R. W. Corkery & Co. Pty Limited on behalf of Sutton Forest Quarries Pty Ltd ("the Applicant"), to undertake hydrogeological field investigations and office-based studies on and surrounding Lot 4 DP 253435, 13302 Hume Highway Sutton Forest, Southern Highlands New South Wales (the Site).

This groundwater assessment report was prepared for inclusion in an Environmental Impact Statement by R. W. Corkery & Co. Pty Limited for the proposed Sutton Forest Quarry Project at Sutton Forest ("the Proposal"). The application for the Proposal would be made as a State Significant Development under Division 4.1 of Part 4 of the Environmental Planning and Assessment Act 1979.

A transient numerical groundwater model was developed by Coffey Geotechnics Pty Ltd (Coffey) to simulate development of the Proposal and predict any potential impacts on the local groundwater system, other groundwater users or the environment.

1.2 SCOPE OF WORK AND OBJECTIVES

This report provides an assessment of the local and regional hydrogeology centred on the location of the Proposal, and the potential impacts on the groundwater system that may be associated with the proposed sand extraction operations of the Proposal.

The objectives of this hydrogeological assessment are to:

- establish and assess local and regional hydrogeological conditions;
- establish the existing groundwater utilisation in the region;
- estimate recharge volumes in the area centred on the Site;
- carry out baseline analytical testing to characterise the groundwater;
- develop a conceptual hydrogeological model;
- develop a steady-state numerical groundwater computer model;
- assess any potential impacts of the extraction of sandstone on local and regional aquifer systems, local and regional water tables, down-gradient groundwater dependent ecosystems (GDEs), groundwater chemistry and local water users;
- provide recommendations including operational safeguards, mitigation measures and contingency planning; and
- propose a long-term groundwater monitoring program and reporting and database management protocols.

1.3 LOCATION OF THE SITE

The Site is in a locality referred to as Sutton Forest, approximately 28 km southwest of Berrima and 14 km northeast of Marulan. The Site is located approximately 1 km west of the Hume Highway, approximately 1.7 km south of the intersection of the Hume Highway and Sallys Corner Road. The location of the Site is shown in **Figure 1**.

The Site is located in Lot 4 DP 253435 near Sutton Forest within the Southern Highlands, New South Wales. An aerial photo showing the local setting is shown in **Figure 2**.

1.4 DESCRIPTION OF THE SITE

The Site (shown in **Figure 3**) comprises the Quarry Operations Area comprising an extraction area and processing and stockpiling area. The Quarry Operations Area is situated on privately owned land on Lot 4 DP 253435. Product despatch and access to the Quarry Operations Area would be via the Quarry Access Road which would traverse the Crown Road Reserve between Lot 12 DP 241054 and Lot 4 DP 253435. The Quarry Access Road would join with a new interchange that would allow vehicles to enter and exit the Hume Highway.

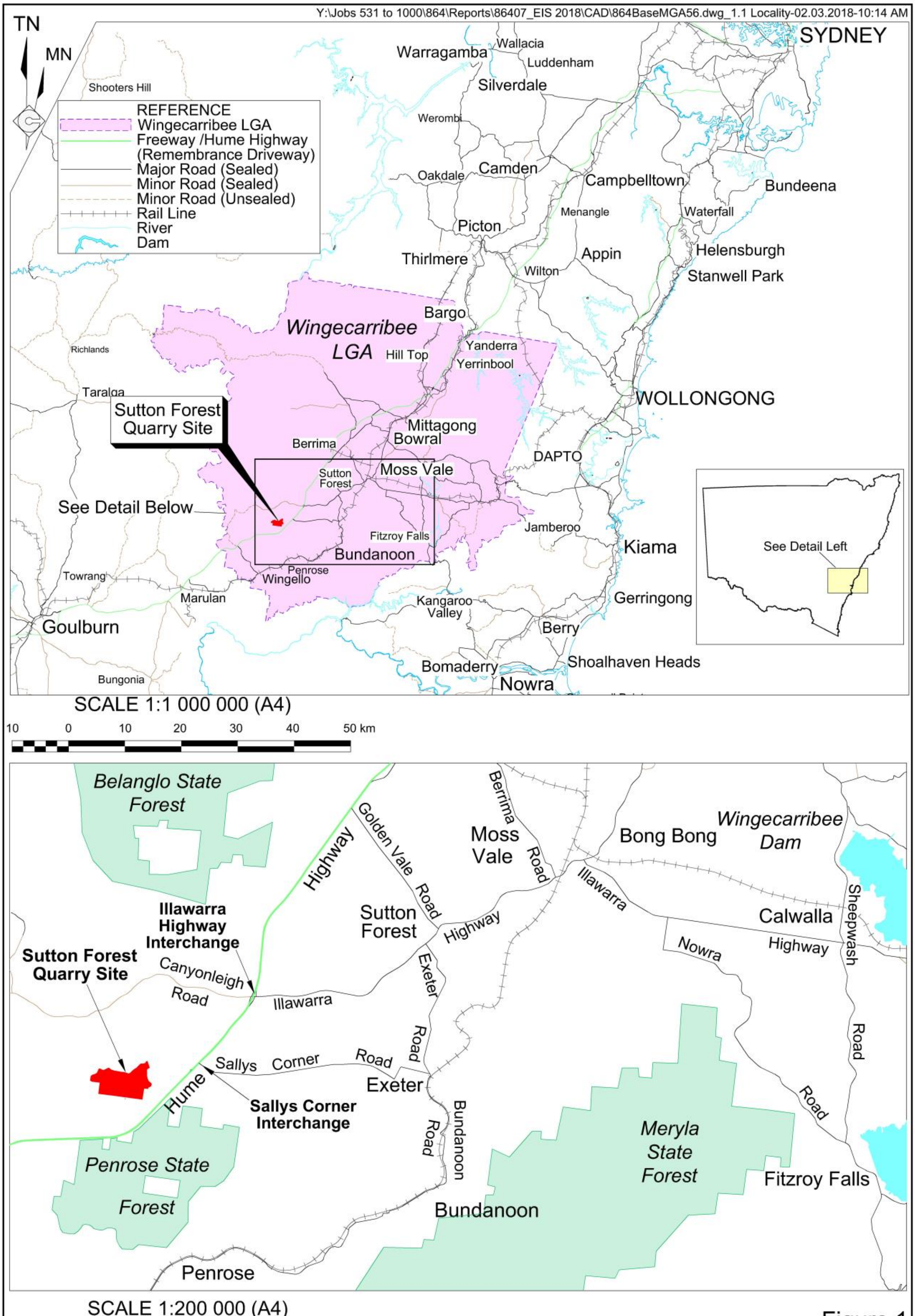

Figure 1
LOCALITY PLAN

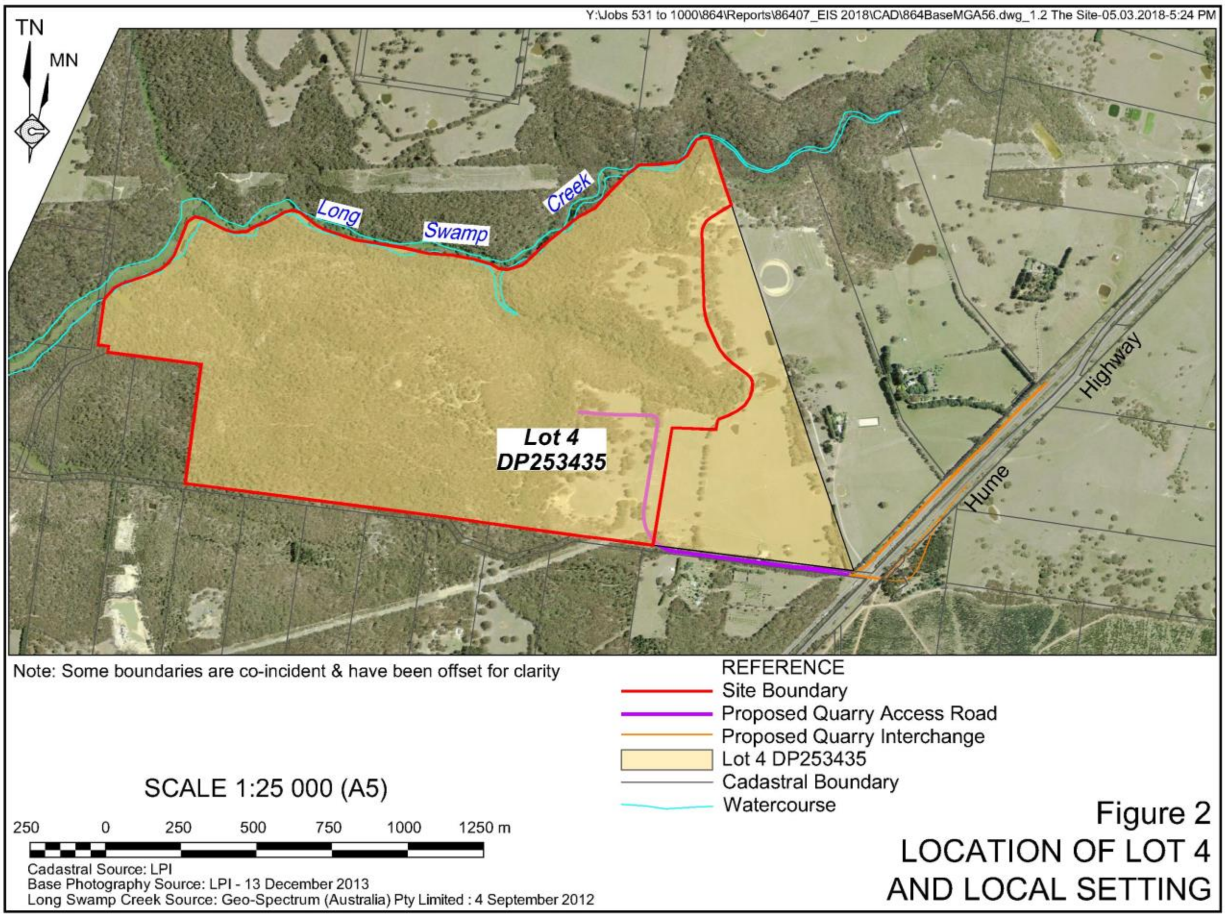

Figure 2
LOCATION OF LOT 4
AND LOCAL SETTING

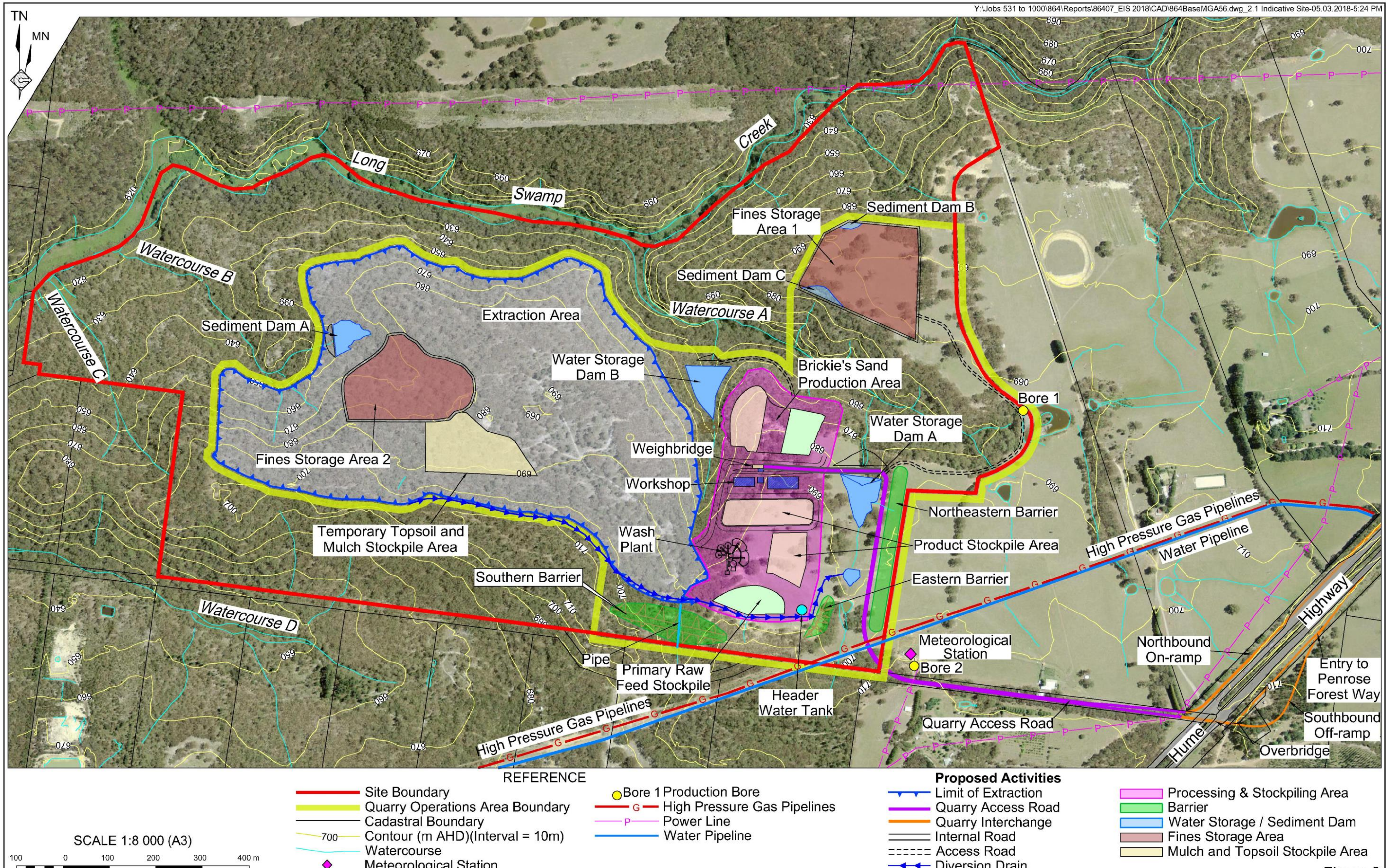

Figure 3
THE SITE

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2. DESCRIPTION OF PROPOSED SAND EXTRACTION OPERATIONS

The Applicant proposes to develop and operate a sand extraction and processing operation on the Site. Extraction would be achieved by ripping, pushing, loading and haul operations. Eight indicative stages (0 to 7) of extraction moving from east to west are proposed over 45 years as shown in **Figure 4**. However, the development consent currently sought is anticipated to enable extraction of the sand resource until Year 30 which is represented by Extraction Stage 5. Further development of the subsequent stages (stages 6 and 7) will be subject to additional development consent in the future.

Recovery of friable sandstone would occur within the first years of operation within the processing and stockpiling areas.

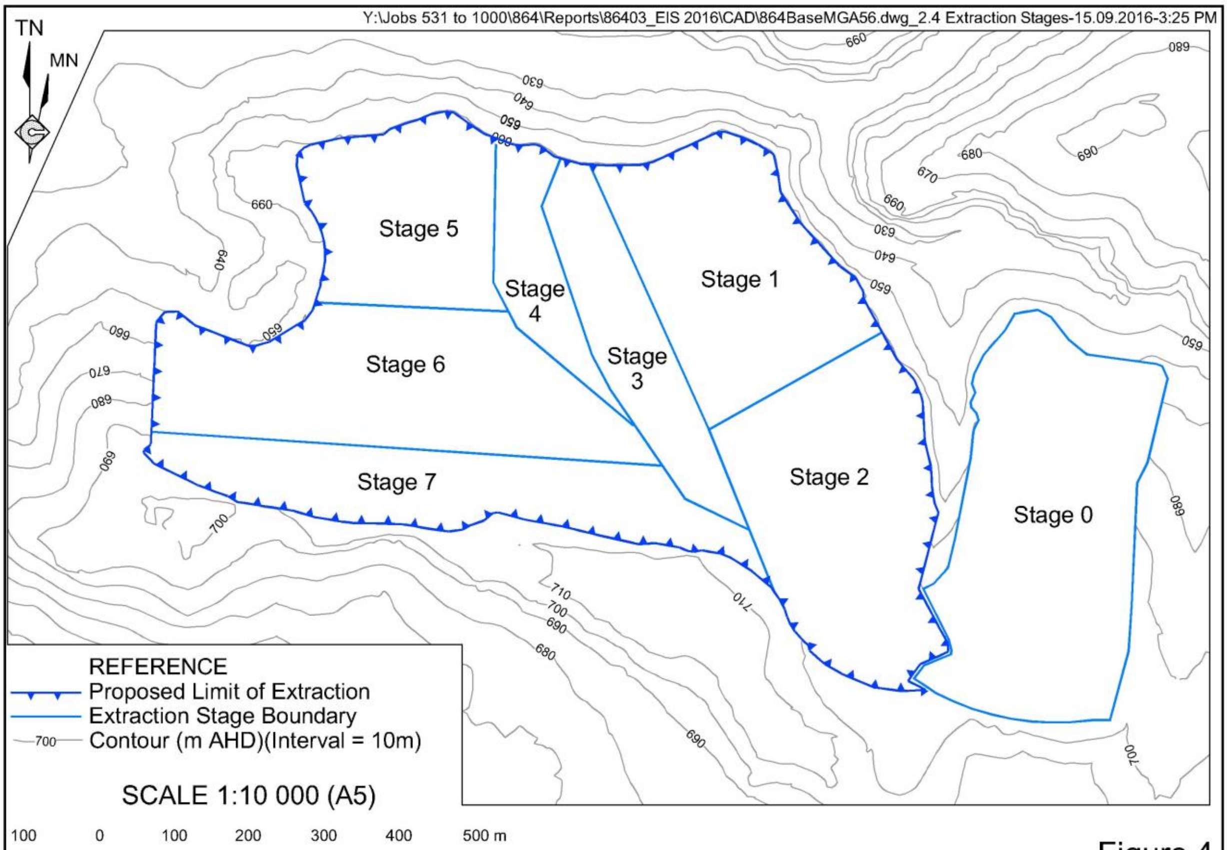


Figure 4
INDICATIVE EXTRACTION STAGES

The proposed elevations at the base of extraction are shown in **Figures 5 and 6**.

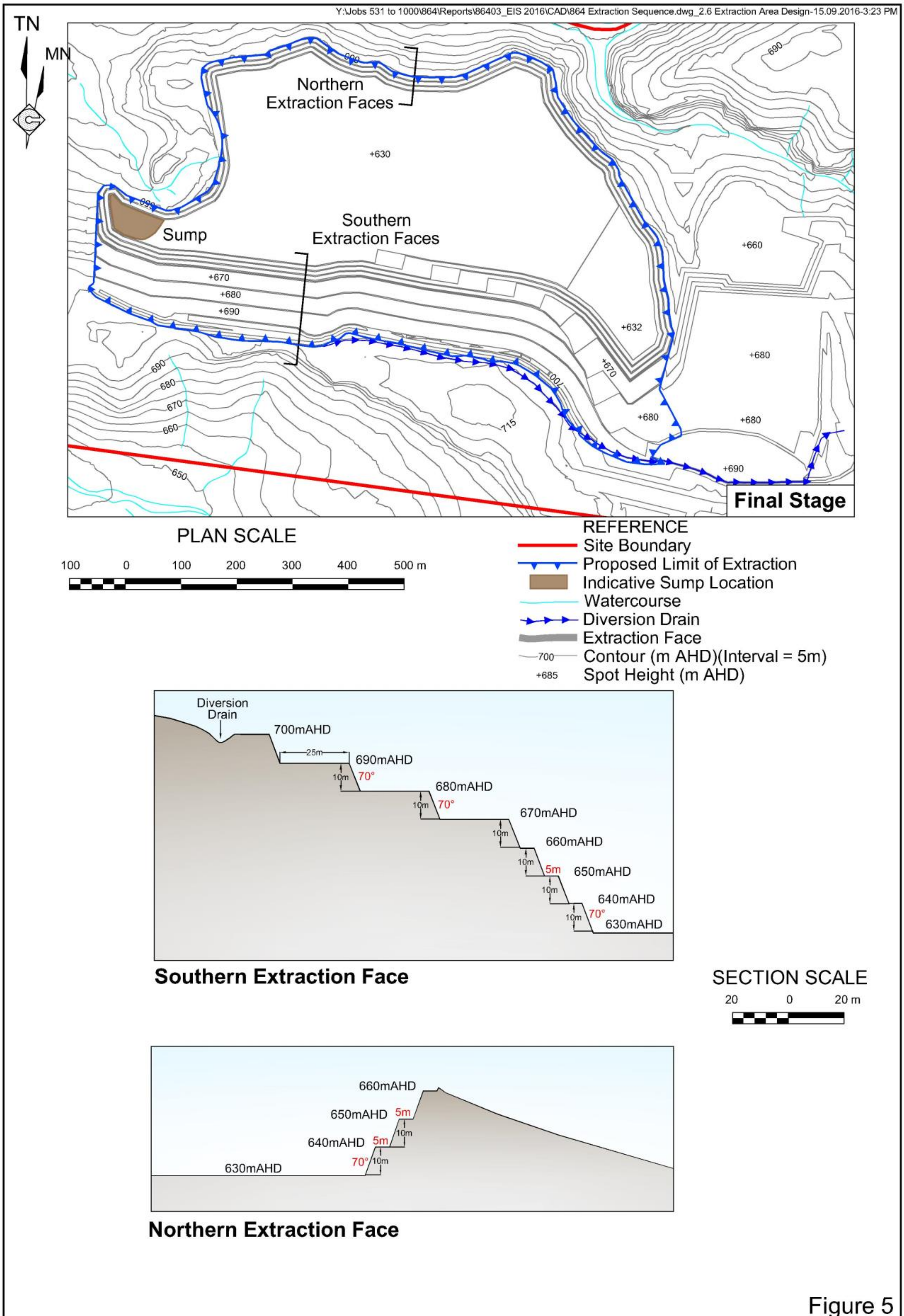
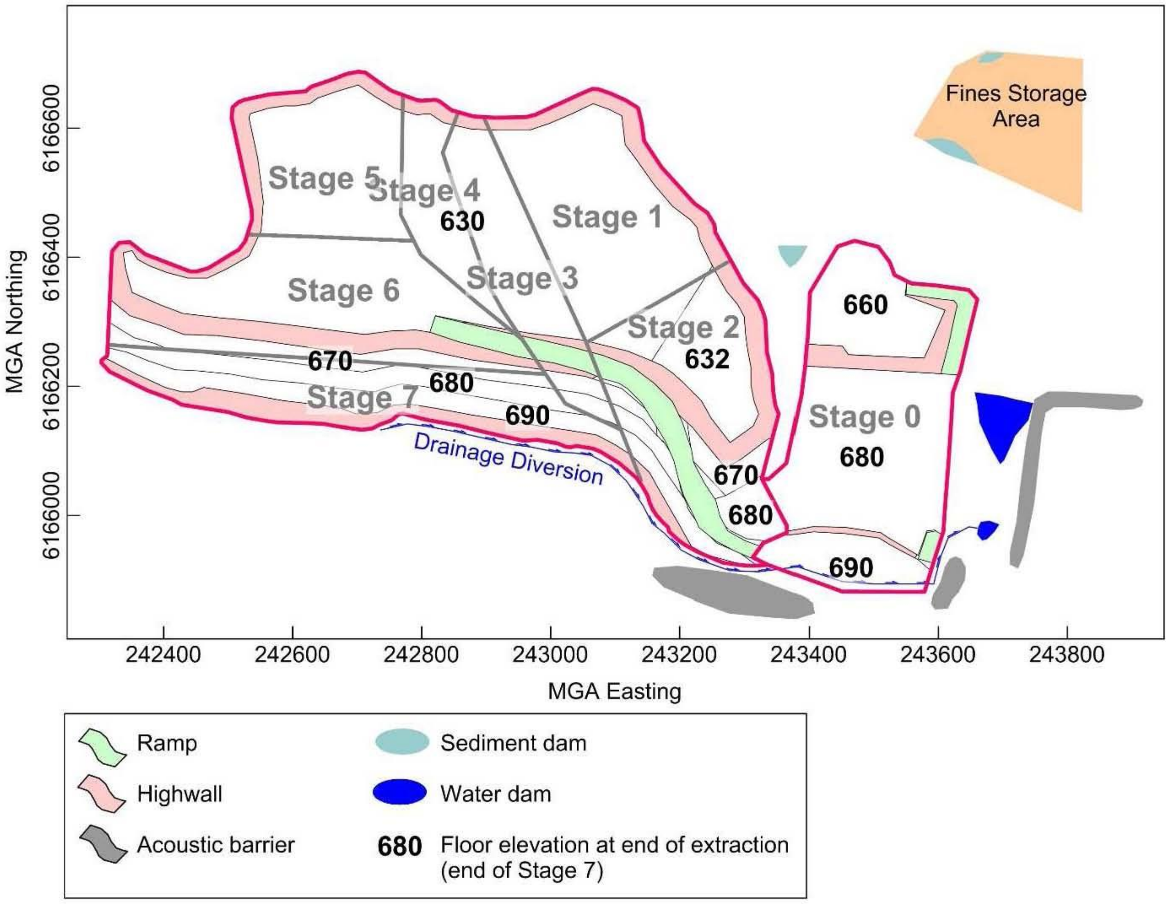


Figure 5
ELEVATIONS OF THE PIT

Figure 6 Elevations of the Base of Pit Stages



It is understood that extraction of raw feed would commence during the construction of the processing and stockpiling area. Approximately 1.7 million tonnes of friable sandstone would be recovered from this area. A range of graded sand products including mortar sand would be produced.

The key processing equipment would be a processing plant incorporating washing, screening and dewatering with product stockpiling using radial stackers. The processing plant would produce up to 260 tph of sand products.

The raw sand comprises approximately 14% fines, the bulk of which would be removed by washing resulting in a product suitable for concrete manufacture. In order to maximise the amount of water for recycling, a series of filter presses would be used to recover process water. The presses produce a filter cake consisting of fines (silt and clay) and approximately 10% water. The filter cake would be stored on site and later placed in completed section of the extraction area as part of background operations. Placement of fines in the extraction area would predictably impede and possibly reduce direct recharge from rainfall but aid in the recovery (equilibration) of the water table surrounding the extraction area.

The total annual design requirements for water including make-up requirements for the operation of the wash plant and maximum annual use for dust suppression are:

Annual Washed Sand Production	Total Water Requirement
390 000 tpa	48 ML
630 000 tpa	71 ML
780 000 tpa	85 ML

It is understood that in 50% of years there would be an estimated water deficit of 33 ML (SEEC, 2018).

3. RELEVANT GOVERNMENT PLANS, LEGISLATION, POLICIES AND GUIDELINES

3.1 INTRODUCTION

The legislation, plans, policies and guidelines relevant to this proposed development are listed in **Table 1**.

Table 1
Relevant Legislation, Plans, Policies and Guidelines

NSW Water Management Act 2000
NSW Water Act 1912
The Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources (2011).
NSW State Groundwater Policy Framework Document (NSW Government 1997)
NSW State Groundwater Dependent Ecosystems Policy (NSW Government 2002)
Environment Australia: Environmental Flows Initiative technical report No.2 (2001)
NSW State Groundwater Quality Protection Policy (NSW Government 1998)
Draft NSW Groundwater Quantity Management Policy (DLWC, 2001)
NSW Aquifer Interference Policy – (NSW Office of Water, 2012)
NSW Policy for Managing Access to Buried Groundwater Sources (NSW Office of Water, 2011)
ANZECC 2000 Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Agriculture and Resource Management Council of Australia and New Zealand and the Australian and New Zealand Environment and Conservation Council, 2000)

3.2 THE WATER SHARING PLAN FOR THE GREATER METROPOLITAN REGION GROUNDWATER SOURCES

The Site is located within the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources (the WSP). Groundwater resources of the Site falls within the Sydney Basin Nepean Groundwater Source within which two management zones exist, namely Nepean Management Zone 1 and Nepean Management Zone 2. The groundwater resource of Site is managed under Nepean Management Zone 1.The WSP is made under the Water Management Act 2000 which provides the mechanism for control and management of groundwater within NSW and applies to areas of NSW that have WSPs in place. The WSP commenced on 1 July 2011 and applies until July 2021.

The WSP includes rules for protecting the environment, extractions, managing licence holders' water accounts, and water trading in the plan area.

The water sharing rules of the WSP allocate water for the environmental needs of the groundwater sources, directs how water is shared among different water users and provides rules for protecting the environment, extractions, managing licence holder’s water accounts and water trading (water dealing).

The objectives of this WSP, as gazetted, are to:

a) protect, preserve, maintain and enhance the high priority groundwater dependent ecosystems and important river flow dependent ecosystems of these groundwater sources,

b) protect, preserve and maintain the integrity of aquifers in these groundwater sources,

c) protect, preserve, maintain and enhance the Aboriginal, cultural and heritage values of these groundwater sources,

d) contribute to the sustainable and integrated management of the water cycle across these groundwater sources,

e) protect basic landholder rights,

f) manage these groundwater sources to ensure equitable sharing between users,

g) provide opportunities for market based trading of access licences and water allocations within sustainability and system constraints,

h) provide security and certainty for the life of the plan to stakeholders that utilise groundwater resources,

i) provide water allocation account management rules which allow sufficient flexibility to encourage responsible use of available water,

j) contribute to the maintenance of water quality,

k) provide recognition of the connectivity between surface water and groundwater,

l) adaptively manage these groundwater sources,

m) contribute to the environmental and other public benefit outcomes identified under the Water Access Entitlements and Planning Framework in the *Intergovernmental Agreement on a National Water Initiative (2004)* (the *NWI*), and

Note. Under the NWI, water that is provided by NSW to meet agreed environmental and other public benefit outcomes as defined within relevant water plans is to:

- be given statutory recognition and have at least the same degree of security as water access entitlements for consumptive use and be fully accounted for,

- be defined as the water management arrangements required to meet the outcomes sought, including water provided on a rules basis or held as a water access entitlement, and
- if held as a water access entitlement, may be made available to be traded (where physically possible) on the temporary market, when not required to meet the environmental and other public benefit outcomes sought and provided such trading is not in conflict with these outcomes.

n) where necessary, allow for the supplementation of the water supply for the people of Sydney, the Illawarra, the Shoalhaven, the Southern Highlands, and the Blue Mountains, which comprise approximately 70% of the NSW population.

3.2.1 Water Licensing

Licensing ensures that the amount of water taken from each water source does not exceed the extraction limit set in the water sharing plan (WSP). Water licences (including an aquifer access licence) are required to account for the water taken from both groundwater and surface water sources through aquifer interference activities regardless of its quality. A licence with sufficient water allocation (entitlement) must be held to account for all take of water, both during the life of a Proposal such as extraction and for any ongoing take after the aquifer interference activity has ceased. Allocations issued under a licence generally state the number of “share components” the holder of the licence is entitled to take from the resource with one share component representing a specified volumetric unit, in this assessment share components are referred to as ML/year. Further, under Section 2.2 of the AIP, *“Where there is ongoing take of water, the licence holder must retain a water licence for the period until the system returns to equilibrium or surrender it to the Minister.”*

The total volume of water to be taken from each water source as a result of the aquifer interference activity must be determined before development consent can be granted. Importantly, a water licence is required whether water is taken directly from a groundwater or surface water source for consumptive use or whether it is taken incidentally (indirectly) by the aquifer interference activity such as induced flow from a connected groundwater or surface water source by the aquifer interference activity such as extraction. Incidental water take can result from intentional dewatering of aquifer as a result of groundwater inflows to the extraction area but also includes the volume of groundwater inflow to voids that results in evaporative losses where the void intersects the water table.

3.3 AQUIFER INTERFERENCE POLICY

The NSW Aquifer Interference Policy (AIP) was released in September 2012. The AIP provides an explanation of the water licensing and impact assessment processes for aquifer interference activities under the Water Management Act 2000 and other relevant legislation. The AIP details the way in which the CL&W assesses aquifer interference projects to determine their potential impacts on water resources. There are three key components of the AIP, namely:

1. all water taken must be properly accounted for;
2. the aquifer interference activity must address Minimal Impact Considerations for any potential impacts on the water table, water pressure levels and water quality; and
3. planning for measures in the event that the actual impacts are greater than predicted including a contingency for monitoring.

3.3.1 Minimal Impact Considerations

The groundwater source in the area centred on the extraction area, as determined from Section 3.2.1 of the AIP for the Greater Metropolitan Region Groundwater Sources-Management Zone 1 is "**Porous and Fractured Rock Groundwater Sources (general)**". The category of the groundwater sources documented in the Greater Metropolitan Region Groundwater Sources- Management Zone 1 is **"Highly Productive"**.

The minimal impact considerations and thresholds documented in Table 1 of the AIP for this groundwater source are provided in **Table 2**.

Table 2
Minimal Impact Considerations - NSW Aquifer Interference Policy

Water Sharing Plan	Greater Metropolitan Region Groundwater Sources- Management Zone 1		
Groundwater Source	Porous and Fractured Rock		
Source Category	Highly Productive		
	Maximum Impacts Considered Acceptable		
	Water Table	**Water Pressure**	**Water Quality**
Water Supply Work	≤ 2m cumulative water level decline unless make good provisions	≤ 2m cumulative water level decline unless studies can demonstrate that the activity would not prevent the long term viability of the water supply work or make good provisions	Not detailed
GDE/CSS	≤ 10% cumulative variation in the measured water table level in the first year of the WSP at a distance of 40 m from a GDE or CSS unless studies can demonstrate that the activity would not prevent the long term viability of the GDE or CSS.	Not detailed	Not detailed
Aquifer Interference Activity	Not detailed	Not detailed	No change in beneficial use category of the groundwater source >40m from activity unless studies can demonstrate that change in groundwater quality would not prevent the long term viability of any GDE, CSS or water supply work

GDE: Groundwater Dependent Ecosystem
CSS: Culturally Significant Site

3.3.2 Water Table

The water table assessment examines the actual height of the groundwater in parts of the groundwater sources that are not confined by overlying rocks or sediments.

3.3.3 Water Pressure

The water pressure assessment examines the height of the piezometric surface corresponding to the pressure of the groundwater in parts of the groundwater sources that are confined by overlying rocks or sediments and is therefore under pressure.

3.3.4 Water Quality

The water quality assessment examines whether a change to any water quality parameter would result in a change in the water quality sufficient to potentially impact on current or future uses. In particular, the assessment also considers whether the activity would increase the salinity of the groundwater.

The outcome of the assessment is either a Level 1 impact which is considered acceptable under the AIP while a Level 2 impact requires further studies and impact assessments.

4. DIRECTOR-GENERAL'S REQUIREMENTS

The key groundwater issues identified within the relevant Director-General's Requirements are summarised in **Table 3** together with reference to where each requirement is addressed in this document. The requirements were prepared by the Department of Planning and Environment (DPE) following consultation with, and submissions from, relevant government agencies.

Table 3
Director-General's Requirements and Key Issues Relating to Groundwater

Page 1 of 4

Organisation	Paraphrased Requirement/Issue	Relevant Section(s)
DIRECTOR-GENERAL'S REQUIREMENTS		
SOIL AND WATER		
The EIS must address the following specific issues:		
Water Resources including – • detailed assessment of potential impacts on the quality and quantity of existing surface and ground water resources, including the impacts on: - existing user entitlements, affected licensed water users and basic landholder rights;		15
- groundwater-dependent and riparian ecology; and		16
- regional water supply infrastructure.		NA
• a detailed site water balance, including a description of site water demands, water disposal methods (inclusive of volume and frequency of any water discharges), water supply infrastructure and water storage structures;		NA
• a detailed consideration of maintenance of an adequate buffer between all excavations and the highest predicted groundwater table;		15.4
• identification of any licensing requirements or other approvals under the Water Act 1912 and/or Water Management Act 2000;		3.2.1, 18
• demonstration that water for the construction and operation of the development can be obtained from an appropriately authorised and reliable supply in accordance with the operating rules of any relevant Water Sharing Plan (WSP) or water source embargo; and		13.7, 18
• a detailed description of the proposed water management system, water monitoring program and other measures to mitigate surface and groundwater impacts.		19.3
ISSUES RAISED BY OTHER GOVERNMENT AGENCIES		
WATER – GENERAL		
EPA (21/01/14)	Demonstrate that environmental outcomes for the project ensure: • There is no pollution of waters (including surface and groundwater) except in accordance with licence requirements • Wastewater is captured on the site and directed to reticulated sewer where available or collected, treated and beneficially reused, where this is safe and practicable to do so • There is consistency with any relevant Statement of Joint Intent established by Healthy Rivers Commission; and • It contributes to the protection of achievement over time of River Flow Objectives and Water Quality Objectives.	15.5 NA NA NA
	Describe the nature and the degree of any likely impacts that the proposed project may have on the receiving environment and clearly outline the proposed mitigation, monitoring and management measures	15, 16 , 19.3
	Determine the requirements that apply to the local catchment and clearly identify any sensitive areas.	16

Table 3 (Cont'd)
Director-General's Requirements and Key Issues Relating to Groundwater

Page 2 of 4

Organisation	Paraphrased Requirement/Issue	Relevant Section(s)
ISSUES RAISED BY OTHER GOVERNMENT AGENCIES (Cont'd)		
EPA (21/01/14) (Cont'd)	Address the potential for any diesel or chemical spills and any necessary bunding and/or spill management measures	NA
	Document the soil and water management controls that will be implemented during the project to minimise any potential impacts on water quality	NA
	Address impacts and mitigation measures associated with water supply at the site.	13.7, 15
DPI - NOW (06/02/14)	The EIS should demonstrate: • An adequate and secure water supply for the proposal. Confirmation that water supplies for the quarry operation, associated activities incorporated into product and any other losses, are sourced from an appropriately authorised and reliable supply.	13.7
	• Identify through a water balance the: - site water demands in terms of volume and timing; - water sources (surface and groundwater); - water disposal methods; - water storage structures including Maximum Harvestable Right Dam Capacity; - annual volume of groundwater to be intercepted - annual volume of groundwater to be extracted/used for quarry purposes and any other losses - annual volume of surface water intercepted by the quarry operations and volumes extracted for any purpose; - volume and purpose of all dams/water storages on the contiguous land holding of the proponent; and • any water reticulation infrastructure that supplies water to and within the site. • Existing and proposed water licensing requirements in accordance with the Water Management Act 2000 and Water Act 2012 (as applicable). This is to demonstrate that existing licences (include licence numbers) and licensed uses are appropriate, and to identify where additional licences are proposed. • Ensure licensing is commensurate with the anticipated volume of groundwater take and surface water take prior to this take occurring.	 NA 13.7 NA NA 17 13.7, 17 NA NA NA 3.2.1, 18 18
	• An impact assessment on adjacent licensed water users (surface and groundwater), basic landholder rights, and groundwater-dependent ecosystems, notably Long Swamp and Stingray Swamp as well as Long Swamp Creek and adequate provision of buffer requirements.	15, 16

Table 3 (Cont'd)
Director-General's Requirements and Key Issues Relating to Groundwater

Page 3 of 4

Organisation	Paraphrased Requirement/Issue	Relevant Section(s)
	ISSUES RAISED BY OTHER GOVERNMENT AGENCIES (Cont'd)	
DPI - NOW (06/02/14) (Cont'd)	• Assess watercourses to be crossed and describe appropriate techniques and mitigating measures to minimise impacts on those watercourses.	NA
	• Design and construct any crossings/works in/within 40m of watercourses are to be in accordance with NSW Office of Water Guidelines for Controlled Activities on Waterfront Land (July 2012).	NA
	• An assessment of the potential to intercept and/or impact groundwater and predicted dewatering volumes, water quality and disposal/retention methods. This will need to address the requirements of relevant policy including the Aquifer Interference Policy. It is recommended final landforms of open voids containing groundwater are minimised. Where there is ongoing groundwater take induced by evaporative loss this must be identified and addressed by retaining the appropriate water licence entitlement at the site.	15, 17
	• Adequate mitigating and monitoring requirements to address surface water and groundwater impacts.	19
	Water Sharing Plans	
	Demonstrate that the proposed project is consistent with the relevant access and trading rules within the following:	
	• Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011	NA
	• Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011.	3.2.1, 18
	Detail the extent to which the proposed project is consistent with relevant legislation, policies and guidelines, and justify any inconsistencies	16.4, 18
	The EIS should include an assessment of potential groundwater issues and potential degradation to the groundwater source and provide the following:	
	• Detail the predicted highest groundwater table at the development site	15
	• Detail any works likely to intercept, connect with result in pollutants infiltrating into groundwater sources.	NA
	• Detail any proposed groundwater extraction, including purpose, location and construction details of all proposed bores and expected annual extraction volumes.	13.7, 17
	• Describe the flow directions and rates and the physical and chemical characteristics of the groundwater source	11, 13.9
	• Detail the predicted impacts of any final landform on the groundwater regime.	14.7.4
	• Detail the existing groundwater users within the area (including the environment) any potential impacts on these users and safeguards measures to mitigate impacts	11.6, 11.7, 11.8, 11.9

Table 3 (Cont'd)
Director-General's Requirements and Key Issues Relating to Groundwater

Page 4 of 4

Organisation	Paraphrased Requirement/Issue	Relevant Section(s)
ISSUES RAISED BY OTHER GOVERNMENT AGENCIES (Cont'd)		
	• Assess the quality of groundwater for the local groundwater catchment.	13.9
	• Detail the expected impacts of the proposed development on the quality of groundwater both in the short and long term.	15.5
	• Detail measures to prevent groundwater pollution so that remediation is not required.	19.3
	• Quantify impacts on groundwater dependent ecosystems (GDEs) if applicable.	16
	• Detail protective measures to minimise any impacts on GDEs.	19.3
	• Detail proposed methods for the disposal of waste water and approval from the relevant authority.	NA
	• Assess the potential for saline intrusion of the groundwater and measures to prevent such intrusion into the groundwater aquifer.	15.5
	• Detail results of any models or predictive tools used to predict groundwater drawdown, inflows to the site and impacts on affected water sources.	14
	Include an impact assessment that identifies limits to the level of impact and contingency measures that would remediate, reduce or manage potential impacts to the existing groundwater resource and any dependent groundwater environment or water users.	14
	Provide details of any proposed monitoring programs, reporting procedures including mechanism for transfer of information to Department of Industry – Crown Lands and Water (Formerly NOW).	19.3
	Ensure all proposed groundwater works, including bores for purpose of investigation, extraction, dewatering, testing, or monitoring are identified in the proposal and an appropriate approval obtained from the Office of Water prior to their installation.	Noted
	Identify any known or potential GDEs that may be impacted by the proposal and detail management and mitigation measures in accordance with the *NSW Aquifer Interference Policy* and the *NSW Groundwater Dependent Ecosystem Policy*	19

5. METHODOLOGY

The methodology employed in meeting the objectives identified in Section 1.2 and the Director General's Requirements in Section 4 included a comprehensive combination of literature review, data collection and field assessments.

Specifically the assessment comprised the following.

- Research and collation of the results of any previous geological, hydrogeological and environmental investigations within 2 km to 3 km from the boundary of the proposed extraction area.

- Examination and detailed interpretation of recent State government colour aerial photographs taken over the district, and remotely sensed data recently produced for the Proposal by Geo Spectrum (Australia Pty Ltd).
- A review of recent and historic published geological mapping of the district at various scales including 1:250000 and 1:100000. This review incorporated a review of relevant unpublished geological documents.
- A review of data and information for registered boreholes in the district held by the Department of Industry – Crown Lands and Water (CL&W).
- Establishing and assessing local and regional hydrogeological and hydrological conditions. Assessment of aquifer type, aquifer distribution, recharge estimates, groundwater recharge areas and discharge areas (springs), aquifer yields, groundwater quality, determination of groundwater hydraulic gradient and direction of groundwater flow.
- Collection of baseline water level and water quality data sets.
- Submit groundwater samples to a NATA registered laboratory for specific testing and the determination of a designed suite of analytes.
- Describe and document the surface water system on and surrounding the Site to establish the interaction between surface water and groundwater.
- Establishing existing groundwater utilisation in the local area including the location and details of any registered and possibly unregistered neighbouring bores, purposes and water entitlements.
- Establishment of a groundwater monitoring network.
- Develop a conceptual geological model and a transient groundwater computer (numerical) model.
- Assessing potential impacts of the extraction on local and regional aquifer systems, local and regional water tables, any groundwater dependent ecosystems (GDEs), groundwater chemistry and local groundwater users.
- Conducting hydraulic conductivity testing to establish indicative aquifer characteristics for the Site.
- Developing a database of standing water levels and water quality data derived from the monitoring bore network.
- Preparation of a long-term monitoring program for the Site and data logger maintenance plan to be incorporated in future Management Plans.
- Development of a protocol for in-house groundwater data management and statutory reporting.
- Recommendations including mitigation measures and contingency planning.
- Preparation of a Groundwater Impact Assessment report including results of investigations, prediction of any impacts and mitigation measures.

6. PREVIOUS HYDROGEOLOGICAL INVESTIGATIONS

It is understood that no previous hydrogeological investigations have been carried out over the Site. However, regional hydrogeological studies have been undertaken by the NSW State Government (CL&W) (formerly the NSW Office of Water (NOW)) as part of the development of groundwater management areas, in particular the development of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources.

7. LOCAL SETTING

The Site is located on the Southern Tablelands Plateau within the headwaters of several first-order watercourses located on the northern, southern and western boundary of the Site which flow west into the Long Swamp Creek system.

The highest point on the Site is in the south-eastern section at an elevation of 705 m Australian Height Datum (AHD), close to the ridge line defined by the position of the Hume Highway. The lowest part of the Site is at an elevation of approximately 620 m AHD in the northwestern section.

8. GEOLOGY

8.1 REGIONAL GEOLOGY

The Site is located in the southwestern extremity of the Sydney Basin where the upper part of the Triassic sedimentary sequence is exposed. **Figure 7** displays the regional geological setting of the Site. The region is largely underlain by Triassic-age Hawkesbury Sandstone (referred to as “Rh” on **Figure 7**) which consists of a moderately thick sequence of interbedded massive and cross-bedded (sheeted) medium to coarse grained quartz sandstone with occasional interbeds and lenses of dominantly grey shale. Interbeds of very fine to medium-grained sandstone also occur in some units. The sandstone unit has a recorded maximum thickness of approximately 80 m beneath the Site.

Regional geological mapping by State government geologists identify that the Hawkesbury Sandstone in this region generally dips to the north-northwest towards the central part of the Sydney Basin at approximately 1.0^{o} to 1.5^{o}. However, a review of available geological data on the position of the base of the Hawkesbury Sandstone in the Southern Highlands from coal exploration programs and water bore logs suggests that at least on the local scale, the sequence dips to the northeast.

The Hawkesbury Sandstone can be divided into three distinct litho-stratigraphic units that persist throughout the Sydney Basin (Lee J. and Cook L., 2005). (The upper third and basal third of the Hawkesbury Sandstone are interpreted to be predominantly ’clean’ quartz-dominant units. The middle unit is significantly more ‘silty’ and demonstrably less prospective for groundwater supplies (unless substantially fractured)).

Widely spaced vertical and sub-vertical joint sets are common in the Hawkesbury Sandstone with major parallel joints commonly about 3 m apart but these can range from 0.3 to 10.0 m. The main joint direction varies between about 90^{0} and 125^{0} (True) with a subsidiary northeasterly joint set.

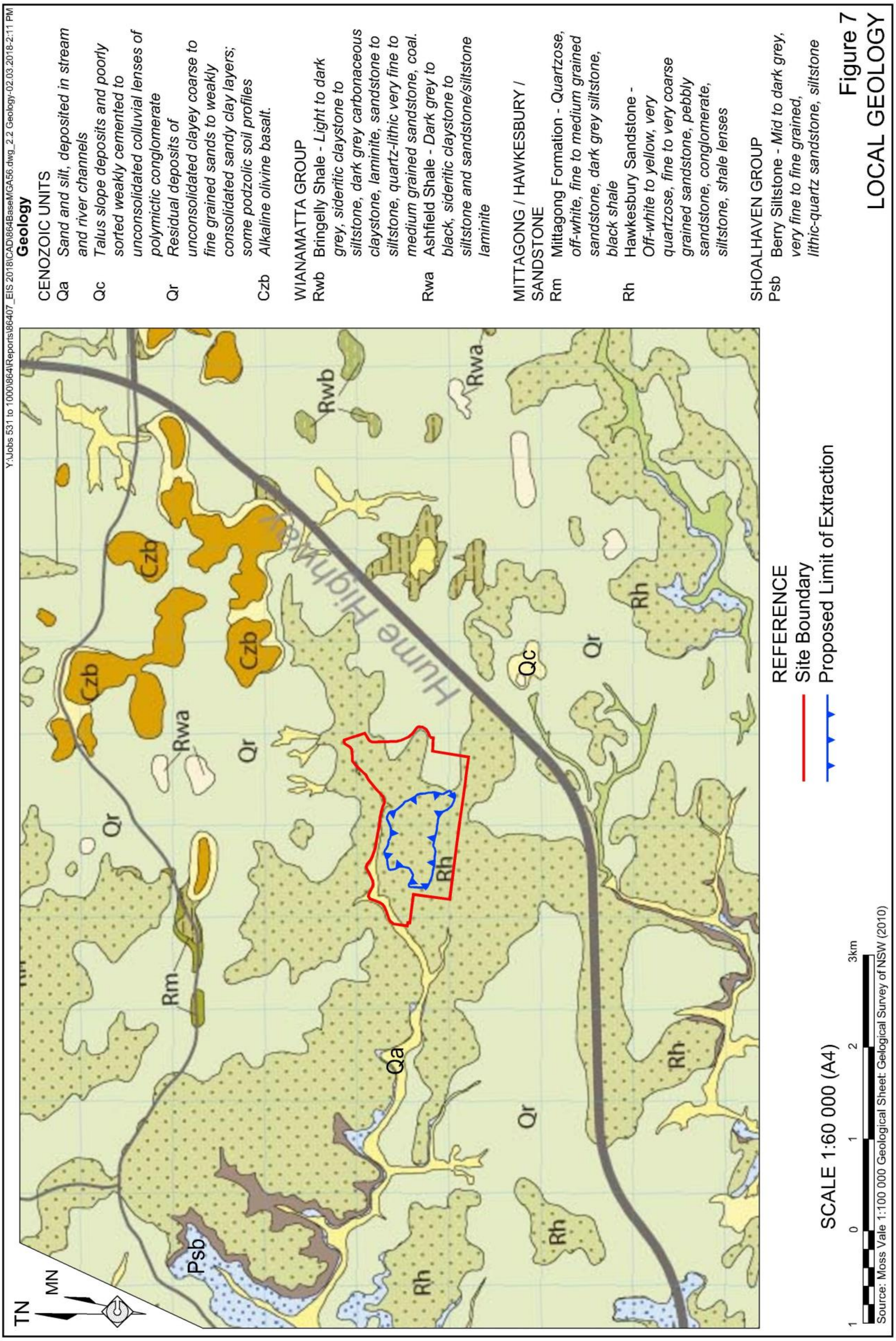


Figure 7
LOCAL GEOLOGY

Sub-horizontal bedding plane partings, and in places fractures, are also known to occur within the sandstone sequence at depths down to approximately 50 m, particularly in close proximity to deeply incised valleys. These fractures can be markedly open and are thought to be associated with stress relief due to erosion and resultant unloading of vertical stresses.

The Triassic sedimentary sequence in the southern part of the Sydney Basin is in parts intruded by Triassic basaltic igneous bodies and Jurassic-age basic to intermediate stocks, sills and dykes. Some of these intrusives are presently quarried for a range of aggregates.

Although the structural geometry of the geology of the Sutton Forest area is not fully understood, there have been several published and unpublished geoscientific investigations that have taken into consideration the imposed structural geometry in this part of the Sydney Basin.

In summary, the results of the interpretation of remotely sensed data and the results of geological research in the Sydney Basin by Larry Cook & Associates, Hydroilex and others (e.g. Mauger et al, 1984) reveals that the Hawkesbury Sandstone and underlying rocks are dissected by an ordered structural geometry of sub-vertical to vertical structural discontinuities. These secondary defects imposed on the relatively brittle rock mass have resulted in the development of a series of structural ‘blocks’ and a network of interconnecting and crosscutting joints, fractures, faults and in parts, complimentary shear sets.

In addition, there are several sub-parallel north-northeast trending synclinal and monoclinal flexures mapped in the southern part of the basin. Several of these structures are known in the Southern Highlands. Recent exploration drilling on the Site for this sand resource by Southern Tablelands Drilling and interpretation by Graham Lee & Associates (2016) suggests that a gently southern-plunging anticlinal structure may exist. This structure is discussed in Section 8.2.

8.2 LOCAL GEOLOGY

There have been three published interpretations of the district geology; Geological Survey New South Wales (1966), Mason (1995) and Geological Survey New South Wales (2010). The reader is also referred to the published 1:100,000-scale Sydney Southern Coalfield Regional Geology Map (NSW Mineral Resources, 1999). The local geology based on the state government’s mapping in 2010 is shown in **Figure 8**.

As noted in Section 8.1 and shown on **Figure 7**, the Site is underlain by relatively flat-lying to gently dipping Triassic Hawkesbury Sandstone (Rh) which unconformably overlies Permian sedimentary rocks belonging to either the Illawarra Coal Measures or the Shoalhaven Group (Psb). The Triassic Narrabeen Group sedimentary rocks (Ashfield Shale (Rwa), Bringelly Shale (Rwb) and Mittagong Formation (Rm) belonging to the Wianamatta Group) are not present in the Site area but outcrop to the east and north. Remnant outcrops of Jurassic basalt (Sutton Forest Basalt (Czb)) overlies the Wianamatta Group east and north of the Site. The thickness of the Hawkesbury Sandstone beneath the Site was estimated from interpretation of geological logs from water bore drilling, coal exploration drill holes and analysis of geophysical bore logs run in several water bores. Coffey (Coffey, 2014) collated all available geological data including in-house data and concluded that the Hawkesbury Sandstone dips to the northeast in the local area.

The interpreted thickness of the Hawkesbury Sandstone beneath the extraction area is approximately 80 m. Elevation contours of the interpreted base of the Hawkesbury Sandstone are annotated in **Figure 9**. As can be seen from **Figure 9**, the average elevation of the base of the Hawkesbury Sandstone beneath the extraction area is approximately 623 m AHD. A cross section prepared by Coffey for the numerical groundwater computer model (Coffey, 2016) shows the geology beneath the Site (**Figure 9**).

Figure 8 Local Geology
(Modified after Coffey, 2016)

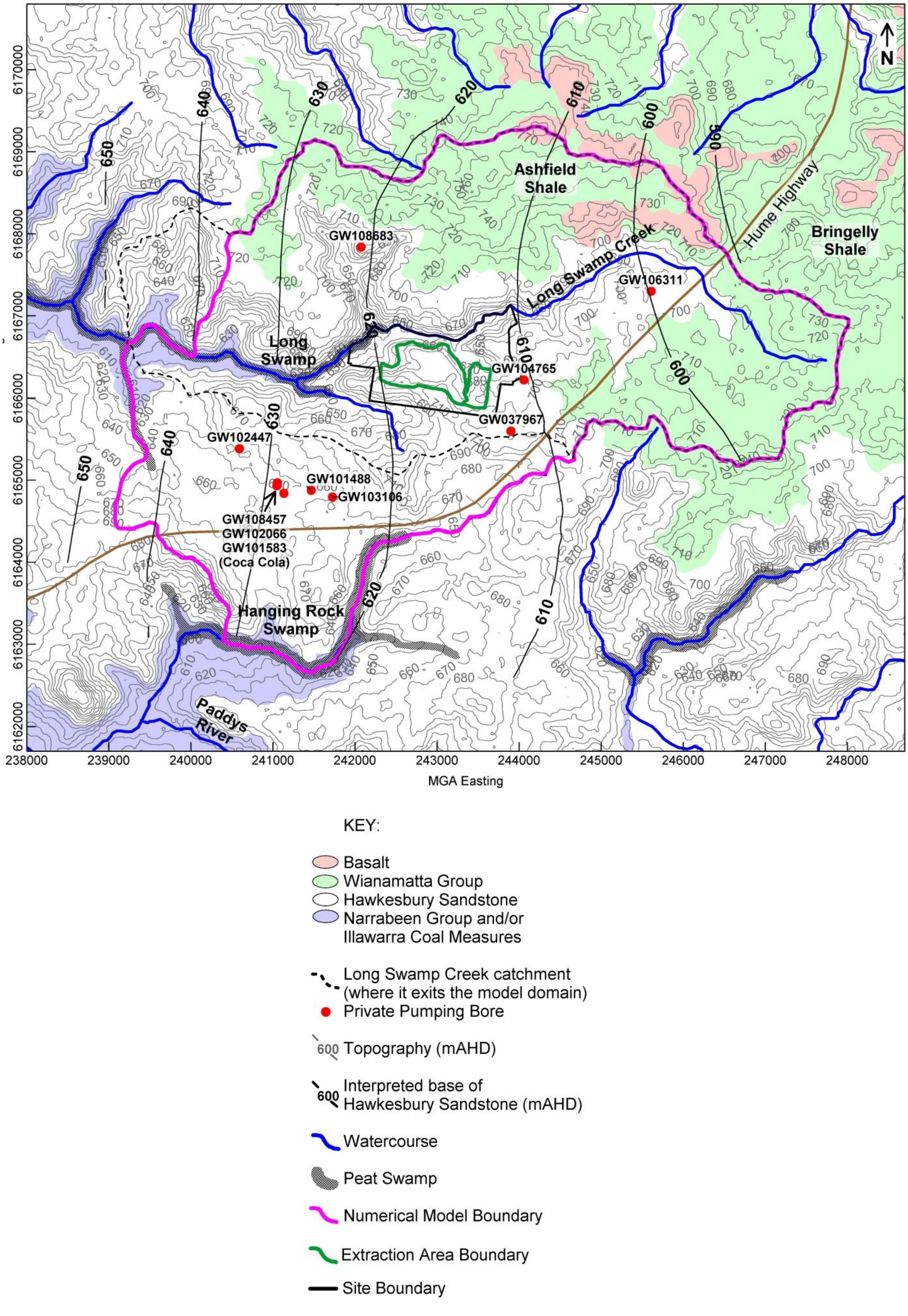
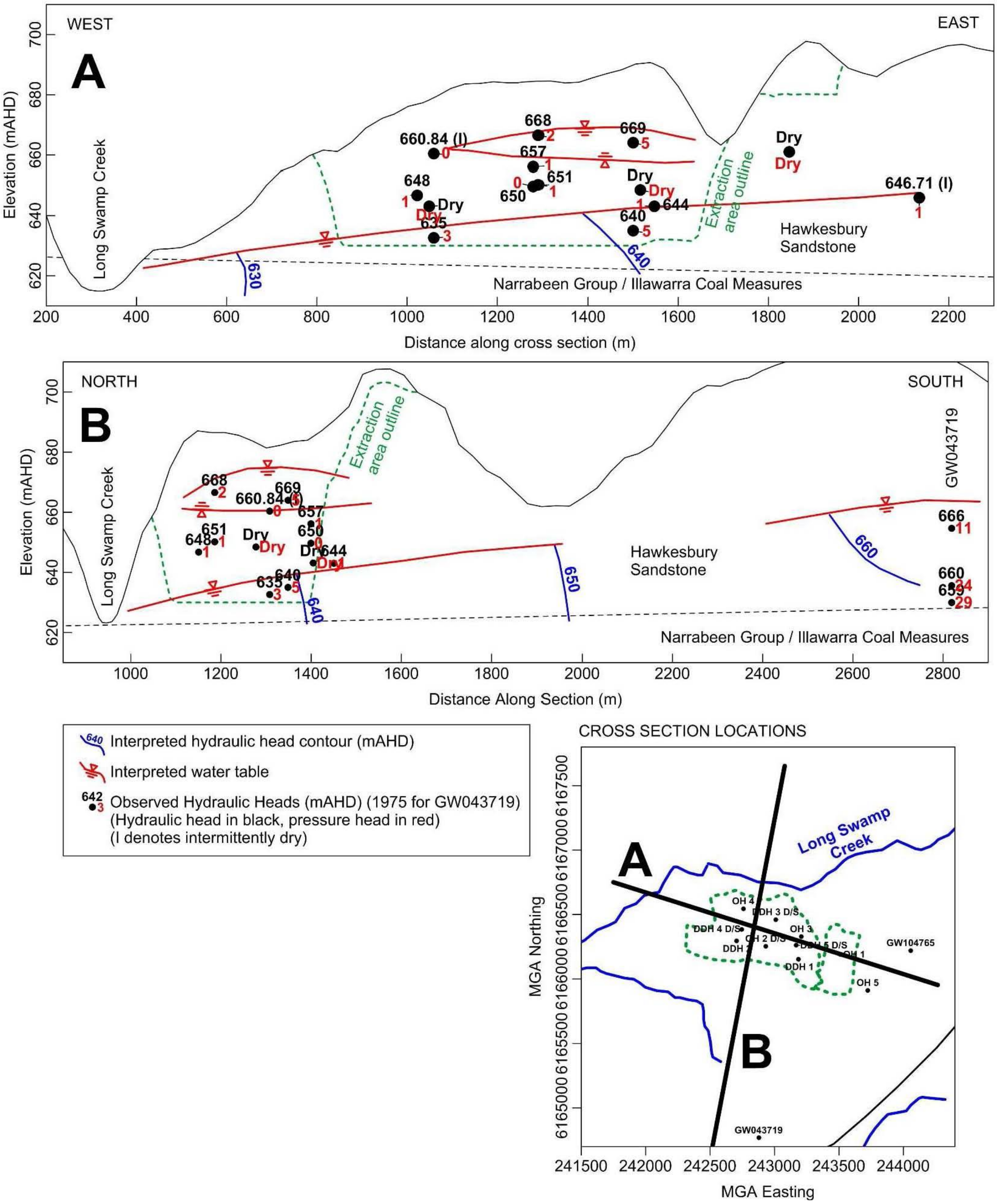


Figure 9 Cross Sections Through Local Area Showing Local Geology

(Modified after Coffey, 2016)



A network of interpreted geological faults was mapped approximately 4 km east of the Site. Interpretation of regional bore logs, geology maps and topographic maps indicates that the sedimentary sequence east of this interpreted fault line has been downthrown by about 25 m. This is consistent with the results of geological studies carried out by Larry Cook Consulting and others in the Kangaloon area (Larry Cook & Associates & Groundwater Data Collection Services 2008).

The Hawkesbury Sandstone is exposed as relatively horizontal sheet-like (shelf) outcrops across many parts of the Site. In other parts of the Site, the sandstone is covered by a relatively thin veneer of organic rich sandy loam topsoil. Soil investigations by SEEC (2018) indicate that the thickness of this layer is between approximately 0.1 and 0.2 m.

The exploration methods used in the delineation of the sandstone resource beneath the Site was a combination of diamond drilling and rotary percussion drilling designed by Graham Lee & Associates (2013). Two additional, partly cored, resource holes were drilled in early 2016. These holes were converted to monitoring bores which are documented in Section 12. It is noted that SFQ OH5 was drilled as a dedicated monitoring bore and not included in the exploration drilling. The locations of the drill holes are shown in **Figure 10**.

Diamond drilling was used to accurately map the relatively flat-lying sandstone sequence down to the base of the resources and enable representative sampling of the sandstone for resource estimation, grain size analysis and determination of quality. Selected core were also utilised for laboratory permeability testing.

In summary, the Hawkesbury Sandstone beneath the Site within the extraction area comprises a predominantly massive medium to coarse grained quartz sandstone with occasional interbeds and lenses of shale. Interbeds of very fine to medium-grained sandstone, pebbly sandstone and minor conglomeratic sandstone also occur. In detail, diamond (core) drilling in 2012 by Graham Lee & Associates revealed 'friable variously pale-coloured sands and clayey sands, and thin pale greyish coloured clay, with darker grey shale interbedded at the bottom of some of the drill holes.' (Graham Lee & Associates, 2013). The drill core and cuttings from the two holes drilled in 2016 were assessed by Graham Lee & Associates in 2016, and although the Triassic geology was reported to be similar, the base of the holes intersected the contact between the Hawkesbury Sandstone and underlying Berry Siltstone (Graham Lee & Associates, 2016).

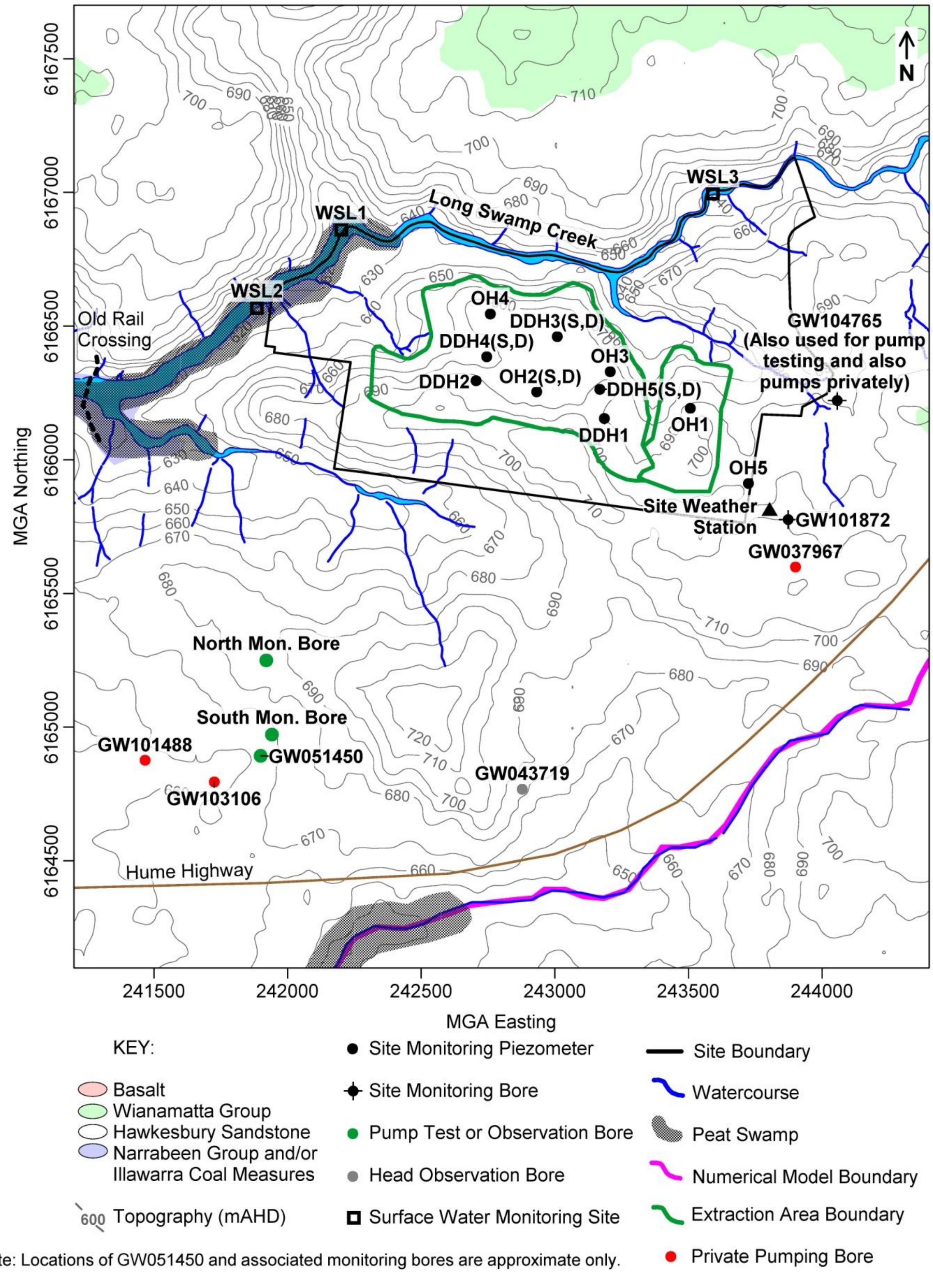
Graham Lee & Associates (2016) noted that grey shale was intersected in three of the exploration holes on the Site and in several neighbouring water bores. This information was used by Graham Lee & Associates (2016) to construct subsurface contours of the top of the shale in the local area which dips to the south 'with the axis of a gentle south plunging anticline structure located just east of the drilled area'. Graham Lee & Associates (2016) also noted that shale was not recorded in all water bores which 'may be due to either a deficiency in the bore logging, or that the shale does not occur at the site of these bores; while some of the recently completed drill holes also have not intersected the grey shale unit.'

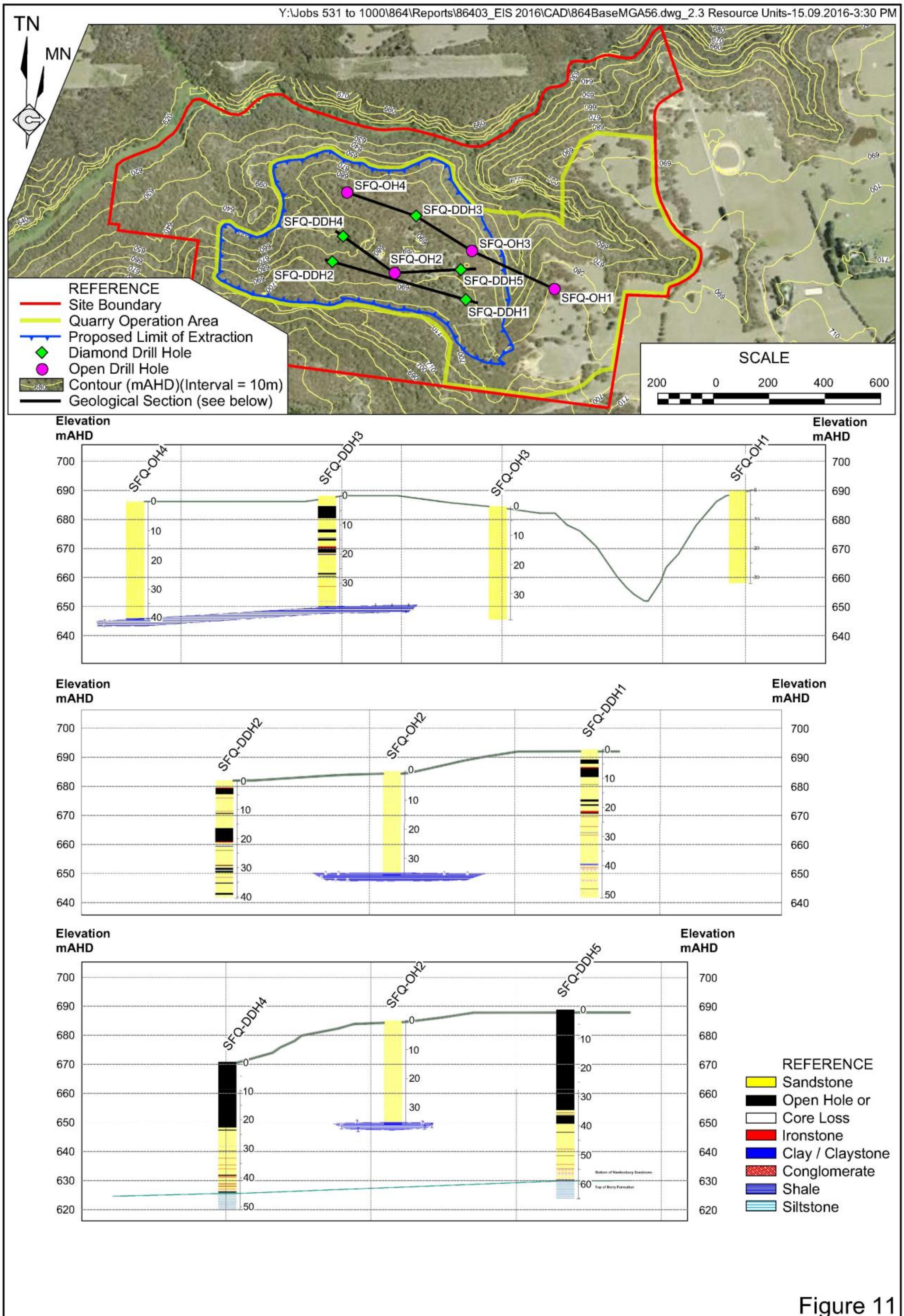
The elevations of the grey shale unit in the three drill holes that intersected the unit are shown in the cross sections prepared by Graham Lee & Associates (2016) and reproduced in **Figure 11**. The locations of the section lines AA', BB' and CC' are also shown in **Figure 11**.

As can be seen, shale was intersected in the base of drill holes SFQ-OH 2, SFQ-OH4 and SFQ-DDH 3 but not in SFQ-DDH1, SFQ-DDH2, SFQ-OH1 or SFQ-OH3. Graham Lee & Associates (2016) concluded that if the shale exists at the locations of the four drill holes that failed to intersect it, it must be deeper than the base of the holes. *'The implication is that either; the shale unit only fills the lower parts of a meandering stream or lake system, or that the surface between the shale and the sandstone is an unconformable erosion surface with significant relief in the order of 5 metres, or more. There is no evidence in the SFQ drill core to suggest that a significant unconformity exists, and thus deposition in a lake or meandering stream system possibly with billabongs, is the most likely explanation for the occurrence of this shale unit.'* Graham Lee & Associates (2016) further suggested that *'the grey shale unit fills the low areas in such a meandering stream or lake system that is surrounded along the sides by higher sand deposits forming banks that now present as a vertical continuous sandstone sequence in drill holes.'*

Graham Lee & Associates (2016) noted that drill holes SFQ-DDH4 and SFQ-DDH5 both intersected grey siltstone at their base, interpreted to be the Permian Berry Siltstone, as shown in **Figure 11**.

Figure 10 Location of Drill Holes
(Modified after Coffey, 2016)





Base Photography Source: Sixmaps (13 December 2013)
Source: G. Lee and Associates (2016) - Figures 4, 5 and 6

Figure 11
RESOURCE DRILLING RESULTS

In terms of the hydrogeological investigation and assessments, the shale unit recorded within the sandstone sequence of the extraction area can be described as an aquitard (defined as a water-bearing (saturated) layer of low permeability) hosted by the sandstone-hosted aquifer system. An aquitard cannot transmit significant quantities of water. The groundwater flow is assumed to be predominantly vertical as compared with the relatively more permeable overlying and underlying sandstone aquifers where the groundwater flow is predicted to be predominantly horizontal.

Aquitards are semi-pervious formations or leaky formations and as such, are important components of the computer groundwater model.

9. CLIMATE

No continuous temperature, evaporation and rainfall data are available for the Site. The closest official Bureau of Meteorology (BoM) station is Eling (BoM Id. 068093) which has a continuous record spanning 59 years. Other stations in the district are Sutton Forest (Uralba) (BoM Id. 68058), Sutton Forest (Cherry Tree Hill) (BoM Id. 68075) and Moss Vale (BoM Id. 68045).

An average annual rainfall of 902 mm was adopted for the Site by SEEC (2018) in their surface water assessment based on long-term rainfall data from several surrounding weather stations (SEEC, 2018). An average annual pan evaporation for the Site 1497 mm was derived from the Australian Bureau of Meteorology (BoM) gridded database dataset. The average annual potential evapotranspiration (PET) was estimated by SEEC to be approximately 1167 mm (SEEC, 2018).

10. HYDROLOGY

The description of the hydrology is largely drawn from SEEC (2018) with supplementary information from a site inspection of Long Swamp by Larry Cook Consulting and a Coffey groundwater consultant in mid-2014.

The district centred on the Site is drained by Long Swamp Creek to the north and Paddys River to the south (**Figure 8**).

An un-named second-order watercourse which discharges into Long Swamp Creek is located to the south of the proposed extraction area (SEEC 2018). Long Swamp Creek is a fourth order watercourse which lies to the north and west of the extraction area, and has a catchment of approximately 19 km^2 to a point just downstream of the extraction area (SEEC 2018). Long Swamp Creek was inspected by SEEC staff in August 2013 and March/April 2016, and observed to be flowing, however much of the flow west of the proposed extraction area was through thick reed beds (SEEC 2018). SEEC (2018) estimated the mean annual flow in Long Swamp Creek at location WSL2 (see **Figure 10**, referred to as WQL3 in SEEC 2018) (excluding baseflow) to be approximately 2 050mL/year, based on a catchment size of 19 km^2 and a runoff coefficient of 0.12.

An inspection of Long Swamp was carried out in mid July 2014 by Larry Cook Consulting and a Coffey groundwater consultant in the vicinity of an old crossing used during historic peat mining. At that time, no rainfall had been recorded in the preceding month. Long Swamp in this location was observed to be approximately 100 m wide with historically mined water-filled voids in the peat bed on either side of the crossing. The voids were observed to be connected by a watercourse channel approximately 1.0 m wide (estimated visually) running beneath the crossing. The flow velocity in the channel was broadly estimated at approximately 0.003m/sec. The geometry of the voids observed suggested that the channel, assuming a high hydraulic conductivity for the peat, would intersect a significant proportion of the baseflow through the peat bed. Therefore, the channel flow was calculated to be approximately 4.3 ML/day, assuming a channel depth of approximately 1.5 m (estimated visually).

11. HYDROGEOLOGY

11.1 SANDSTONE HOSTED AQUIFERS

Water-bearing zones (aquifers) are commonly developed within the Hawkesbury Sandstone in the Southern Highlands at different elevations down to the base of the unit, which is the contact with the underlying Permian Illawarra Coal Measures or the Shoalhaven Group. Registered bores in the Sutton Forest area extract water from aquifers hosted by the Hawkesbury Sandstone. The aquifers are known throughout the sandstone sequence but are more productive in the upper and lower thirds (Lee J. and Cook L., 2005). The central part of the Hawkesbury Sandstone, which is not present in the local area is relatively 'silty' with poor prospects of useable groundwater supplies.

Groundwater is typically acidic and 'soft' with low salinity. However, the sandstone-hosted aquifers in some, but not all areas are known to contain dissolved iron which, when oxygenated during bore pumping (drawdown) and/or exposure to the atmosphere, can cause staining problems. Manganese is also elevated in some aquifers.

Published and unpublished results of groundwater studies and investigations in the Hawkesbury Sandstone of the Southern Highlands including the Sutton Forest area indicate that aquifers hosted by the Hawkesbury Sandstone in the area of the Site are found in two main occurrences.

- Sub-horizontal relatively porous and stacked layers (beds) of sheeted sandstone with increased primary permeability (in contrast to less permeable interbedded massive 'tight' sandstone units, and shale). These primary aquifers provide the main aquifer storage and are characterised by variable yields.
- Pervasive sub-vertical, semi-continuous to continuous, rock defects such as fractures and joints with secondary 'enhanced' permeabilities. These aquifers constitute a major component of the aquifers transmissivity but only a minor component of the aquifers storage. Fracture controlled sandstone aquifers provide relatively moderate to occasionally high yields which, in some areas, can be up to between 5 and 20 times the average yield for the regional system.

The occurrence of stacked and interbedded, flat-lying massive and sheeted sandstone units indicate that semi-confined to confined hydrogeological conditions exist. The occurrence of a shale unit partly intersected in the base of drill holes SFQ DDH 3, SFQ OH 2 and SFQ OH 4 suggests that confined conditions may exist. The shale units may also cause perching of the water table in some locations.

The superimposed structural geometry of relatively low permeability sub-vertical discontinuities results in anisotropic hydrogeological conditions which can render the analysis of local and regional groundwater flow difficult. For example, sub-vertical discontinuities can be relatively 'open' and enable groundwater flow. However, some discontinuities are geotechnically 'tight' or contain clay, iron oxide and to a lesser extent carbonate mineral deposits which effectively form impermeable barriers to lateral groundwater flow.

Some of these discontinuities can be faults which can displace flat-lying porous sandstone beds (primary aquifers) thus impeding or prohibiting lateral flow of groundwater within a particular primary aquifer.

These sandstone-hosted 'hardrock' aquifers of the Hawkesbury Sandstone provide important water supplies in the Southern Highlands, with water extracted via bores. The regional hydraulic gradient and direction of groundwater flow is to the north-nothwest and parallels the gentle 1.0^0 to 1.5^0 dip to the north-northwest of the Hawkesbury Sandstone sequence. However, the direction of groundwater flow on the local scale may be influenced by the gently-plunging anticlinal flexure interpreted beneath the Site by Graham Lee & Associates (2016). In either case, the local piezometric surface is interpreted to mimic the deeply dissected local topography.

In addition, 'shallow' groundwater is found in the forms of springs, often collectively referred to as 'water features', are commonly developed in the Southern Highlands area. Springs are further discussed in Section 11.3.

11.2 AQUIFER RECHARGE

Aquifer recharge is primarily by way of excess precipitation (rainfall) in particular the water that infiltrates the vadose (unsaturated) zone and not lost through evapotranspiration.

Based on climate data and statistics from the official Bureau of Meteorology (BoM) station at Moss Vale (BoM Id. 68045, 140 years continuous data), the rainfall data indicates a range of precipitation of between approximately 643 mm and 1312 mm per annum. The median precipitation is approximately 933 mm per annum. This data is used to estimate recharge volumes for the district centred on the Site. The median precipitation differs slightly from the average annual rainfall (902 mm) used by SEEC (2018). However, the Moss Vale data includes statistics useful for estimating a range of recharge volumes.

A review of the Canyonleigh 1:25000-scale topographic sheet and knowledge of the occurrence of Hawkesbury Sandstone in the region suggest that the recharge area for sandstone-hosted aquifers in the vicinity of the Site is approximately 22 km^2.

Based on the average rainfall data, broad estimates of recharge for a 22 km^2 area were calculated using a recharge proportion of 3% (documented in the WSP). Based on a 3% recharge proportion, annual recharge is estimated at approximately 425 ML for relatively 'dry' years, approximately 865 ML for relatively 'wet' years and 615 ML for median rainfall years. However, it is noted that a reduced recharge proportion would apply to areas of Hawkesbury Sandstone presently overlain by Wianamatta Group sedimentary rocks. Based on the results of regional hydrogeological investigations, Coffey (2016) suggests a recharge proportion of 0.4 % of rainfall for sandstone overlain by the Wianamatta Group shale (Coffey, 2016). Calibration recharge rates adopted by Coffey in the numerical groundwater model approximate 3.2 % for Hawkesbury Sandstone areas to 0.4 % for areas covered by shale.

Coffey (2016) estimates that approximately one half of this recharge would provide base flow to the watercourses surrounding the Site such as Long Swamp Creek. The remainder is likely to be consumed by evapotranspiration and escarpment discharge.

The existence of elevated springs in the local area may indicate that some of this recharge percolates down to very shallow sandstone zones, possibly to the base of the weathered zone or localised shale lenses where 'perching' of shallow groundwater may occur. This water then may migrate laterally to potentially discharges at high elevation as springs.

11.3 AQUIFER DISCHARGE

Natural discharge of groundwater from the sandstone aquifer system within and surrounding the Site is mainly via springs and lateral flow to ephemeral watercourses and perennial watercourses such as the Long Swamp Creek catchment.

A series of 'water features' which are essentially areas of shallow groundwater discharge have been identified by several State government and private workers in the region (Larry Cook Consulting, 2012, Larry Cook & Associates & Groundwater Data Collection Services 2008, Coffey Geosciences, 2007). These 'water features' are in the main developed where there is a permeability contrast at the contact between more permeable sheeted sandstone overlying less permeable massive sandstone or where sheeted sandstone overlies shale units. The existence of a spring requires that below the subsurface, the infiltrating water encounters a low-permeability zone and is unable to continue to percolate downward as fast as it is supplied at the surface. As a result, the water spreads laterally until it intersects the land surface where erosion has lowered the topography to the water's level (e.g., on the side of a gully, hill or valley).

Spring discharge of local subsurface flow systems is closely related to recharge via precipitation and can show wide fluctuations in flow.

Although the discharge from these springs are believed to vary in response to seasonal and climatic factors, anecdotal evidence indicates that many are likely to be low volume permanent flows. Relatively moderate flow was recorded by Larry Cook Consulting in a spring located close to the confluence of Long Swamp Creek and the first order watercourses immediately southwest of the Proposal, approximately 1.7 km west of, and downstream of the Site on the northern-facing flank of the Long Swamp Creek Valley. This spring had been historically protected by placing a concrete pipe over the site and allowing discharge into Long Swamp Creek via a weir and pipe. A photo of the outlet is provided in **Plate 1**. The flow was recorded to be approximately 2 L/s on 28 July 2014 despite there being no rainfall in the catchment over the previous 25 days.

Plate 1 Spring Discharge – Long Swamp Creek
1.7 km west of this Quarry

Anecdotal evidence also suggested the occurrence of a ‘small’ spring feature at the head of the water storage dam on the “Bridgewater” property near the Site. The dam is in close proximity to the watershed in this area. However, a site inspection did not reveal any direct evidence of this spring.

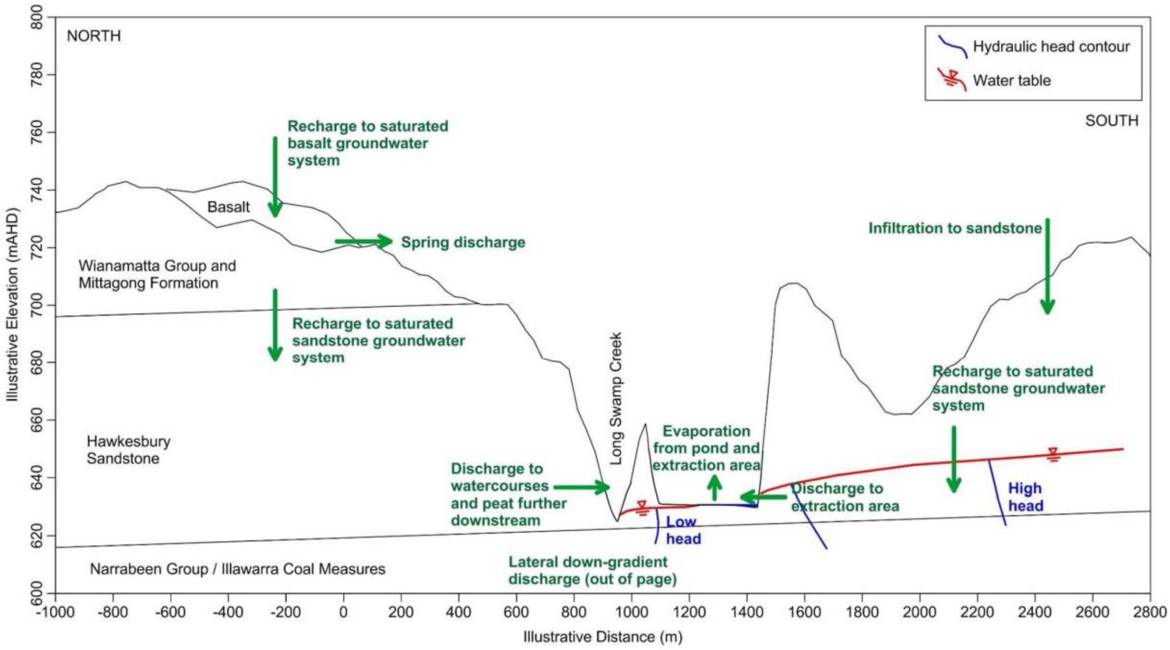
This hydrogeological investigation has identified elevation-controlled springs that discharge into the Long Swamp Creek valley system west, and downstream of the Site. However, the occurrence of flat-lying sandstone and steeply dissected valley topography along the Long Swamp Creek valley system bordering the Site to the north suggest that a multitude of elevation-controlled springs may exist but are difficult to locate due to debris covering the slopes and inaccessible country.

The apparent elevation control of these springs is believed to be associated with the base of the sheeted sandstone beds of the Hawkesbury Sandstone sequence.

The importance of spring systems is that they can support GDEs which are often established at these groundwater discharge points and are commonly referred to as ‘hanging swamps’. A schematic cross section developed through the flat-lying Hawkesbury Sandstone sequence for the numerical computer model by Coffey (2016) showing the relationship between the sedimentary rock sequence, springs and GDEs is shown in **Figure 12**.

Figure 12 Hydrogeological Conceptual Model

(after Coffey, 2016)



11.4 GROUNDWATER-SURFACE WATER INTERACTION

All surface water and groundwater initially originates from rainfall. With the exception of the duration of a rainfall event and immediately following, the majority of surface water in watercourses is sourced from the release of groundwater from the groundwater system, commonly referred to as base flow.

The results of the hydrogeological investigations for the district centred on the Proposal and results of the SEEC (2018) surface water assessment indicates that watercourses within the local area can be classified as either ephemeral, intermittent or perennial. The first order watercourses close to the Proposal are considered to be ephemeral. That is, apart from periods of rainfall, they are relatively dry and only flow in response to runoff. Some watercourses will flow during only part of the year when base flow runoff triggers flow conditions that are sustained for a longer period due to the water table being sufficiently high to intersect the stream bed thus providing the watercourse with hydraulic support. The larger watercourses such as Long Swamp Creek are permanent watercourses (perennial) as they receive year-round base flow from groundwater.

The ephemeral watercourses in this setting are losing / disconnected watercourses where the flow decreases in a downstream direction due to infiltration through the channel bed which recharges surrounding sandstone hosted aquifers as the local potentiometric surface is at a lower elevation than the stream bed of the watercourse. The higher order watercourses in the area such as Long Swamp Creek are considered to be gaining systems where groundwater continually enters into the stream as the stream bed is at a lower elevation than the local potentiometric surface.

Hydrologic conditions are dynamic, and watercourses may temporarily change from being ‘gaining’ to ‘losing’ systems. Equally, watercourses can be ‘gaining watercourses’ along one segment of their length and ‘losing’ watercourses’ along another part depending on their relationship to the water table at those points.

11.5 AQUIFER PROPERTIES

11.5.1 Hydraulic Conductivity

The hydraulic conductivity of sandstone without major structural deformation generally varies from around 0.1 m/day at the surface to around 0.003 m/day at a depth of 100 m (Coffey, 2016). This is typical for brittle fractured sedimentary rocks which are subject to large variations in the in-situ stress field due to their developed landforms (cliff lines and steep topography) and has been observed in the hydraulic conductivity of Triassic Hawkesbury sandstones - in the northern Sydney metropolitan area (Tammetta and Hewitt, 2004).

Structural deformation generally increases sandstone permeability and may impart a higher ratio of vertical to horizontal hydraulic conductivity when deformation is largely along sub-vertical features. Coffey (2016) re-analysed pump test data from a local bore (GW051450) and concluded that lateral anisotropy occurs within the sandstone sequence associated with north-northwest and east-southeast sub-vertical geological defects which are, according to Coffey common in the southwestern margins of the Sydney Basin. A horizontal hydraulic conductivity (Kh) of 0.68 m/day was estimated from the pumping test which, according to Coffey (2016) corresponds to moderately structurally disturbed areas at Kangaloon.

11.5.2 Specific Yield

Specific yield for the Hawkesbury Sandstone is an important storage parameter. For the purposes of steady state modelling, storage parameters are not required, however for the purposes of conceptual model development, Coffey (2016) note that the specific yield will depend upon the following.

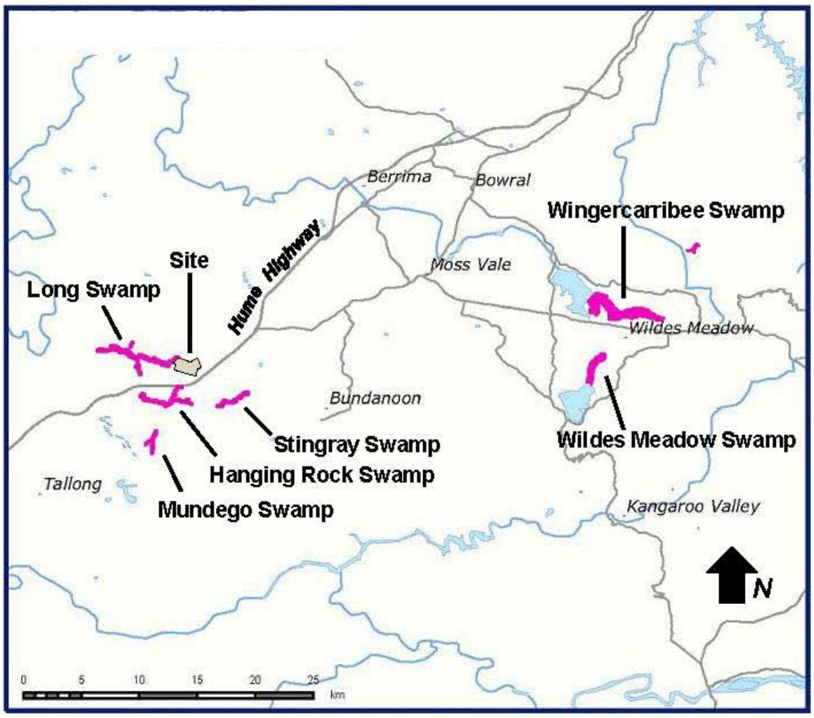
- Primary (matrix) interconnected void space. The specific yield of the matrix heavily depends on its pore size distribution and the degree to which these pores are able to drain freely under gravity.
- Secondary (defect) interconnected void space. The specific yield of defects (hydraulically linked fractures, joints, and other partings) can be as high as 95% of the defect volume depending on defect aperture size (and the influence of capillary forces) and defect intersection.

Studies conducted in the Sydney metropolitan area and elsewhere by Tammetta and Hewitt (2004) suggests a specific yield of between 0.010 and 0.015 as reasonable for typical, undeformed Hawkesbury Sandstone. The primary (matrix) porosity presented by Tammetta and Hewitt (2004) varied between 0.10 and 0.20 however cementation generally reduces the interconnected void space formed by these pores to virtually nil, with the specific yield of the secondary void space being the dominant factor.

11.6 GROUNDWATER DEPENDENT ECOSYSTEMS

A number of high priority GDEs have been identified by State government mapping in the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources. In the Southern Highlands, a set of Temperate Highland Peat Swamps are developed on sandstone. The locations of the peat swamps in the Southern Highlands are shown in **Figure 13**. These GDEs are known in the area surrounding the Site and are collectively labelled the Paddys River Swamps which include Hanging Rock, Long Swamp, Mundego and Stingray Swamps (**Figure 13**).

Figure 13 Indicative Locations of Temperate Highland Peat Swamps (after DEH, 2004)



The Temperate Highland Peat Swamps in the Southern Highlands are developed on sandstone at elevation of between approximately 600 and 700 m AHD with water supply sourced from runoff and spring discharge. The swamps share similar vegetation; Sphagnum bogs and fens occupy the wetter parts while sedge and shrub associations occur in the drier parts of the swamps. The Paddys River Swamps occur in natural depressions or along watercourses such as Long Swamp which is located to the north and west of the Proposal. Hanging Rock Swamp is located further to the south. The location of Long Swamp is shown in **Figures 10 and 13**. Photos of Long Swamp taken downstream of the confluence between Long Swamp Creek and a first order tributary southwest of the Proposal are shown in **Plates 2** and **3**. Anecdotal evidence indicates that the open pond area in the foreground of **Plates 2 and 3** are a consequence of historic peat extraction.

Plate 2 Long Swamp (looking upstream)

Plate 3 Long Swamp (looking downstream)

Coffey carried out studies in the Wingecarribee Swamp approximately 37 km to the northeast of the Site in 2007 (Coffey, 2007). Coffey (2007) concluded that spring discharge from adjacent basaltic terrain was a significant component of the water balance for that swamp. Equally, discharge from beneath the remnant basalt occurrences north of the Site and Long Swamp Creek is also believed to contribute significant volumes of water to Long Swamp Creek. Coffey notes in the groundwater model report (Coffey, 2016) that rainfall recharge to basalt can exceed 10% of annual rainfall with greater than 5% potentially reporting to baseflow.

In April 2005, the Paddys River Swamps (including Long Swamp) were listed as endangered ecological communities under Section 181 of the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). Other swamps in the region shown in **Figure 13** (Wildes Meadow Swamp and Wingecarribee Swamp) were also included.

The NSW State Groundwater Dependent Ecosystems Policy (NSW Government 2002) identifies four types of GDEs which are supported by five broad types of aquifers. The dominant type of GDE identified near the Site is Terrestrial Vegetation which is 'supported by shallow groundwater either permanently or seasonally'. The dominant type of groundwater system is 'Sedimentary Rock Groundwater Systems' described as 'sedimentary rock aquifers include sandstone shale and coal'. The setting for this type of GDE (Peat Swamp), in particular Long Swamp is shown in a cross section constructed by Coffey (2016) through Long Swamp Creek north of the Site (**Figure 12**).

11.7 GROUNDWATER AVAILABILITY AND UTILISATION

A district search for data and information for registered boreholes held by CL&W (formerly the New South Wales Office of Water (NOW)) in their computerised database revealed the existence of 43 registered bores within a 24 km^2 search area centred on the extraction area. The area was selected to cover areas of potential impacts from the Proposal operations on neighbouring water users. The locations of the registered bores including those on the Site are shown in **Figure 14**.

It is noted that the data and information for the registered bores documented in this groundwater impact assessment is that acquired from the CL&W computerised database and the NSW Water Register in February 2018. The NSW Register provides public access to information about water licences, approvals, water trading, water dealings, environmental water and other matters related to water entitlements in NSW..

The NSW Water Register is complemented by the Water Access Licence Register maintained by Land and Property Information, which provides more detailed information about every water access licence in NSW.

Consultation with CL&W officers in the Parramatta office on 28th February 2018 revealed that a new state government bore database is in development. Although the data and information contained within this assessment is that currently available on-line, data and information for any recently drilled bores and details for any new approvals or license upgrades may not be presently available.

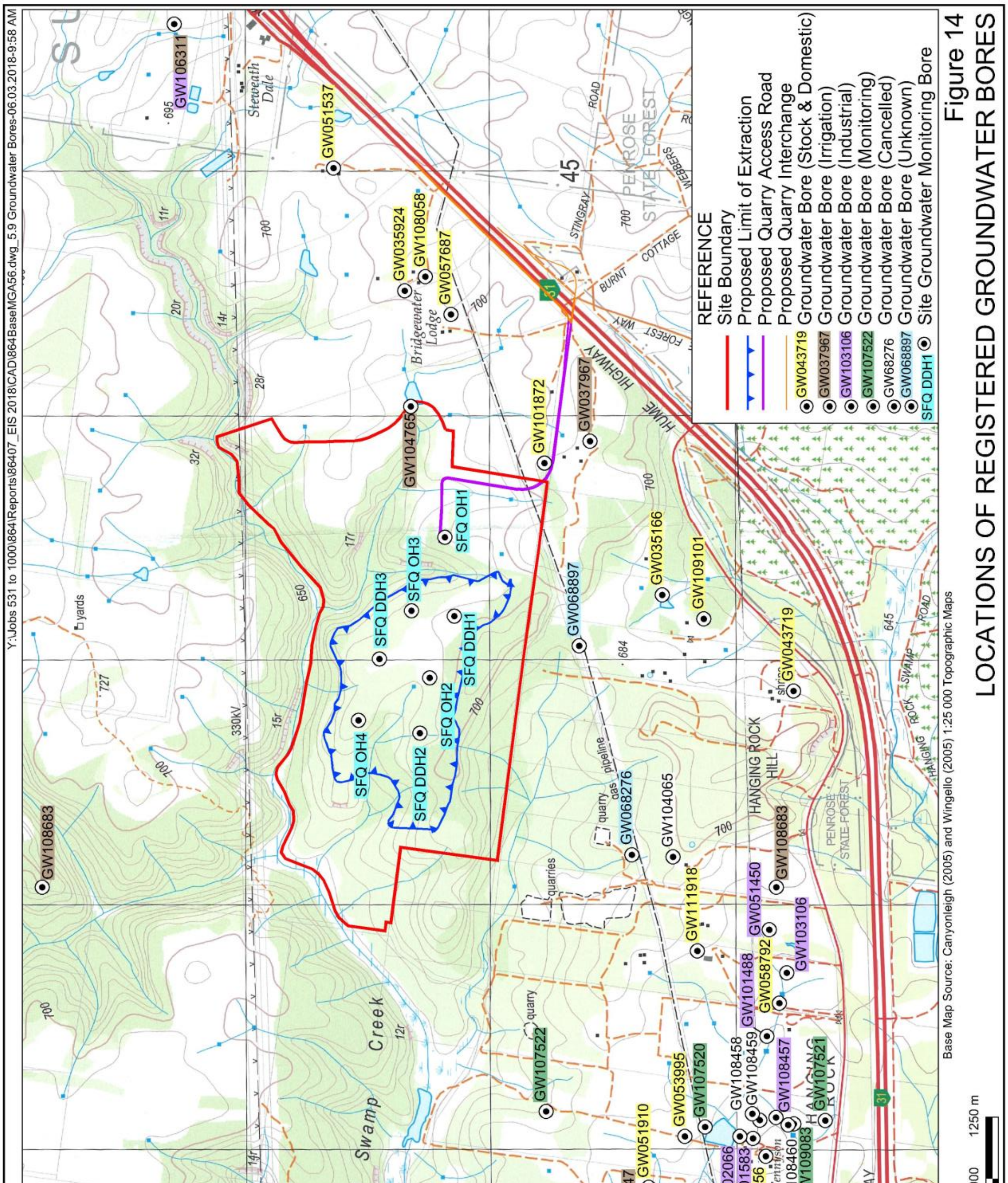


Figure 14
LOCATIONS OF REGISTERED GROUNDWATER BORES

A summary of bore details and information is presented in **Table 4**.

Table 4
Summary Details of Registered Bores

Page 1 of 4

Bore, Approval, Licence	Authorised Purpose	Coordinates (m MGA Zone 56) E	N	Depth (m)	Date Drilled	Aquifers/ Yield	Water Level (m)	Water Quality	Bore Geology
GW034229 10BL027185 Cancelled	Domestic	239655	6165141	16.8	Dec 71	14.6 (1 52 L/s)	6.1	Fresh	0.0 – 0.3 Soil 0.3 – 5.2 Clay 5.2 – 16.8 S/S
GW035166 10WA109728 Basic Rights 1.7.11 - Current	Stock & Domestic	243271	6165304	65.2	Mar 73	56.0 - 65.1 (1 L/s)	40.8	nil	0.0 - 1.4 Soil 1.4 - 52.4 S/S 52.4 - 52.9 Sh 52.9 - 56.1 Bas 56.1 - 65.2 S/S
GW035924 10WA109734 Basic Rights 1.7.11 - Current	Stock & Domestic	244516	6166356	76.2	Jun 73	45.7 - 46.0 (0.1 L/s) 67.0 - 69.4 (0.5 L/s) 70.1 - 76.1 (1.0 L/s)	42.6 60.9 60.9	nil	0.0-1.1 Soil 1.1 – 59.4 S/S 59.4 - 62.5 Sh 62.5 - 76.2 S/S
GW037967 10CA111648 10AL111647 WAL25020 1/7/11 -30/6/21 Current	Irrigation Share Component (19 ML)	243900	6165599	83.8	Nov 73	39.0 - 39.3 (0.3 L/s) 65.5 - 68.0 (0.5 L/s) 81.6 - 82.8 (1.2 L/s)	30.4 54.8 60.9	nil	0.0 - 1.8 Sand 1.8 - 83.8 S/S
GW038812 10BL029675	Stock	240140	6164198	30.7	Dec 73	nil	nil	nil	nil
GW043719 10WA110628 Basic Rights 1.7.11 - Current	Stock & Domestic	242878	6164768	54.8	Mar 75	28.9 - 29.5 (0.9 L/s) 48.1 - 48.4 (0.9 L/s) 53.9 - 53.9 (1.3 L/s)	18.2 24.3 24.6	nil	0.0 - 1.2 Soil 1.2 - 38.4 S/S 38.4 - 40.2 Sh 40.2 - 54.6 S/S 54.6 54.9 Sh
GW044710 10BL103914	Stock & Domestic	239759	6165082	19.8	Jan 76	7.6 - 14.6 (3.1 L/s) 15.2 – 19.8 (5.8 L/s)	2.7	nil	0.0 – 0.6 Soil 0.6 – 1.5 Sand 1.5 – 19.8S/S
GW051450 10CA118812 10AL118819 WAL36525 20.11.13- 19.11.23 Current	Industrial Share Component (35ML)	241901	6164866	54.0	Oct 80	25.0 - 40.0 (2.0 L/s)	12.0	nil	0.0 - 40.0 S/S 40.0 - 54.0 Sh
GW051537 10WA109798 Basic Rights 1.7.11 - Current	Stock & Domestic	245018	6166647	92.0	Oct 80	49.0 - 53.0 (0.5 L/s) 61.0 - 67.0 (0.8 L/s) 80.0 - 85.0 (1.8 L/s)	 41.2	Fair	0.0 - 19.0 Sand 19.0 - 21.0 Sh 21.0 - 92.0 S/S
GW051910 10WA109804 Basic Rights 1.7.11 - Current	Stock & Domestic	240847	6165359	31.0	Oct 80	16.8 - 18.0 (1.5 L/s) 21.4 - 23.0 (3.5 L/s) 24.4 - 26.0 (4.0 L/s)	 4.0	Good	0.0 -2.0 Silt 2.0 - 26.0 S/S 26.0 - 31.0 Sh
GW053995 10WA111429 Basic Rights 1.7.11 - Current	Stock & Domestic	214055	6165211	30.5	Nov 82	6.7 - 7.0 (0.2 L/s) 23.2 - 23.5 (1.1 L/s)	4.3 4.3	nil	0.0 - 0.3 Soil 0.3 - 30.5 S/S

Table 4 (Cont'd)
Summary Details of Registered Bores

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Bore, Approval, Licence	Authorised Purpose	Coordinates (m MGA Zone 56) E	N	Depth (m)	Date Drilled	Aquifers/ Yield	Water Level (m)	Water Quality	Bore Geology
GW054877 10BL118278 Current	Stock & Domestic	240255	6164664	38.0	Oct 81	23.0 – 38.0 (1.5 L/s)	16.5	Fair	0.0 – 0.6 Soil 0.6 – 38.0 S/S
GW057687 10WA109879 Basic Rights 1.7.11 - Current	Stock & Domestic	244419	6166168	90.0	Mar 83	46.0 - 47.0 (0.6 L/s) 64.0 - 66.0 (0.1 L/s))	46.0 46.0	Good	0.0 - 7.0 Soil 7.0 - 64.0 S/S 64.0 - 70.0 Sh 70.0 - 90.0 S/S
GW058792 10WA109873 Basic Rights 1.7.11 - Current	Stock & Domestic	241061	6164825	33.5	Cct 81	nil	nil	nil	nil
GW068276 Unknown	No data/ information	242208	6165428	68.6	Dec 82	nil	nil	nil	nil
GW068897 Unknown	No data/ information	243063	6165644	61.0	Aug 80	0.0 - 30.5 (0.1 L/s) 30.5 - 61.0 (0.6 L/s)	20.0 20.0	Good	nil
GW101488 10WA112184 10AL112183 WAL24897 1.7.11 – 30.5.26 Current	Industrial Share Component (20 ML) Condition 3: ≤ 1.5 L/s	241466	6164876	23.0	Feb 98	10.0 - 11.0 (0.1 L/s) 15.0 - 18.0 (1.7 L/s) 19.0 - 20.0 (1.1 L/s)	7.0 7.0 7.0	300 µS/cm 300 µS/cm 300 µS/cm	0.0 - 0.5 Soil 0.5 - 23.0 S/S
GW101583 10CA111798 10AL111797 WAL24997 1.7.11 - 12.7.24 Current	Industrial Share Component 120 ML incorporates GW 102066 & GW108457 Condition 3: ≤ 1.0 L/s	241047	6164933	34.0	Dec 94	33.0 - 34.0 (1.3 L/s)	7.5	nil	0.0 - 0.4 Soil 0.4 - 34.0 S/S
GW101872 10WA110379 Basic Rights 1.7.11 - Current	Stock & Domestic	243873	6165776	204.0	Feb 96	71.0 - 72.0 (0.3 L/s) 89.0 - 90.0 (0.3 L/s)	63.0	4 ?	0.0 - 28.0 S/S 28.0 - 28.5 Clay 28.5 - 32.5 S/S 32.5 - 33.0 Clay 33.0 - 96.0 S/S 96.0 - 204 Silt
GW101926 10WA112232 10AL112231 WAL24810 1.7.11-30.6.24 Current	Industrial Share Component (40ML)	240062	6164991	33.1	May 96	23.6 – 24.0 (1.4 L/s) 29.0 – 30.0 (3.6 L/s)	13.2	3 mg/L	0.0 – 1.0 Soil 1.0 – 33.0 S/S 33.0 – 33.1 Coal
GW102066 10CA111798 10AL111797 WAL24997 1.7.11 -12.7.24 Current	Industrial Share Component 120 ML incorporates GW 101583 & GW108457 Condition 3: ≤ 1.0 L/s	241055	6164967	34.0	Dec 94	26.0 - 27.0 (2.5 L/s)	7.1	nil	0.0 - 3.0 Soil 3.0 - 34.0 S/S

Table 4 (Cont'd)
Summary Details of Registered Bores

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Bore, Approval, Licence	Authorised Purpose	Coordinates (m MGA Zone 56)		Depth (m)	Date Drilled	Aquifers/ Yield	Water Level (m)	Water Quality	Bore Geology
		E	N						
GW102447 10CA111912 10AL111911 WAL25041 1.7.11 26.1.25 Current	Industrial, Irrigation Recreation Share Component 60 ML	240591	6165383	36.5	Jan 07	nil (7.5 L/s ?)	24.4	nil	nil
GW103106 10WA111868 10AL111867 WAL24832 1.7.11–26.7.24 Current	Industrial, Domestic Share Component 63 ML	241725	6164795	37.0	Aug 00	22.0 - 23.0 (0.5 L/s) 27.0 - 28.0 (1.0 L/s)	26.7	nil	0.0 - 31.0 S/S 31.0 - 37.0 Silt
GW104065 10BL163357 Cancelled	No data/ information	242199	6165260	60.0	Jan 96	nil	nil	nil	nil
GW104765 10CA112020 10AL112019 WAL25051 1.7.11–30.6.24 Current	Irrigation Share Component 45 ML Condition 3: ≤ 2.0 L/s	244057	6166221	108.0	May 03	53.0 - 54.0 (2.0 L/s)	41.6	nil	0.0 - 6.0 Fill 6.0 - 30.0 S/S 30.0 - 36.0 Sh 36.0 - 78.0 S/S 78.0 - 108.0 Silt
GW106311 10CA112054 10AL112053 WAL25052 1.7.11–20.9.24 Current	Irrigation, Industrial Share Component 30 ML	245608	6167299	91.0	Sep 04	34.0 - 35.0 (0.3 L/s) 43.0 - 44.0 (0.6 L/s) 59.0 - 60.0 (1.4 L/s) 84.0 - 85.0 (2.8 L/s)	34.0	80 µS/cm 57 µS/cm 70 µS/cm 28 µS/cm	0.0 - 36.0 S/S 36.0 - 38.0 Sh 38.0 - 91.0 S/S
GW107520 10BL162358 N/A to WSP	Monitoring	241094	6165129	15.0	Aug 06	nil	12.5	nil	0.0 - 15.0 S/S
GW107521 10BL162358 N/A to WSP	Monitoring	241120	6164637	35.0	Aug 06	29.0 - 29.5 (0.3 L/s)	16.5	nil	0.0 - 34.2 S/S 34.2 - 35.0 Silt
GW107522 10BL162358 N/A to WSP	Monitoring	241158	6165779	42.0	Aug 06	nil	30.4	nil	0.0 - 1.5 Sand 1.5 - 42.0 S/S
GW107556 10WA110642 Basic Rights 1.7.11 - Current	Stock & Domestic	240974	6164881	nil	Oct 06	nil	nil	nil	nil
GW108058 10WA111342 Basic Rights 1.7.11 - Current	Stock & Domestic	244574	6166272	102.0	Aug 06	68.0 - 72.0 (0.1 L/s) 72.0 - 78.0 (0.2 L/s) 80.0 - 84.0 (1.0 L/s)	62.8	nil	0.0 - 3.0 Soil 3.0 - 94.0 S/S 94.0 - 102.0 Silt

Table 4 (Cont'd)
Summary Details of Registered Bores

Page 4 of 4

Bore, Approval, Licence	Authorised Purpose	Coordinates (m MGA Zone 56)		Depth (m)	Date Drilled	Aquifers/ Yield	Water Level (m)	Water Quality	Bore Geology
		E	N						
GW108457 10CA111798 10AL111797 WAL24997 1.7.11–12.7.24 Current	Industrial Share Component 120 ML incorporates GW 102066 & GW108457	241133	6164839	31.5	Nov 07	20.0 - 21.0 (0.4 L/s) 23.0 - 30.0 (1.3 L/s)	16.5	35 µS/cm 32 µS/cm	0.0 - 2.5 Sand 2.5 - 31.5 S/S
GW108458 10BL602044 Cancelled	Test	241148	6164936	31.5	Nov 07	17.0 - 18.0 (0.4 L/s) 20.0 - 26.0 (0.3 L/s)	11.0	nil	0.0 - 1.0 Sand 1.0 - 31.5 S/S
GW108459 10BL602044 Cancelled	Test	241122	6164905	32.5	Nov 07	19.0 - 20.0 (0.4 L/s) 21.0 - 28.0 (0.3 L/s)	15.5	nil	0.0 - 1.5 Sand 1.5 - 32.5 S/S
GW108460 10BL602044 Cancelled	Test	241102	6164789	32.0	Nov 07	21.0 - 29.0 (0.4 L/s)	17.0	nil	0.0 - 1.5 Sand 1.5 - 32.0 S/S
GW108683 10CA112082 10AL112081 WAL25055 1.7.11–30.6.24 Current	Irrigation Share Component 25 ML	242075	6167838	114.0	Mar 08	26.0 - 27.0 (0.1 L/s) 62.0 - 63.0 (0.2 L/s)	50.0 50.0	nil	0.0 - 114.0 S/S
GW109083 10BL602204 N/A to WSP	Monitoring	241106	6164766	32.0	Jul 08	21.0 - 29.0 (0.4 L/s)	17.0	31 µS/cm	0.0 - 1.5 Sand 1.5 - 32.0 S/S
GW109101 10WA111020 Basic Rights 1.7.11 - Current	Stock & Domestic	243173	6165134	110.0	Jul 08	nil (1.5 L/s)	25.0	27 µS/cm	nil
GW109785 10BL601957	Monitoring	240017	6165241	29.0	Jul 07	nil	22.1	58 mg/L	0.0 - 29.0 S/S
GW109786 10BL601957	Monitoring	239964	6164905	24.0	Jul 07	nil	19.2	57 mg/L	0.0 – 9.5 S/S
GW109787 10BL601957	Monitoring	240114	6164864	24.0	Jul 07	nil	22.5	70 mg/L	0.0 – 24.0 S/S
GW109788 10BL601957	Monitoring	240043	6164557	32.0	Jul 07	nil	22.0	78 mg/L	0.0 – 4.5 Clay 4.5 – 32.0 S/S
GW111918 10WA110488 Basic Rights 1.7.11 - Current	Stock & Domestic	241814	6165160	54.0	Aug 98	46.0 - 47.0 (0.8 L/s)	13.0	nil	0.0 - 0.5 Sand 0.5 - 51.0 S/S 51.0 - 54.0 Silt

Kind of Approval for production Bores: Water Supply Works and Water Use
Work Type: Extraction Works Groundwater
Groundwater Management Zone: Nepean Management Zone 1

Notes:

S/S	sandstone	µS/cm	microsiemens per centimetre
Silt	siltstone	L/s	Litres per second
Sh	shale	N/A to WSP	Not subject to Water Sharing Plan
		Cancelled	Not converted to WAL. No longer valid

A summary breakdown of the authorised purposes and status of the 43 bores is provided in **Table 5**.

Table 5
Summary of Authorised Purposes

Authorised Purpose	Bores
Stock and Domestic (basic rights)	16
Industrial (Mineral Water Extraction)	6
Domestic and Industrial	1
Industrial and Irrigation	2
Irrigation	3
Monitoring	8
Unknown	2
Cancelled	5
Total	**43**

The majority of registered bores intersect aquifers at various elevations within the Hawkesbury Sandstone. The bores were drilled to depths of between 23 m and 204 m with five of these bores drilled to depths greater than 100m. The main use of the groundwater is stock and domestic under basic rights licences. A total of 10 bores are licensed for industrial and/or irrigation with water entitlements ranging from 19 ML to 120 ML. The majority of the 'high volume' groundwater extraction licences within the search area are attached to properties adjacent to Hanging Rock Road on the southern side of the Long Swamp Creek system greater than 1.5 km from the Site and down the hydraulic gradient.

Three high volume access licences are located up this hydraulic gradient from the Site (GW104765, GW106311 and GW037967). GW104765 is located on the Site with an annual share component of 45 ML held for the purpose of irrigation. The conditions on the licence include a restriction on the pumping rate of ≤ 2 L/s. This bore may be used as a supplementary water supply for the Proposal subject to State government approval and a successful application to change the purpose from 'irrigation' to 'industrial'.

The register of bores also includes eight bores located to the southwest of the Site for the purpose of monitoring which are not subject to the WSP. These bores are dedicated monitoring bores and were required by the state government to monitor water levels and water quality in close proximity to Coca Cola Amatil's production bores and the production bore in Lot 2 DP 240164 (GW101926). Any data acquired in these bores is proprietary and not publicly available.

Recorded aggregate aquifer yields ranged from 0.3 to greater than 2.0 L/s with a median yield of less than 1.0 L/s. The highest yields were recorded in Bores GW051090 (4.0 L/s) and GW102447 (7.5 L/s). Water levels recorded in the bores range from 4.0 to 62.8 m below ground level. This indicates that the hardrock aquifers are anisotropic, confined or semi-confined and under pressure.

The available water quality records were noted from the driller's 'taste tests' during drilling and a small number of field tests. The records reveal that the groundwater quality from the sandstone-hosted aquifers encountered is 'good' or 'fresh' or less than approximately 80 µS/cm. This indicates low salinity.

11.8 REGISTERED PUMPING BORES

As detailed in Section 11.7, a total of 12 pumping bores with irrigation and industrial share components were identified from the 43 registered bores. Details of these bores including property information are provided in **Table 6**.

Table 6
Summary Details of Pumping Bores with Irrigation and Industrial Share Components

Page 1 of 2

Bore, Approval, Licence	Authorised Purpose	Coordinates (m MGA)		Property	Ground Elevation (m AHD)	Approximate Distance from Proposed Quarry (m)	Depth (m BGL)
		E	N				
GW037967 10CA111648 10AL111647 WAL25020 1/7/11 -30/6/21 Current	Irrigation Share Component (19 ML)	243900	6165599	Danellan	720	600	83.8
GW051450 10CA118812 10WA109817 10AL118819 WAL36525 20.11.13-19.11.23 Current	Irrigation Share Component 35 ML	241888	6164865	Springwood	664	1,450	54.0 (backfilled to 39 m)
GW101488 10WA112184 10AL112183 WAL24897 1.7.11 – 30.5.25 Current	Industrial Share Component (20 ML) Condition 3: ≤ 1.5 L/s	241466	6164876	Wandoo	655	1600	23.0
GW101583 10CA111798 10AL111797 WAL24997 1.7.11 - 12.7.24 Current	Industrial Share Component 120 ML incorporates GW 102066 & GW108457 Condition 3: ≤ 1.0 L/s	241047	6164933	Tennyson Park (Coca Cola)	650	1800	34.0
GW101926 10WA112232 10AL112231 WAL24810 20.11.13-19.11.23 Current	Industrial Share Component 40 ML	240062	6164991	Weekes	660	2,500	33.1
GW102066 10CA111798 10AL111797 WAL24997 1.7.11 -12.7.24 Current	Industrial Share Component 120 ML incorporates GW 101583 & GW108457 Condition 3: ≤ 1.0 L/s	241055	6164967	Tennyson Park (Coca Cola)	650	1800	34.0

Table 6 (Cont'd)
Summary Details of Pumping Bores with Irrigation and Industrial Share Components

Page 2 of 2

Bore, Approval, Licence	Authorised Purpose	Coordinates (m MGA)		Property	Ground Elevation (m AHD)	Approximate Distance from Proposed Quarry (m)	Depth (m BGL)
		E	N				
GW102447 10CA111912 10AL111911 WAL25041 1.7.11 26.1.25 Current	Industrial, Irrigation Recreation Share Component 60 ML	240591	6165383	Penrose (Coca Cola)	645	1900	36.5
GW103106 10WA111868 10AL111867 WAL24832 1.7.11–26.7.24 Current	Industrial, Domestic Share Component 63 ML	241725	6164795	Edith Vale	660	1900	37.0
GW104765 10CA112020 10AL112019 WAL25051 1.7.11–30.6.24 Current	Irrigation Share Component 45 ML Condition 3: ≤ 2.0 L/s	244057	6166221	Henderson	690	600	108.0
GW106311 10CA112054 10AL112053 WAL25052 1.7.11–20.9.24 Current	Irrigation , Industrial Share Component 30 ML	245608	6167299	Sutton Forest Estate Wines	960	2300	91.0
GW108457 10CA111798 10AL111797 WAL24997 1.7.11–12.7.24 Current	Industrial Share Component 120 ML incorporates GW 102066 & GW108457	241133	6164839	Tennyson Park (Coca Cola)	650	1800	31.5
GW108683 10CA112082 10AL112081 WAL25055 1.7.11–30.6.24 Current	Irrigation Share Component 25 ML	242075	6167838	Robinson	700	1300	114.0

11.9 REGISTERED BORES ON LOT 4 DP 253435

Details of the two registered bores on Lot 4 DP 253435 including depth, authorised use and aquifer details are provided in **Table 7**.

Table 7
Summary Details of Registered Bores on Lot 4 DP 253435

Bore, Approval, Licence	Authorised Purpose	Coordinates (m MGA)		Depth (m)	Date Drilled	Aquifers/ Yield	Water Level (m)	Water Quality	Bore Geology
		E	N						
GW101872 10WA110379 Basic Rights 1.7.11 - Current	Stock and Domestic	243873	6165776	204.0	Feb 96	71.0 - 72.0 (0.3 L/s) 89.0 - 90.0 (0.3 L/s)	63.0	nil	0.0 - 28.0 S/S 28.0 - 28.5 Clay 28.5 - 32.5 S/S 32.5 - 33.0 Clay 33.0 - 96.0 S/S 96.0 - 204 Silt
GW104765 10CA112020 10AL112019 WAL25051 1.7.11–30.6.24 Current	Irrigation Share Component 45 ML Condition 3: ≤ 2.0 L/s	244057	6166221	108.0	May 03	53.0 - 54.0 (2.0 L/s)	41.6	nil	0.0 - 6.0 Fill 6.0 - 30.0 S/S 30.0 - 36.0 Sh 36.0 - 78.0 S/S 78.0 - 108.0 Silt

Recorded aggregate yields range from 0.6 to 2.0 L/s with the best yield recorded in Bore GW104765. Water levels were recently recorded in the two bores. The recently recorded water levels range from 62.43 m below ground level in Bore GW101872 to 41.47 m below ground in Bore GW104765. m below ground level.

12. MONITORING BORES

A network of 14 monitoring bores was established on the Site. The network utilises nine resource drill holes sunk in 2012 and 2016 which consisted of five HQ3 diamond drill holes (SFQ DDH 1D, SFQ DDH 2D, SFQ DDH 3D, SFQ DDH 4D and SFQ DDH 5D) and four 99 mm-diameter polycrystalline diamond (PCD) ‘open’ drill holes (SFQ OH 1, SFQ OH2, SFQ OH3 and SFQ OH4) within, or close to the extraction footprint. The locations of these nine drill holes are shown in **Figure 10**. Initially, five diamond drill holes were equipped with 50 mm-diameter Class 18 PVC casing, Class 18 PVC screen, gravel pack and bentonite seal and constructed for use as piezometers. The four ‘open’ drill holes were initially retained as ‘open’ holes with surface casing installed to impede any surface collapse. Due to damage, four ‘open’ holes were rehabilitated using a geotechnical drilling rig and constructed using 50 mm-diameter PVC casing, PVC screen, gravel pack and a bentonite seal.

Four additional shallow piezometers were installed between 2012 and 2016 (SFQ DDH 3S, SFQ DDH 4S, SFQ DDH 5S and SFQ OH2S).

A dedicated 99 mm diameter PCD hole (SFQ OH 5) was also drilled outside of the Proposal as a control piezometer (**see Figure 10**). This hole was also constructed as a piezometer with 50 mm-diameter PVC casing, PVC screen, gravel pack and a bentonite seal.

Details of the eight monitoring bores (piezometers) is provided in **Table 8**.

Table 8
Register of Groundwater Monitoring Bores

	Coordinates (MGA Grid)		Elevation Ground Level (m AHD)	Depth of Hole (m BGL)	Piezometer Details							
					Elevation TOC (m)	Stickup (m AGL)	SWL 11 May 2016 (m BGL)	Elevation SWL (m AHD)	Blank Casing 50 mm uPVC		Screen 50 mm uPVC	
Monitoring Site	**Easting (m)**	**Northing (m)**							**From (m)**	**To (m)**	**From (m)**	**To (m)**
SQF DDH 1	243185	6166154	692.7	51.10	693.16	0.46	47.11	645.59	+0.46	48.00	48.00	51.00
SQF DDH 2	242705	6166295	682.0	40.50	682.57	0.57	Dry	Dry	+0.57	37.40	37.40	40.40
SQF DDH 3 D	243009	6166460	688.0	38.90	688.65	0.65	36.70	651.30	+0.65	35.80	35.80	38.80
SQF DDH 3 S	243009	6166460	688.0	23.00	688.86	0.86	19.09	668.91	+ 0.86	17.00	17.00	23.00
SQF DDH 4 D	242745	6166385	671.0	51.10	671.75	0.75	36.02	634.98	+ 0.75	35.00	35.00	41.00
SQF DDH 4 S	242745	6166385	671.0	11.00	672.01	1.01	Dry	Dry	+ 1.01	5.00	5.00	11.00
SQF DDH 5 D	243168	6166263	689.0	65.50	689.76	0.76	47.18	641.82	+ 0.76	51.00	51.00	57.00
SQF DDH 5 S	243168	6166263	689.0	28.00	689.65	0.65	19.21	669.79	+ 0.65	22.00	22.00	28.00
SQF OH 1	243507	6166192	690.0	33.00	690.50	0.50	Dry	Dry	+0.50	27.00	27.00	33.00
SQF OH 2 D	242932	6166254	685.2	36.00	685.68	0.48	32.12	653.08	+0.48	30.00	30.00	36.00
SQF OH 2 S	242932	6166254	670.2	15.00	670.76	0.56	9.34	660.86	+ 0.56	9.00	9.00	15.00
SQF OH 3	243207	6166329	684.5	39.00	685.17	0.67	Dry	Dry	+0.67	33.00	33.00	39.00
SQF OH 4	242758	6166545	686.0	40.70	686.73	0.73	37.31	648.69	+0.73	34.70	34.70	40.70
SQF OH 5	243724	6165912	687.0	42.00	687.63	0.63	Dry	Dry	+0.63	38.85	38.85	41.85

Revised: 30.6.15 Note: SFQ OH 5 is the control monitoring bore outside of the Proposal footprint

Reference:
AHD: Australian Height Datum
BGL: Below Ground Level
AGL: Above Ground level
ToC: Top Of Collar
SWL: Standing Water Level
PVC: Poly(vinyl chloride)

13. AQUIFER CHARACTERISTICS

13.1 WATER LEVEL MEASUREMENTS, DIRECTION OF GROUNDWATER FLOW AND HYDRAULIC GRADIENT WITHIN THE SITE

13.1.1 Introduction

Baseline water level measurements were collected between October 2012 and July 2014 in eight of the on-site monitoring bores. Progressive manual water level measurements were also collected and collated. It is noted that following construction of piezometers in the four rehabilitated 'open' drill holes (SFQ OH 1, 2, 3 and 4), the water levels were remeasured and found to be slightly different to the earlier results when the bores were 'open'. This indicated that a vertical leakage component may exist. The numerical computer groundwater model developed by Coffey Geotechnics (Coffey, 2016) shows that the total hydraulic head of the area is characterised by large downward total head gradients which are very typical for steeply dissected topography.

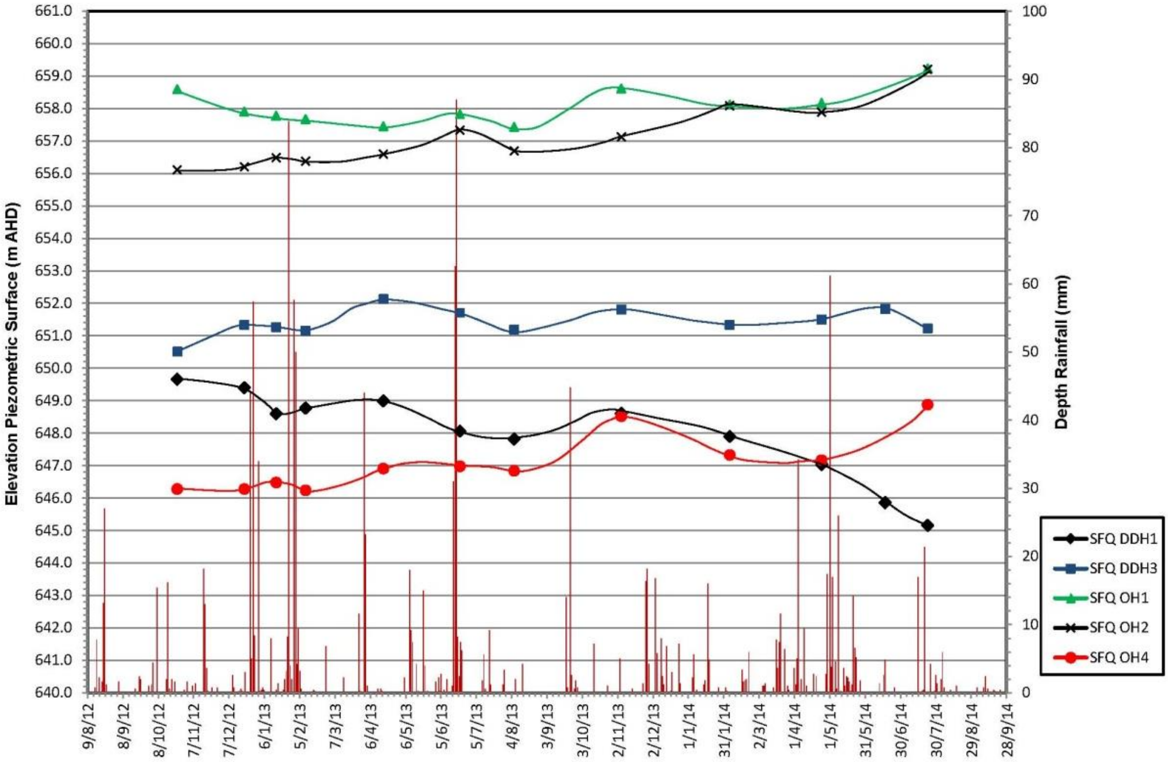
Automated water level sensors and loggers with a telemetry function were installed in six of the monitoring bores in July 2015 in order to collect 'real time' water level data. The sensors measure water levels at a frequency of one reading every four hours. The monitoring bores equipped with water level sensors are:

- SFQ-DDH 3D
- SFQ-DDH 4D
- SFQ-DDH 4S
- SFQ-DDH 5D
- SFQ-DDH 5S
- SFQ-OH 2D

13.1.2 Water Level Monitoring October 2012 – July 2014

The manual measurements of water levels intermittently recorded in the eight monitoring bores between October 2012 and July 2014 are listed in **Annexure 1**. A composite set of hydrographs for the eight monitoring bores are presented in **Figure 15**. Daily rainfall data acquired from the official BoM Moss Vale (BoM Id. 68045) weather station for the corresponding monitoring period is also plotted.

Figure 15 Hydrographs for On-Site Monitoring Bores



In summary, the hydrographs reveal fluctuating water levels in all monitoring bores. The water levels recorded in monitoring bores SFQ DDH3, SFQ OH1 and SFQ OH4 fluctuate within an approximate 1.0 m range whilst monitoring Bore SFQ OH 2 fluctuates over approximately 2.0 m. There appears to be a general correlation between fluctuations in water level and rainfall. The water level in monitoring Bore SFQ DDH1 remains relatively constant until about January 2014 then exhibits a decline over approximately 2.0 m, with the observed decline in the water level difficult to interpret. It is noted that the interpretation is based on manual water level measurements. Increased frequency of water level measurements and local rainfall observations would provide improved and more accurate analysis of the association between rainfall and groundwater levels.

It is noted that an interbed (or lens) of shale was recorded in the base of monitoring bores SFQ DDH3 and SFQ OH4 by Graham Lee & Associates (Graham Lee & Associates, 2016). Perching of shallow groundwater is likely to occur at this geological contact.,

It is noted that following construction of piezometers in open monitoring bores SFQ 1, 2, 3 and 4, the water levels in SFQ OH 1, SFQ OH 2, SFQ OH 4 were observed to rise between approximately 1.0 m and 2.0 m.

The elevation of the water level measured in on-site monitoring bores in July 2014 (following repairs to the monitoring bore network), and proximity to the proposed base of the extraction area are shown in cross sections presented in **Figures 16 and 17**. As can be seen, based on the available data, the water table is located below the base of the proposed extraction area in monitoring bores SFQ DDH1, SFQ DDH2 and SFQ OH3), and above the base in the central part of the extraction area in three monitoring bores (SFQ OH2, SFQ OH4 and SFQ DDH3). The locations of the cross sections are shown in **Figure 11**.

Figure 16 Water Table – Cross Section

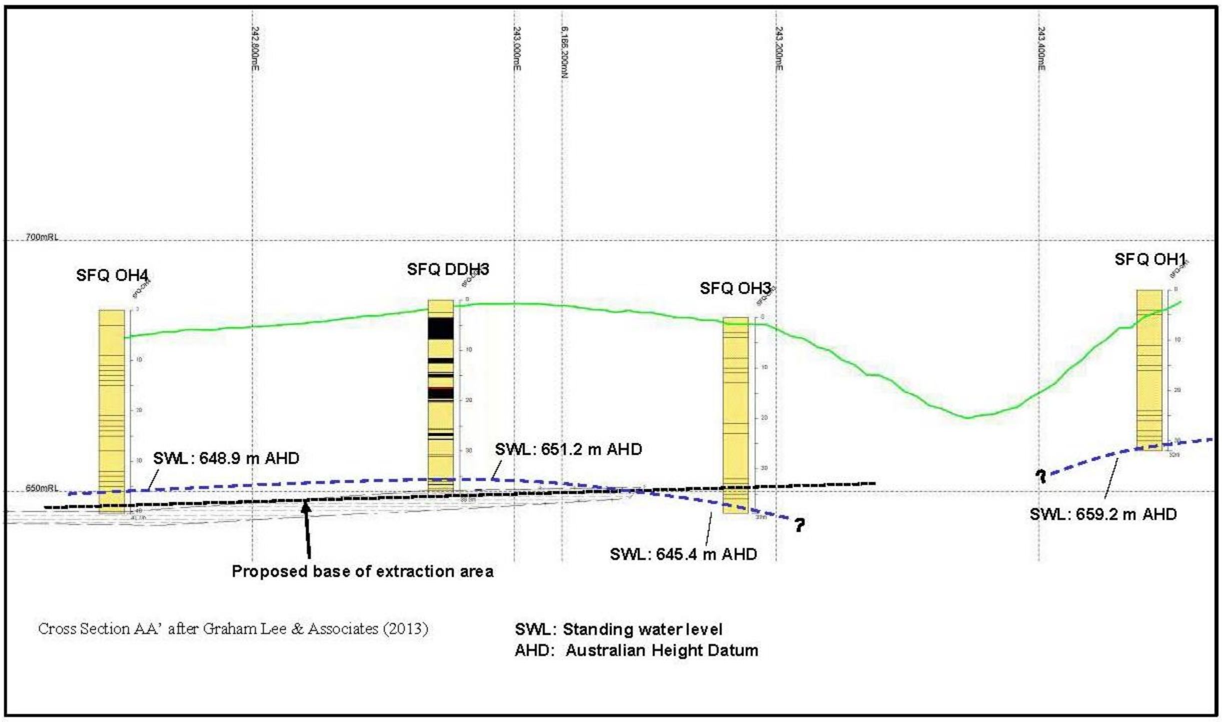
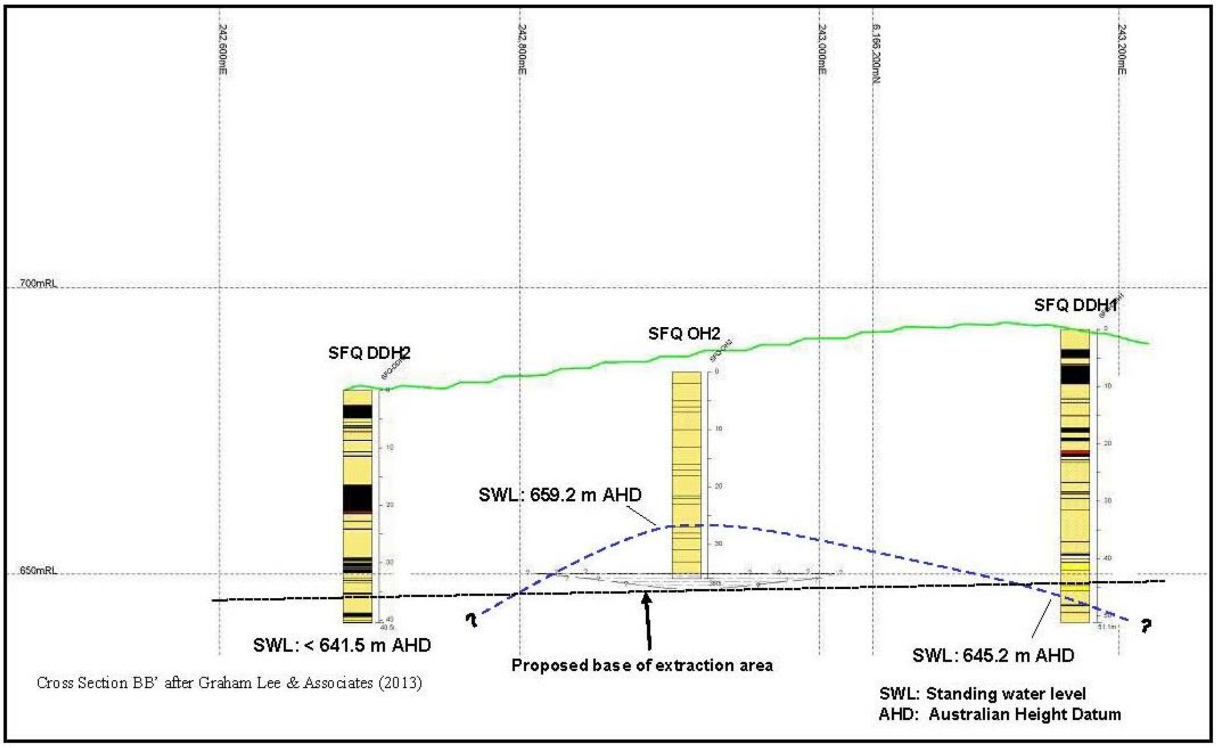


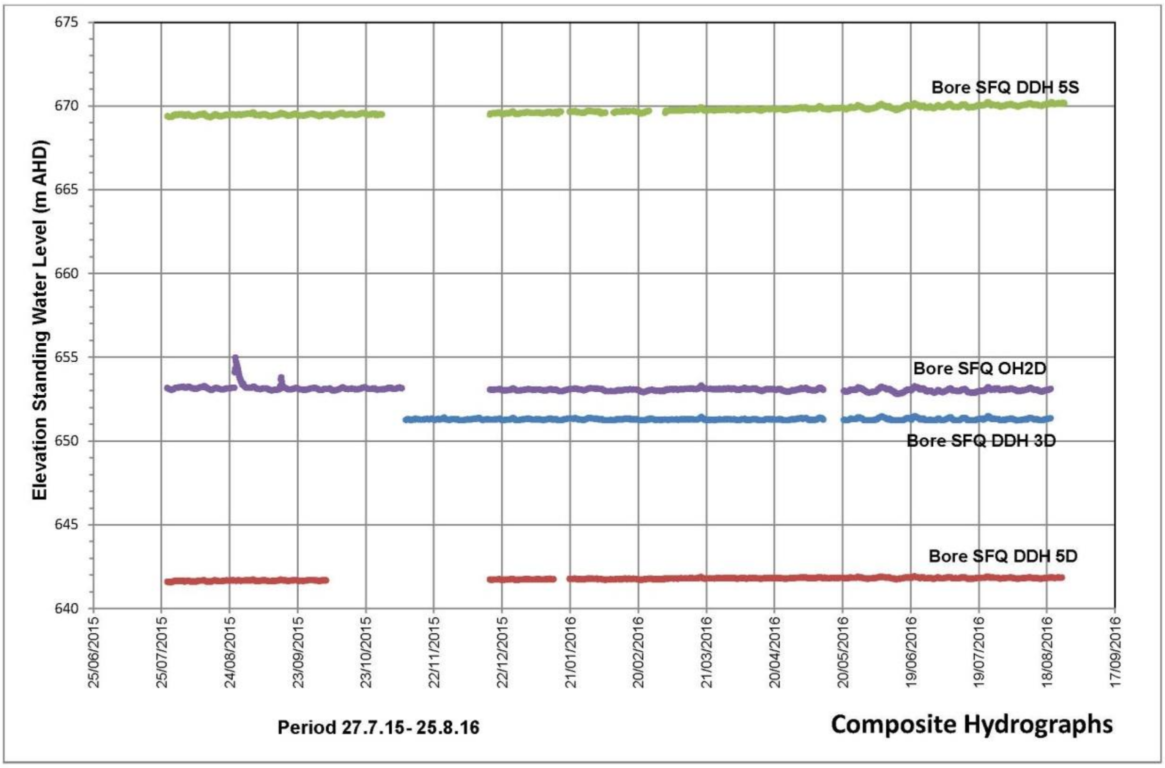
Figure 17 Water Table – Cross Section



13.1.3 Water Level Monitoring July 2015 – August 2016

A composite set of hydrographs for four of the six monitoring bores equipped with 'real time' water level sensors are presented in **Figure 18**. It is noted that nested monitoring bores SFQ DDH 4D and SFQ DDH 4S were 'dry'.

Figure 18 Hydrographs July 2015 – August 2016



The water levels monitored in 'deep' piezometers SFQ DDH 3D SFQ DDH 5D and SFQ OH 2D reveal relatively static conditions with minor fluctuation noted. The hydrograph for 'shallow' piezometer SFQ DDH 5S reveals a gradual but small 0.7 m rise in the water table over the 13-month monitoring period.

13.2 AQUIFER TESTING

An attempt was made to carry out short-term pumping tests in those monitoring bores with the longest water columns in order to establish a set of representative aquifer parameters including hydraulic conductivity and transmissivity. However, none of these monitoring bores could sustain continuous periods of pumping (<1hr).

Rising head 'slug' tests were then performed in selected monitoring bores with a sufficient water column to estimate the near-bore hydraulic conductivity. In this regard, monitoring bores SFQ DDH1 and SFQ OH 2 were tested. Methodology and results of slug testing are documented in Section 13.3.

The results of pumping tests carried out in a local bore GW051450 situated outside of the Site by Larry Cook Consulting in 2012 were utilised to complement the aquifer data for the Site and are presented in Section 13.4.1.

Aquifer testing was conducted by Larry Cook Consulting on bore GW104765, adjacent to the Site in June 2015 in accordance with Australian Standard AS21369-90 and comprised a medium term constant rate aquifer test with a complementary recovery phase. The details of the pump testing and results of the drawdown/recovery analysis are documented in Section 13.4.2. Laboratory permeability testing was carried out on three sections of sandstone drill core collected from drill holes SFQ DDH 1 and SFQ DDH 3. The results of the testing and estimates of hydraulic conductivity are provided in Section 15.

13.3 SLUG TESTING

13.3.1 Slug Test Methodology

An automated pressure transducer was first installed near the base of the selected monitoring bore to measure and record water level fluctuations. The logger was programmed to measure the water level at a frequency of one measurement per second.

The results from a series of rising head tests were compared and representative global estimates of hydraulic conductivity (K) calculated. A near bore Transmissivity (T) and Storativity (S_o) were estimated.

13.3.2 Slug Test Results

Analysis of the slug test results was carried out using aquifer models developed by Hvorslev (1951), Bouwer and Rice (1976), Cooper et.al (1967) and Kansas Geological Survey (KGS) (KGS, 1994). Aquifer parameters calculated and estimated from the slug tests undertaken on 9 February 2013 are summarised in **Table 9**. Both monitoring bores tested were open holes. The range of aquifer parameters for each bore and the adopted figures used in the assessment of potential impacts are also listed in **Table 9**. Slug test computer outputs for each monitoring bore tested are provided in **Annexure 2**.

Table 9
Summary Details - Hydraulic Conductivity Testing

Monitoring Bore	Depth (m)	SWL (m BGL)	Aquifer Thickness (m)	Analysis Methods		
				Hvorslev Model (1951)	Bouwer and Rice Model (1976)	KGS Model (1994)
				K Values (m/day)		
SFQ DDH 1	51.1	45.0	6.1	0.49	0.33	0.35
SFQ OH 2	36.0	28.8	7.2	0.11	0.08	0.09

The results indicate relatively low rock permeabilities with the tests revealing hydraulic conductivities of between approximately 0.10 and 0.35 m/day and transmissivities of between approximately 0.7 and 2.6 m^2/day.

13.4 PUMP TESTING

13.4.1 Pump Testing – GW051450

The results of formal pumping tests undertaken in a local production bore GW051450 located approximately 1.4 km southwest of the Site (**Figure 14**) by Kalf & Associates in 2006 and Larry Cook Consulting in 2012 were utilised to complement the Site aquifer data.

A medium-term 48-hour constant rate pumping test and a measured complimentary recovery phase was commenced on 7th September 2012 at a constant average rate of 2.0 L/s. This rate was selected following an assessment of historical production pumping flow rates, knowledge of the bore, and positions of the aquifers and results of formal pump testing by Kalf & Associates in 2006.

The objective of the test was to estimate the long-term safe and sustainable yield for the bore. A summary of the pump test results, and calculated aquifer parameters are provided in **Table 10**.

Table 10
Aquifer Test Data

	Hydraulic Conductivity (K) (m/day)	Transmissivity (T) (m^2/day)	Storativity
Pump Tests			
GW051450 (2006)	1.63	45.5[1]	1 x 10^{-4} (adopted)
GW051450 (2012)	0.71	18.5[1]	5 x 10^{-3} (calculated)

Notes: 1. Average of T from drawdown phase and recovery phase

13.4.2 Pump Testing – GW104765

A medium-term 48-hour constant rate pumping test and a measured complimentary recovery phase was commenced on 23rd June 2015 at a constant average rate of 3.0 L/s. This rate was selected following an assessment of historical production pumping flow rates and knowledge of the bore, and positions of the aquifers.

The objective of the test was to estimate the long-term safe and sustainable yield for the bore. Summary details for the constant rate pumping and recovery test are provided in **Table 11** and **12** respectively.

Table 11
Summary Details for Constant Rate Pumping Test - 23 June 2015
Bore GW104765

Drawdown			
Discharge Rate (L/s)	**Duration (hrs)**	**SWL m BGL at start (m)**	**SWL m BGL at end (m)**
3.0	48	41.43	52.93

Note: Standing Water Levels (SWL) w.r.t ground level
Pump Position: approximately 68.0 m below ground level
Available Drawdown for Test: approximately 264.0 m

Table 12
Summary Details for Recovery Phase of Constant Rate Pumping Test
Bore GW104765

Recovery to Pre-Test Piezometric Level	Minutes	Hours
75 % (41.43m Bgl)	10	0.2
80 %(41.43m Bgl)	18	0.3
85 % (41.43m Bgl)	52	0.9
90 % (41.43m Bgl)	195	3.3
95 % (41.43m Bgl)	1800	30.0

13.5 ANALYSIS

13.5.1 Pump Test Data of the Results

Analysis was carried out using the methods of Cooper-Jacob (1946), Hantush-Jacob (1955) and Theis (1935) for the residual drawdown/recovery phase. The reader is referred to Kruseman and De Ridder (1994) for explanation of the analyses.

Pump test data and manually constructed drawdown and recovery charts are provided in **Annexure 3**. The data includes a hydrograph of the fluctuations in the piezometric level during pump testing with the interpreted position of the encountered aquifers annotated. This can be useful in explaining any changes in slope of the drawdown curve.

The drawdown curve exhibits three main changes of slope:

- The first change in slope is noted at approximately 3 minutes elapsed time. This initial slope is believed to represent bore storage effects.
- The second change in slope is noted between approximately 3 and 37 minutes elapsed time. This second slope is believed to represent the near-bore hydrogeological characteristics of the sandstone aquifer system.

- A small but recordable increase in the slope of the drawdown curve at approximately 37 minutes following commencement of pumping is believed to reflect the intersection of the expanding cone of depression with a small barrier boundary.
- A small but noticeable decrease in the slope of the drawdown curve at approximately 210 minutes is believed to reflect the intersection of the expanding cone of depression with a small recharge boundary possibly due to aquifer leakage or the intersection of additional geological defects (joints). Evidence of a recharge boundary can also be seen in the recovery chart.

A summary of the calculated aquifer parameters is provided in **Table 13**.

Table 13
Summary of Aquifer Parameters
Bore GW104765

Discharge Rate: 3.0 L/s (259.2 m^3/day)			
Test	**Log cycle Drawdown**	**Transmissivity (T)**	**Estimated Storage Coefficient (Storativity) (S_o)[1]**
Drawdown	1.83 m	25.9 m^2/day	1 x 10^{-2}
Recovery	1.27 m	37.3 m^2/day	1 x 10^{-2}

1. Storativity estimates based on studies by Coffey (2016)

13.5.2 Drawdown Analysis

The known existence of sandstone-hosted ‘dual porosity’ aquifers in the region and moderately high rock permeabilities estimated from the pump test in Bore GW104765 suggests that anisotropic conditions exist, which can render the analysis of groundwater flow difficult.

13.5.2.1 Water Level Measurements – Observation Bore GW101872

Water level measurements were collected in Bore GW101872 – 480m from GW104765 using an automated water level sensor during pump testing. The water level data and hydrograph are provided in **Annexure 3**. The hydrograph reveals that there was no significant drawdown of the piezometric surface at Bore GW101872 during the pumping of Bore GW104765. The maximum recorded drawdown was 0.02 m.

13.5.2.2 Distance Drawdown Analysis

Distance drawdown, as a consequence of pumping in Bore GW104765 were estimated using the method documented by Domenico and Schwartz. (1990). The drawdown was estimated using an adopted transmissivity value of 30 m^2/day that was derived from the interpretation of the pump test data and a range of storativity values; 1 x 10^{-1}, 1 x 10^{-2} and 1 x 10^{-3}. The range of storativity values provides a sensitivity analysis for the distance drawdown calculations.

The distance drawdown calculations are listed in **Table 14** and predict the drawdown at the Bore (GW101872) located approximately 480 m from the pumped bore. The calculations were based on continuous pumping periods of 12, 24, 48, and 72 hours.

Table 14
Distance Drawdown Predictions
Bore GW104765 Pumping

Distance	200m			480m			600m		
Storativity (S)	0.1	0.01	0.001	0.1	0.01	0.001	0.1	0.01	0.001
Duration									
12	0.000	0.000	0.274	0.000	0.000	0.003	0.000	0.000	0.000
24	0.000	0.006	0.570	0.000	0.000	0.038	0.000	0.000	0.009
48	0.000	0.054	0.945	0.000	0.002	0.161	0.000	0.000	0.069
72	0.0072	0.126	1.188	0.000	0.000	0.289	0.000	0.000	0.151

Note:
T = 30.0 m^2/day
Q = 3.0L/s = 259.6 m^3/day

13.6 RESULTS AND STORATIVITY CALCULATIONS

The results of recent aquifer testing in Bore GW104765 hosted by the Hawkesbury Sandstone in suggests that the near-bore global storativity values are approximately 1 x 10^{-2} which is consistent with the results of hydrogeological studies conducted in the Sydney metropolitan area and elsewhere by Tammetta and Hewitt (2004). The results of these studies indicated a specific yield of between 0.010 and 0.015 that is reasonable for typical, undeformed Hawkesbury Sandstone. A storativity of 1 x 10^{-2} is adopted in this groundwater assessment.

13.7 SAFE YIELD ESTIMATE – BORE GW104765

13.7.1 Introduction

The concept of 'safe yield' is difficult to quantify and many workers have discussed its usefulness.

For the purposes of this groundwater investigation, safe yield is defined as the volume of groundwater that can be extracted from an aquifer on a sustained basis over a specified timeframe without impacting on the quality of the groundwater, dewatering the aquifer/s or adversely impacting on the environment.

Fetter (1994) presents a practical and mathematically valid equation that can be solved to determine safe yield.

$$\text{Critical DDL} = SWL + (S_{100} = 4\Delta S) \quad \frac{Q}{Q_{test}}$$

(1)

Where ΔS is the drawdown per log cycle, S_{100} is the drawdown after 100 elapsed minutes, *SWL* is the standing water level in the bore and Q_{test} is the pump discharge test rate and *Critical DDL* is the critical drawdown limit. The *Critical DDL* is based on a practical assessment of the position and yield of the principal aquifers in the bore, an allowance for any seasonal fluctuations in water level in the aquifer and an estimate of friction losses. Due to the results of monitoring in the observation bore during pump testing which shows minimal significant distance drawdown (interference drawdown), no allowance was made for interference drawdown between other production bores.

13.7.2 Assumptions

In determining a safe yield for the pumped bore, the following assumptions are made:

- No hydraulic boundaries are encountered other than those observed during the pumping test for each bore
- No significant rainfall recharge or induced leakage from proximal surface water bodies
- Drainage of saturated strata above the main aquifers but no depletion of deeper aquifer zones.

13.7.3 Calculation of 'Safe Yield'

In estimating a long-term 'safe yield' for the production bore, the most critical factor is considered to be the Critical Drawdown Level (Critical DDL) or sometimes referred to as the maximum drawdown level which is directly related to the position, number and relative yields of any aquifer/s intersected and recorded in the test bore. This level is the level at which the yield of the bore is not significantly compromised and is also the level below which the rate of fall of the water table as pumping continues, significantly increases. The water table during pumping should not fall below the Critical DDL.

Rearranging Equation (1) in order to solve for Q, the safe long-term yield, Equation (2) is derived.

$$Q = \frac{Q_{test}\,(\text{Critical DDL} - SWL)}{(S_{100} + 4\Delta S)}$$

(2)

Table 15 provides a list of the parameters used in the estimation of safe yield for the production bore. A calculated safe yield for the bore is also included.

Table 15
Summary of Safe Yield Calculations

Bore	Pump Discharge Test Rate (L/s)	Critical Drawdown Level (m BGL)	Standing Water Level (m BGL)	Drawdown after 100 minutes (m)	Drawdown per log cycle (m)	Estimated Safe Yield (L/s)
GW1047665	3.0	52.0	41.43	8.96	1.83	2.13
Annual Production Volume – 100% Duty						**67.2 ML**
Annual Production Volume – 70% Duty						**47.1 ML**
Annual Production Volume – 55% Duty						**37.0 ML**

Note: BGL denotes **B**elow **G**round **L**evel

Based on these data and parameters, the aggregate long term safe yield for Bore GW104765 is estimated at 2.1 L/s. This equates to an annual groundwater production of approximately 67.2 ML. For comparison purposes, a 250 day pumping year (70% duty) equates to annual groundwater production of 47.1 ML. Adopting a 200 day pumping year (55% duty), this yield equates to annual groundwater production of approximately 37.0 ML.

It is noted that a recharge boundary was intersected at approximately 210 minutes after pumping commenced during the 2015 pumping test. This decrease in the drawdown slope suggests that the sustainable yield is greater than 2.1 L/s. The annual production volume for 70% duty (47.1 ML) is slightly higher than the approved annual water entitlement for the bore (45 ML). It is understood that for 50% of rainfall years there will be a water deficit of 64 ML for sand processing operations and dust suppression activities. Therefore, an additional supply of water for the Proposal will be required to satisfy any shortfall in 'make up' water.

13.8 LABORATORY PERMEABILITY TESTING

Three samples of drill core collected from drill holes SFQ DDH 1 and SFQ DDH 3 were submitted for laboratory permeability testing. Hydraulic conductivities were calculated using the Falling Head methods of AS 1289.6.7.2. Details of the samples and results are provided in **Table 16**. The laboratory certificate of analysis is provided in **Annexure 4**.

Table 16
Summary Details and Results – Laboratory Permeability Testing

Sample Details			
Sample ID	SFQ DDH 1	SFQ DDH 3	SFQ DDH 3
Sample Interval (m)	35.88 – 36.10	25.75 – 26.03	34.82 – 35.04
Diameter (mm)	61.00	61.30	60.80
Sample length (m)	0.148	0.156	0.147
Results			
Hydraulic Conductivity (m/d)	0.04	0.87	0.07

The hydraulic conductivity results are considered to be relatively high for Hawkesbury Sandstone. Typical values of hydraulic conductivity for the Hawkesbury Sandstone in the Sydney Basin are between approximately 0.005 and 0.01 m/day (Coffey, 2014).

13.9 WATER QUALITY TESTING

13.9.1 Introduction

Routine field measurements of pH and electrical conductivity (EC) were collected from those monitoring bores with water during the field campaigns to collect manual measurements of water level between October 2012 and July 2014. Measurements of pH and EC were undertaken using calibrated TPS-brand instruments. The results of field pH and EC testing are provided in **Annexure 5**.

Baseline groundwater sampling and water quality analysis was carried out in three monitoring bores in July 2014 and in eight monitoring bores in March 2016. The objective of the groundwater sampling and water quality analysis was to establish a baseline set of water quality data for the local aquifer system.

The details and results of the groundwater sampling and analysis carried in 2016 are documented in the following sections.

13.9.2 Sampling

Water samples were collected from the eight monitoring bores using a bladder (low flow) pump. Upon collection, samples were immediately placed in a chilled esky and submitted to a NATA accredited laboratory (Envirolab Services Chatswood) for analysis.

13.9.3 Analytical Results

The analytical results are summarised in **Table 17**. A copy of the laboratory certificate and Chain Of Custody (COC) documentation are provided in **Annexure 5**.

Table 17
Summary of Water Quality Analytical Results - Monitoring Bores

		Bore Id. Limit of Reporting (LoR)	**1** *SFQDDH1*	**2** *SFQDDH2D*	**3** *SFQOH2S*	**4** *SFQOH4*	**5** *SFQDDH3S*	**6** *SFQDDH4D*	**7** *SFQDDH5D*	**8** *SFQDDH5S*
pH (lab)	pH Units		5.1	7.3	5.3	5.2	5.3	7.9	5.5	5.3
Electrical Conductivity (lab)	µS/cm	1.0	61	280	64.0	43.0	26.0	280	76.0	53.0
Total Dissolved Solids	mg/L	5	37	180	38	25	16	220	67	63
Cations										
Calcium	mg/L		<0.5	37	0.7	<0.5	<0.5	52	1	0.5
Potassium	mg/L		<0.5	1.6	<0.5	<0.5	<0.5	2.1	2.4	<0.5
Sodium	mg/L		11	17	9.7	7.1	4.5	9.8	11	8.6
Magnesium	mg/L		1	6.4	1.3	<0.5	<0.5	0.6	0.9	0.8
Anions										
Chloride Cl-	mg/L	1	18	15	16	10	4	13	17	18
Carbonate Alkalinity - CaCO3	mg/L		<5	<5	<5	<5	<5	<5	<5	<5
Bicarbonate HCO3	mg/L	5	7	130	5	5	5	95	7	6
Hydroxide Alkalinity (OH^-) as Ca As CO3)	mg/L	5	<5	<5	<5	<5	<5	<5	<5	<5
Total Alkalinity As CaCO3)	mg/L	5	7	130	5	5	5	95	7	6
Sulphate SO4	mg/L	1	1	10	<1	1	2	40	3	3

Table 17 (Cont'd)

Summary of Water Quality Analytical Results - Monitoring Bores

Page 2 of 2

		Bore Id. Limit of Reporting (LoR)	1 *SFQDDH1*	2 *SFQDDH2D*	3 *SFQOH2S*	4 *SFQOH4*	5 *SFQDDH3S*	6 *SFQDDH4D*	7 *SFQDDH5D*	8 *SFQDDH5S*
Metals										
Arsenic As	µg/L		<1	<1	<1	<1	<1	2	<1	<1
Cadmium Cd	µg/L		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Chromium Cr	µg/L		<1	<1	1	1	<1	1	1	**2**
Copper Cu	µg/L		1	<1	<1	1	1	1	1	<1
Lead Pb	µg/L		<1	<1	<1	<1	1	<1	<1	1
Nickel (Ni	µg/L		3	9	<1	2	<1	<1	2	1
Zinc Zn	µg/L		**19**	**14**	**10**	**21**	**13**	<1	**73**	**36**

Notes:

Results shown in bold are in excess of the aquatic ecosystem guideline for slightly too moderately disturbed surface water systems (ANZEC, 2000)

In summary, the pH recorded in monitoring bores SFQ DDH 2D and SFQ DDH 4D is slightly alkaline with values ranging from 7.3 in SFQ DDH 2D to 7.9 in SFQ DDH 4D. The pH values recorded for the remaining four samples are moderately acidic ranging from 5.1 to 5.5. Laboratory measurements of electrical conductivity (EC) and Total Dissolved Solids (TDS) indicate that the water has low salinity (26 to 280 µS/cm EC).

All samples returned levels of carbonate alkalinity and hydroxide alkalinity less than the Limit Of Reporting (LOR). Samples SFQ DDH 2D and SFQ DDH 4D returned slightly elevated levels of bicarbonate alkalinity.

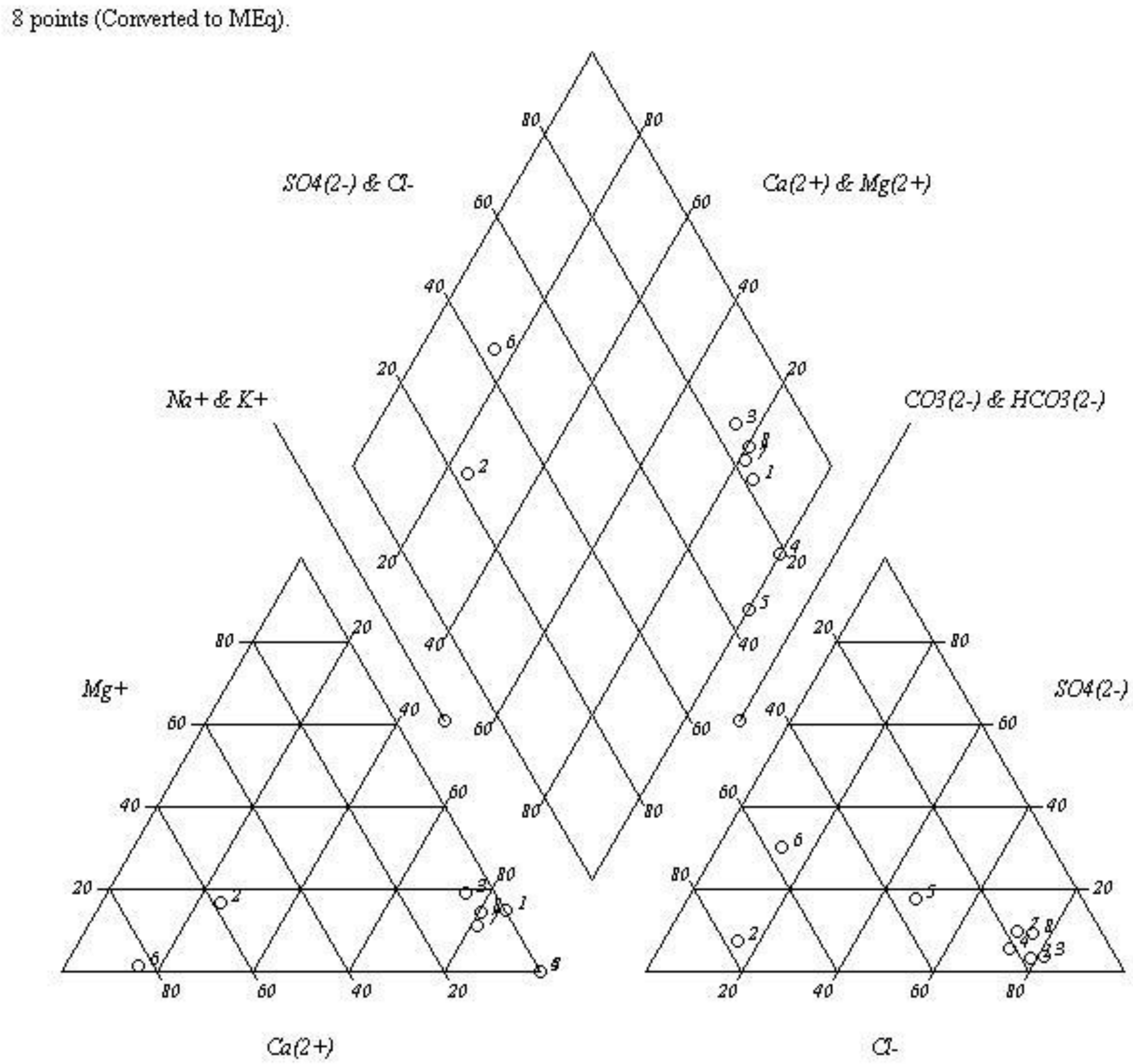
The concentrations of metals were less than guideline values with exception of zinc.

The water samples were collected at similar elevations in the Hawkesbury Sandstone aquifer system. The groundwater chemistry is considered to be typical of the Hawkesbury Sandstone aquifers with low pH and low salinity levels.

13.9.4 Hydrochemical Classification

The major ion proportions for the eight water samples are plotted on a Piper diagram (trilinear plot) in order to characterise the chemistry of the groundwater. The plot is shown in **Figure 19**.

Figure 19 Piper Diagram



1.	SFQ DDH1	5.	SFQ DDH3S
2.	SFQ DDH2D	6.	SFQ DDH4D
3.	SFQ OH2S	7.	SFQ DDH5D
4.	SFQ OH4	8.	SFQ DDH5S

The ion composition indicate that the groundwater is grouped into mainly Sodium Chloride type as shown in **Table 18**.

Table 18
Hydrochemical Classification of Site Groundwater

Bore	Classification
SFQ DDH1	Sodium Chloride
SFQ DDH2D	Calcium Bicarbonate
SFQ OH2S	Sodium Chloride
SFQ OH4	Sodium Chloride
SFQ DDH3S	No dominant type
SFQ DDH4D	Calcium Bicarbonate
SFQ DDH5D	Sodium Chloride
SFQ DDH5S	Sodium Chloride

14. COMPUTER GROUNDWATER MODELLING

14.1 INTRODUCTION

A groundwater modelling assessment for the proposed Sutton Forest Sand Quarry was first carried out in 2014 by *Coffey Geotechnics Pty Ltd* (Coffey). The modelling assessment comprised the development of a steady-state numerical groundwater model. Continual development of the model was undertaken by Coffey between 2014 and 2016 incorporating newly acquired 'real time' water level data from automated sensors installed in six monitoring bores, and improvements in the conceptual hydrogeological model. This additional information enabled the development of a transient groundwater model.

The principal elements of the model and results of the Coffey computer groundwater modelling assessment including the modelling approach, model calibration and results of predictive simulations are summarised in the following sections. A copy of the groundwater modelling assessment is provided in full in **Annexure 6**.

14.2 AIMS OF THE GROUNDWATER MODELLING ASSESSMENT

The main aims of the modelling assessment, as defined by Coffey and Larry Cook Consulting were to develop a three-dimensional groundwater flow model to assess:

- the amount of groundwater drawdown at neighbouring groundwater bores and GDEs due to the extraction operations;
- groundwater inflow to the extraction area, and
- the post-quarrying groundwater regime and long-term impacts.

14.3 SCOPE OF THE GROUNDWATER MODELLING ASSESSMENT

The scope of work for the groundwater modelling study consisted of the following.

- Development and calibration of a transient groundwater flow model to simulate current site conditions (base case).
- Use of the calibrated base case transient groundwater flow model in a predictive capacity to assess the likely impacts of extraction operations. Impacts on the groundwater system were assessed for the following:
  - groundwater drawdown at neighbouring groundwater bores and the Long Swamp GDE north and west of the Site;
  - groundwater inflows to the extraction area and changes in groundwater flow budgets, and
  - post-extraction groundwater regime and long-term impacts.

14.4 CONCEPTUAL HYDROGEOLOGICAL MODEL

14.4.1 Recharge

Groundwater recharge to the sandstone aquifer can occur via the following processes.

- Direct rainfall infiltration.
- Irrigation.
- Leakage from storage dams.
- Leakage from surface water courses such as Long Swamp Creek and its tributaries (under certain circumstances), in particular wherever the water level stage is higher than the water table.

For the purposes of the transient groundwater modelling assessment, the dominant recharge process incorporated into the model is rainfall infiltration.

14.4.2 Discharge

Discharge of groundwater from the sandstone aquifer would occur via the following processes.

- Lateral flow (base flow discharge) to ephemeral watercourses and any perennial watercourses such as Long Swamp Creek.
- Evapotranspiration by vegetation with sufficient root depth and evapotranspiration in the unsaturated zone, in zones with shallow water tables, at escarpments, and in forested areas.
- Groundwater abstraction from surrounding pumping bores, including the bores on Lot 4, i.e. bores GW101872 and GW104765.
- During extraction at elevations below the water table, discharge would also occur via groundwater inflow to the extraction area and consumption of groundwater from evaporation (from the exposed extraction faces).

14.4.3 Schematic Conceptual Model

The elements of the hydrogeological system are summarised in a schematic hydrogeological conceptual model prepared for the Site and surrounding area and shown in **Figure 12**. The pictorial representation is based on the hydraulic head field created by the extraction operations at maximum quarry development.

14.5 MODEL SELECTION AND DEVELOPMENT AND CALIBRATION

14.5.1 Model Selection

A transient numerical groundwater model is considered suitable for the assessment and prediction of impacts from the extraction operation because it utilises 'real time' water level data and enables simulation of strategic stages in the extraction process.

14.5.2 Model Code and Structure

A regional transient groundwater flow model was developed by Coffey to simulate extraction and any potential impacts on the local groundwater system as a consequence. The model was developed using MODFLOW-SURFACT (Version 3), distributed by Hydrogeologic, Inc. (Virginia, USA). It is an advanced version of the standard USGS MODFLOW finite difference algorithm and is able to simulate variably saturated flow and large vertical hydraulic gradients. MODFLOW-SURFACT was operated within the Visual Modflow (Version 2009) pre- and post-processing environment, developed by Schlumberger Water Services.

The active model area is shown in **Figure 8** (referred to as the "numerical Model Boundary" and covers an area of approximately 32 km^2 with approximate dimensions 9 km east-west by 7 km north-south. The physical model boundary follows natural features and is of sufficient coverage to significantly minimise the effect of quarry drawdown on them.

14.5.3 Layering and Cell Mesh

The model grid consists of seven layers with 102 columns and 80 rows. Cell dimensions are 50 m by 50 m over the proposed extraction area expanding to 100 m by 100 m over the remainder of the model domain.

The increased resolution over the extraction area was designed to provide sufficient head and drawdown detail during calibration and predictive simulations.

14.5.4 Boundary Conditions

The perimeter of the model area was selected by Coffey (2016) to be sufficiently distant from the extraction area not to influence drawdown.

The boundary conditions defined by Coffey (2016) at the extremity of the model domain comprise:

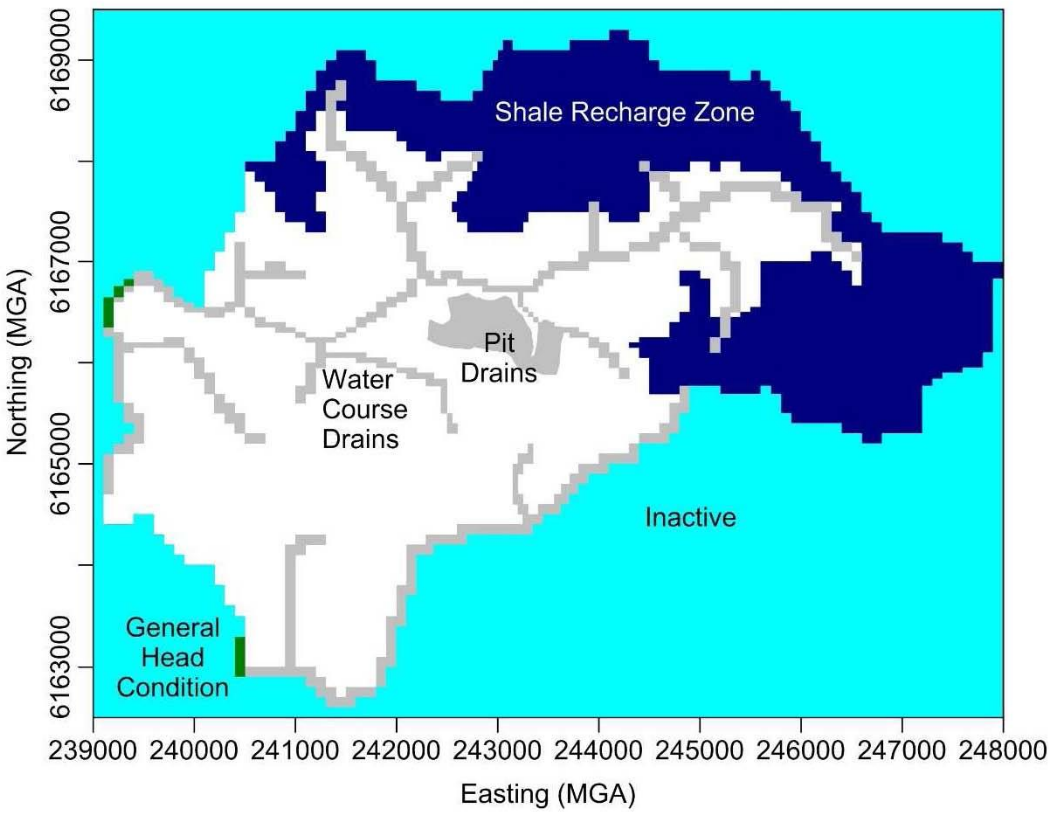
- no-flow at topographic divides;
- discharge/drainage at watercourses;
- use of the "drain package" to simulate seepage faces in the layers within the creek valley;

- a general head condition at the western perimeter in the active layer at that location (Layer 7) to simulate downgradient groundwater flux out of the model at Long Swamp Creek and Paddys River; and
- for predictive simulations, use of the drain "package" to simulate extraction operations.

The perimeter of the model area is shown in **Figure 8**. The boundary conditions are annotated in **Figure 20**. In addition, Coffey (2016) selected the position of the perimeter to encompass the recharge area for each of the 10 identified pumping bores assuming a recharge rate of 3 %.

Figure 20 Boundary Conditions

(after Coffey, 2016)



14.5.5 Watercourses

Coffey (2016) assumed that, based on the available data, the lower lying watercourses (generally below 630 m AHD) are perennial and watercourses at higher elevation are ephemeral. Coffey (2016) note that the lowest level of excavation would also be 630 m AHD. In this regard, there is considered to be a significantly small probability of direct seepage from Long Swamp Creek to the Quarry.

Coffey (2016) simulated all watercourses using the MODFLOW Drain package. Drain elevations were estimated using a 30 m Digital Elevation Model (DEM) and a more detailed DEM for the site developed from photogrammetry by GeoSpectrum.

14.5.6 Rainfall Recharge

Rainfall recharge used in the modelling is net recharge representing that recharge which enters the groundwater system after consumption by evapotranspiration.

Average annual rainfall for the model area was assumed to be 902 mm (SEEC 2018). The model area was divided into two recharge zones according to outcrop lithology (Wianamatta Group / Basalt, and Hawkesbury Sandstone). Net rainfall recharge was applied as a percentage of incident rainfall to the topmost active cell in each. A recharge proportion of 3% was adopted in the model.

14.5.7 Evapotranspiration

Evapotranspiration is not explicitly simulated in the model but is accounted for in the recharge rate.

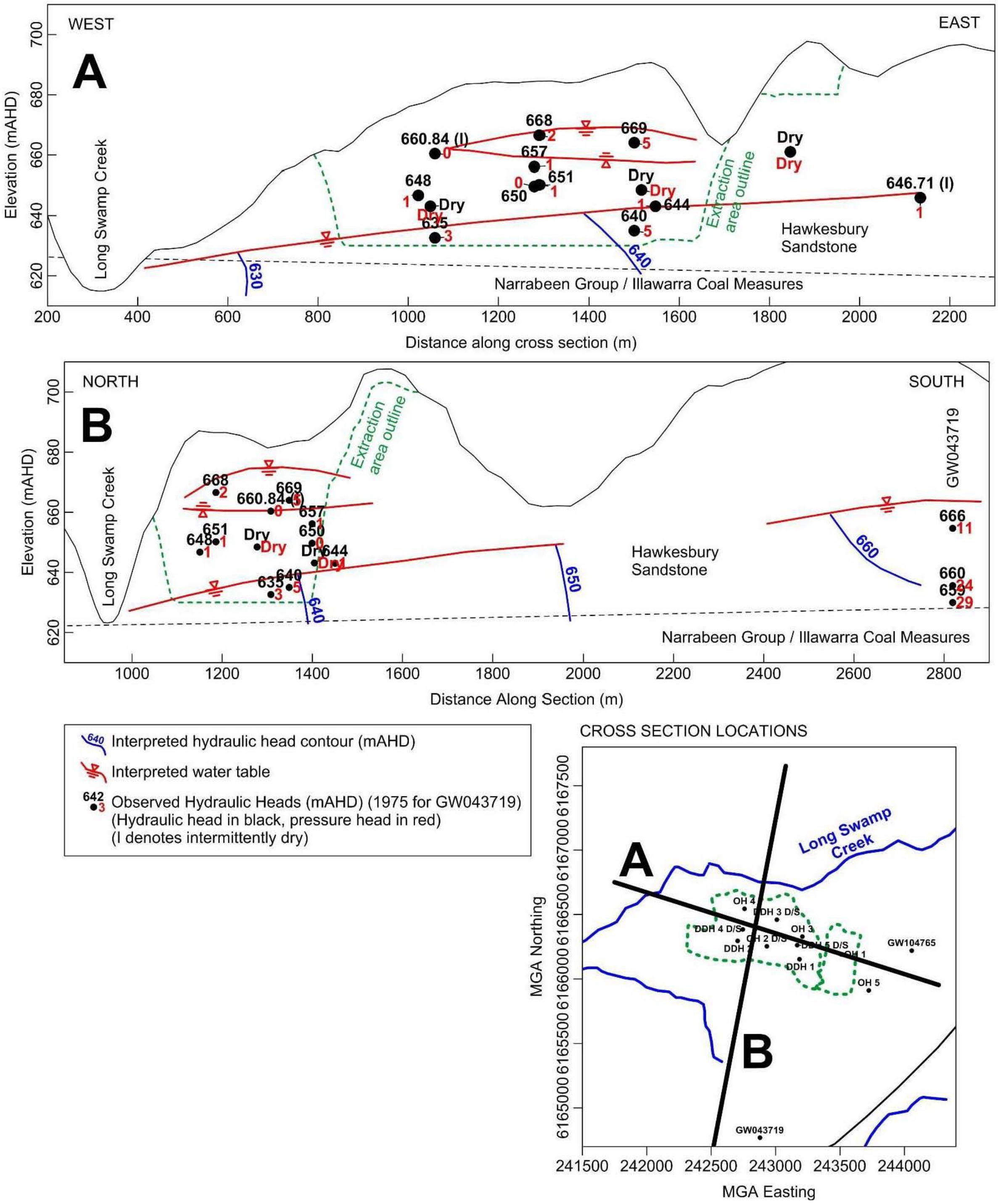
14.5.8 Pumping Bores

The 10 registered bores identified within a 2.5 km radius of the proposed extraction area that have licensed water entitlements were incorporated in the groundwater model using a long-term pumping rate representing 67% of the annual allocation, based on anecdotal information regarding pumping from bores including the Coca Cola bores on 'Tennyson Park'. The three Coca Cola Amatil production bores (GW101583, GW102066 and GW108457), the locations of which are shown in **Figure 8** were modelled as a single bore due to their close proximity and the model cell size of 100m by 100m in that area.

14.5.9 Positions of Water Tables

The vertical gradient results together with hydraulic head measurements from site piezometers, and from private bore GW043719 have been used by Coffey to construct two hydraulic head cross sections along the sections shown in **Figure 9** and reproduced again in **Figure 21**.

Figure 21 Cross Section Showing Interpreted Total Head Contours (after Coffey, 2016)



14.6 MODEL CALIBRATION

Model calibration was undertaken manually in transient mode. The aquifer system was assumed to be in quasi-equilibrium in early to mid-2014. The period of calibration comprised a seven-month period incorporating the available high frequency ‘real time’ water level measurements acquired from automated sensors and recorders and supplementary manually measured observations.

Coffey (2016) documents that a significant source of uncertainty in comparing observed hydraulic heads and modelled heads for the modelled system (which hosts significant vertical gradients) is in relating the vertical position of a piezometer screen to the head calculated by the model for a layer. The calibration results are documented and critically discussed in the groundwater modelling assessment (**Annexure 6**) Coffey (2016) reports that calibration was considered acceptable. Observed vertical total head gradients were considered to be acceptably replicated by the model.

The calibrated water table contours for the sandstone aquifer system are shown in **Figure 22**.

14.7 PREDICTIVE SIMULATION

Two predictive scenarios were simulated:

- **Extraction inactive**. This scenario provides changes in the hydraulic head field with the absence of extraction operations and allows calculation of impacts due to extraction operations only.
- **Extraction active**. This scenario provides drawdowns and inflows in the presence of extraction operations.

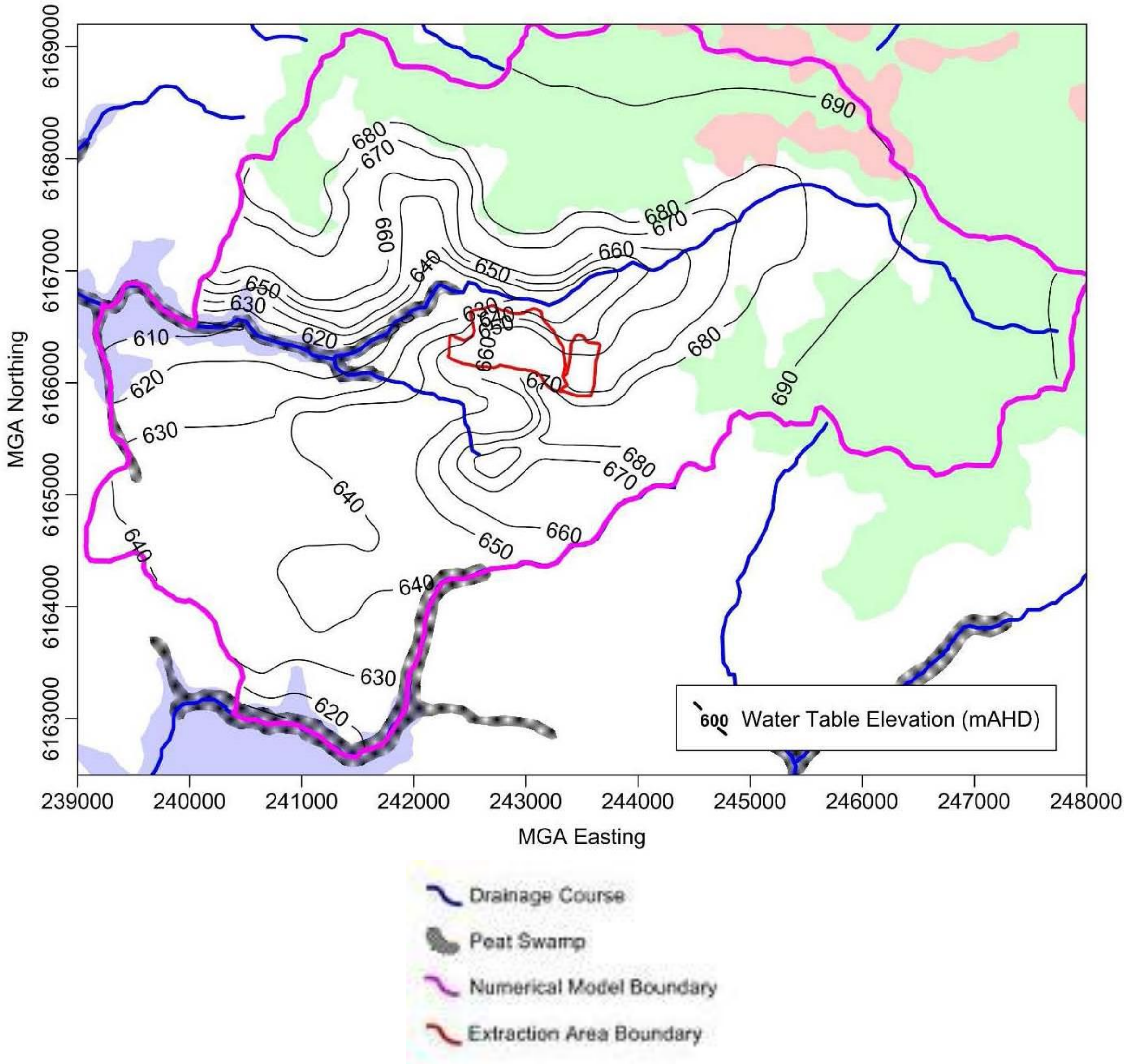
The period of predictive simulation covers 45 years of extraction followed by 20 years recovery. Private pumping is active in both scenarios at the same rate as modelled for the calibrated base case. The results are summarised by Coffey (2016) in the following sections.

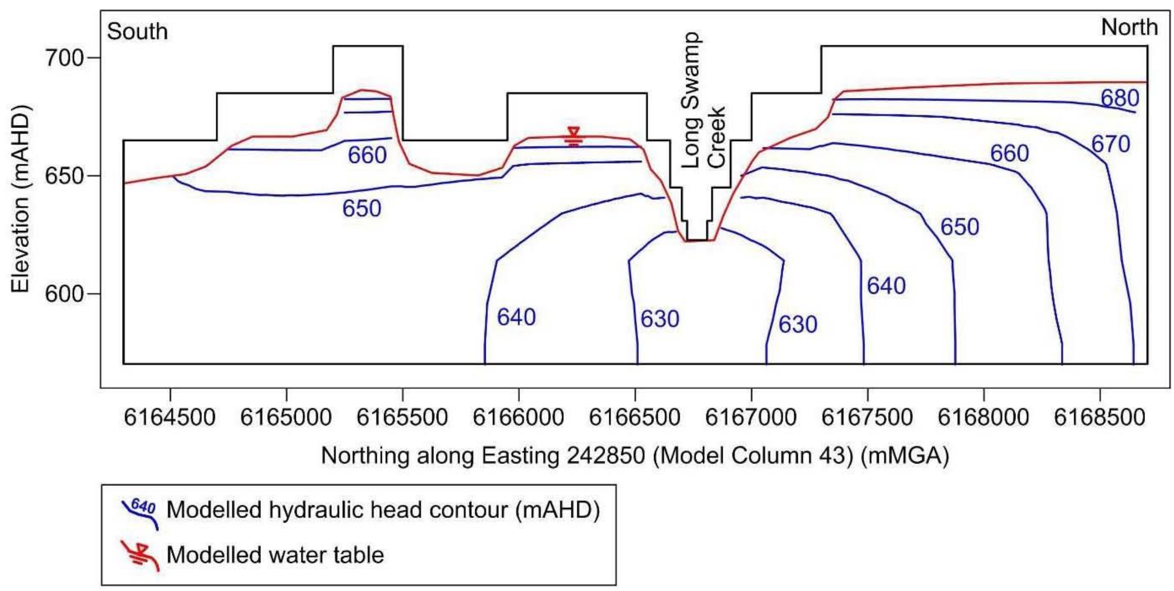
14.7.1 Extraction Inactive Scenario

The flow budget for the extraction inactive (but private bores active) was calculated by Coffey (2016). The modelled baseflow to Long Swamp Creek was 2.01 ML/day. This baseflow, according to Coffey (2016), is consistent with estimates established using on baseflow analyses undertaken for similar catchments in the NSW Southern Highlands.

Figure 22 Calibrated Water Table Contours

(after Coffey, 2016)

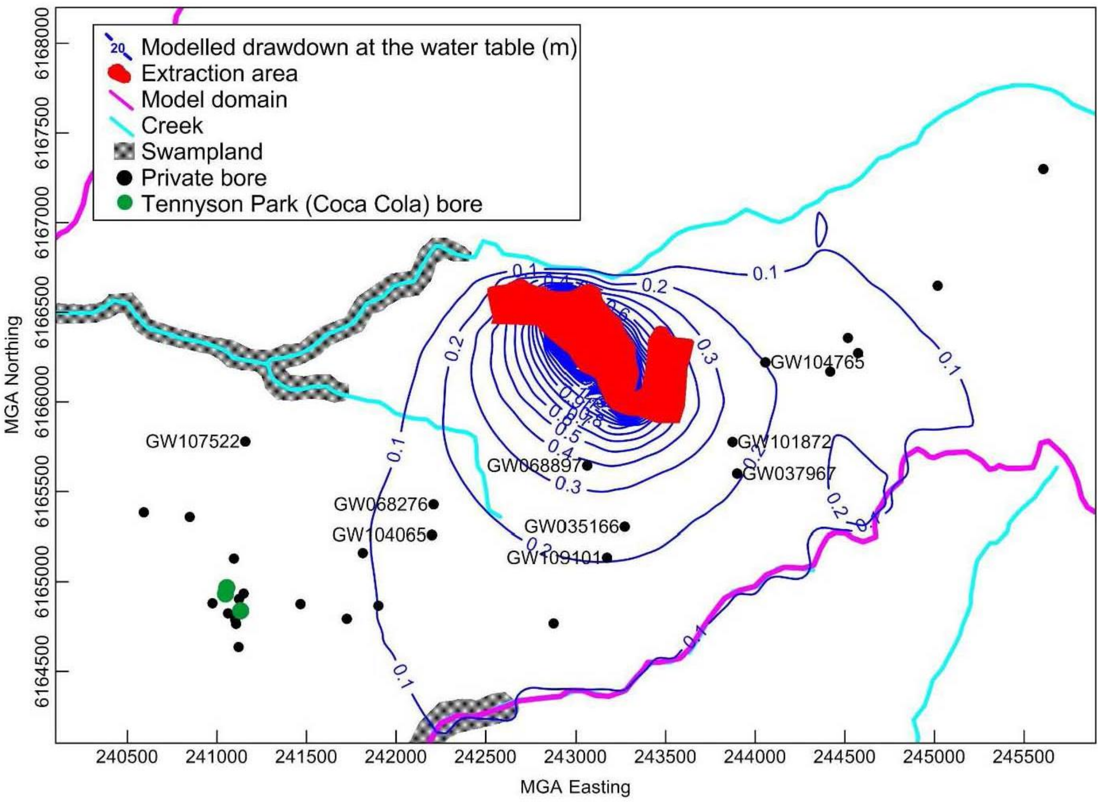




14.7.2 Active Extraction Scenario

The predicted drawdown of the water table at the end of Stage 5 extraction (Year 28) is shown in **Figure 23**. The figure also shows registered private bores in the vicinity of the extraction area.

Figure 23 Predicted Long Term Drawdown – Year 28 (after Coffey, 2016)



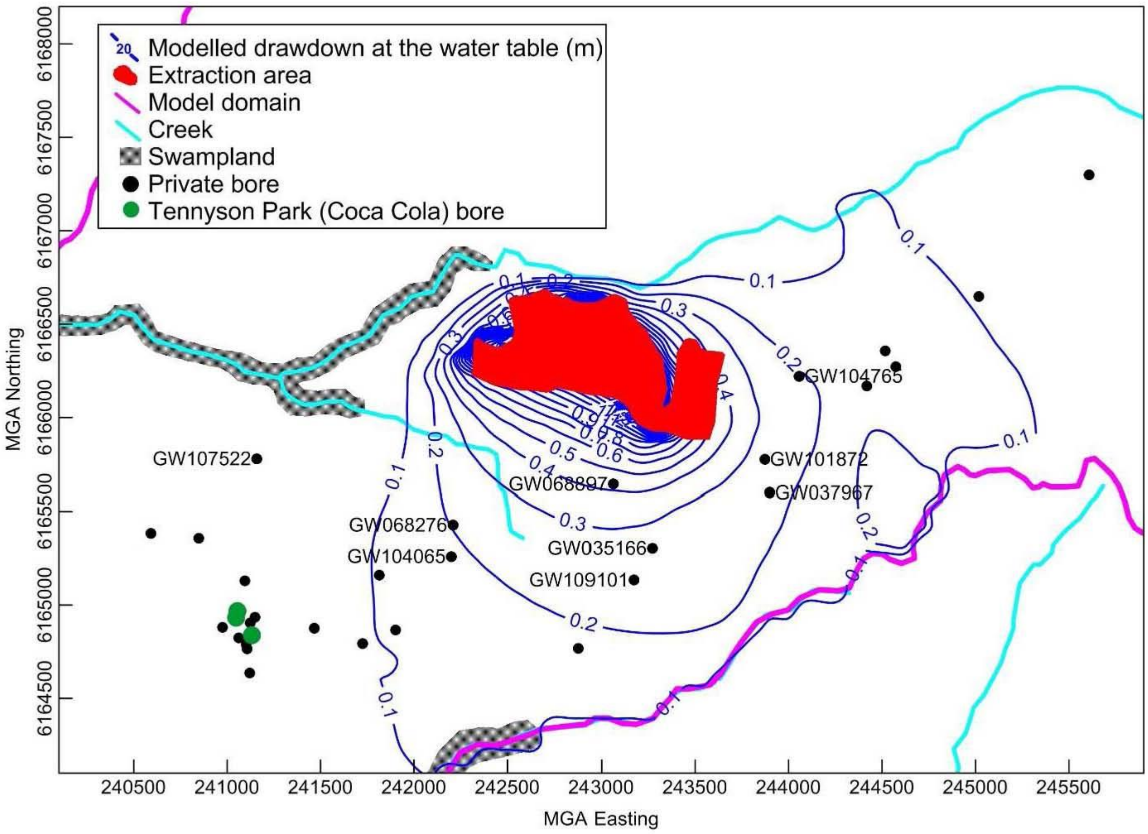
The drawdown at the end of extraction operations (end of Stage 7 at Year 45) is shown in **Figure 24**. The figure also shows registered private bores in the vicinity of the extraction area.

As can be seen, the modelled drawdown of the water table at the end of Year 28 and Year 45 extraction at each private bore is less than 0.5 m. The affected bores and predicted maximum drawdown are listed as follows:

Bore	Maximum Water Table Drawdown at end of Stage 5 (Year 28)	Maximum Water Table Drawdown at end of Stage 7 (Year 45)
GW035166	< 0.3 m	< 0.3 m
GW037967	< 0.3 m	< 0.3 m
GW068897	< 0.4 m	< 0.5 m
GW101872	< 0.3 m	< 0.3 m

Figure 24 Predicted Long Term Drawdown – Year 45

(after Coffey, 2016)



14.7.3 Groundwater Flow

The results of the predictive simulation are as follows:

- Long Swamp and Long Swamp Creek have a modelled baseflow of 2.01 ML/day in the extraction inactive scenario.
- In the extraction active scenario, groundwater inflow to the extraction area would cause a reduction in baseflow to Long Swamp Creek, and other watercourses.
- In the extraction active scenario, with the wells (bores) and extraction area active, the extraction area receives a total, long term modelled inflow of 2332 ML over the 45 years of operation. This leads to a maximum reduction of 0.052 ML/day in baseflow to Long Swamp Creek, and a reduction of 0.019 ML/day in baseflow to other watercourses. Coffey (2016) calculates that the reduction for Long Swamp Creek is 2.6% of the modelled baseflow.
- In the extraction active scenario, inflows into the extraction area would commence once extraction occurs below 665 m AHD in Stages 0 and 1 (approximately the beginning of Year 3) and reach a maximum of approximately 0.2 ML/day in the early part of Stage 6.

14.7.4 Post-Extraction Groundwater Regime

As a result of backfilling, the final landform topography scopes from south to north, in the direction of groundwater flow. The model predicts that the equilibrated water table hosted by the backfill material barely intersects ground surface in the extraction area.

The long-term average groundwater discharge from the backfill in the extraction area is calculated by Coffey (2016) as 0.002 ML/day which is likely to be consumed by evaporation before discharging to watercourses.

14.8 GROUNDWATER MODELLING ASSESSMENT CONCLUSIONS

The results of the groundwater modelling assessment indicate the following:

- The modelled intercepted baseflow to Long Swamp Creek and its tributaries due to extraction is a maximum of about 2.6% compared to the calculated long-term average baseflow.
- The modelled contour of 0.2 m drawdown of the water table (due to Site extraction operations) extends a maximum of about 1 km from the extraction area at the end of Stage 5 (Year 28) and about 1.2 km at the end of Stage 7 (end of extraction operations, Year 45).
- The maximum modelled drawdown of the water table at the end of extraction operations (Year 45) at each private bore is less than 0.5 m. The maximum modelled drawdown of the water table (due to Site extraction operations) at Year 45 (end of extraction operations) in the vicinity of the four closest private bores to the extraction area is as follows:
  - GW035166: < 0.3 m
  - GW037967: < 0.3 m
  - GW068897: < 0.5 m
  - GW101872: < 0.3 m.
- Given the depths of the four closest bores to the extraction area, and their recorded water levels, this is unlikely to cause significant loss of available groundwater at these locations and is within drawdown limits set in the Aquifer Interference Policy.
- Other private bores are unlikely to be influenced by the proposed extraction regime.
- Industrial mineral water extraction bores, including the Coca Cola Amatil bores located between approximately 1.3 km to 2 km south west of the extraction area are unlikely to be influenced by the proposed extraction regime.
- The long-term average groundwater discharge from the backfill in the extraction area is calculated as 0.002 ML/day. This is likely to be consumed by evaporation before discharging to watercourses. Where increased discharge occurs (during higher rainfall periods), the discharge (where not consumed by surface evaporation) will exit the area as watercourse flow.

The modelled reduction in base flow to Long Swamp Creek arising from the active extraction predictive scenario is 2.6% of the long term average. Coffey (2016) conclude that given the depth of the four private bores closest to the extraction area and their recorded water levels, the modelled drawdown is unlikely to cause any significant loss of available groundwater at these locations. The predicted drawdowns are within the maximum interference drawdown of 2.0 m permitted in the Aquifer Interference Policy. Coffey (2016) also predict that the modelled water table drawdown at 20 years after cessation of extraction operations has reduced to less than 0.1 m throughout the modelled domain and occurs only within the footprint of the extraction area.

15. ASSESSMENT OF POTENTIAL GROUNDWATER IMPACTS

15.1 INTRODUCTION

Potential impacts may include impacts to water supply bores, GDEs and culturally significant sites that are dependent on groundwater. The impact assessment criteria have been developed for a range of groundwater sources and whether they fall into a highly productive or less productive category as defined for each WSP area. Highly productive groundwater sources are those meeting the criteria of 1,500 mg/L total dissolved solids (TDS) and a bore yield rate of greater than 5 L/s. Thresholds for minimal impact considerations have been developed for the AIP and relate to impacts on groundwater table and pressure, and to groundwater and surface water quality.

Five potential impacts associated with the Proposal are listed below and discussed in the following sections.

- Local and regional groundwater system;
- Local groundwater users;
- Local creek flow;
- Groundwater chemistry; and
- GDEs.

Potential adverse impacts on GDEs are assessed separately in Section 18.

15.2 LOCAL AND REGIONAL GROUNDWATER SYSTEM

The hydrogeological investigations indicate that the regional direction of sandstone-hosted groundwater flow is to the northeast. The results of the hydrogeological investigations and groundwater modelling indicate that inflows into the pit would commence once extraction extends below approximately 665 m AHD in Stages 0 and 1.

However, the active extraction scenario of this groundwater model predicts that the drawdown of the water table at any of the private bores surrounding the Site during the 45 year operation will be less than 0.5 m. The predicted drawdowns are within the maximum interference drawdown limit of 2.0 m permitted in the Aquifer Interference Policy.

15.3 LOCAL GROUNDWATER USERS

The results of the transient groundwater modelling indicate that the cone of depression associated with the proposed extraction area would have negligible impacts upon a small number of neighbouring private registered bores.

The groundwater model predicts that the extent of the 0.2 m drawdown radius of influence surrounding the extraction area at the end of Year 28 is asymmetrical and extends up to approximately 1 km to the south-southwest and up to 500 m to the east. Modelled contours of maximum drawdown for this case are shown in **Figure 23**.

The model predicts that the extent of the 0.2 m drawdown radius of influence surrounding the extraction area at the end of Year 45 is also asymmetrical and extends up to approximately 1.3 km to the south-southeast and up to 650 m to the east. Modelled contours of maximum drawdown for this case are shown in **Figure 24**.

The maximum modelled drawdown of the water table at the end of extraction operations (Year 45) at each private bore is less than 0.5 m. The maximum modelled drawdown of the water table (due to Site extraction operations) at Year 45 (end of extraction operations) in the vicinity of the four closest private bores to the extraction area is as follows:

- GW035166: < 0.3 m
- GW037967: < 0.3 m
- GW068897: < 0.5 m
- GW101872: < 0.3 m.

A summary of the details for the four potentially affected bores taken from the CL&W computerised database, predicted maximum drawdowns and calculations of the percentage of available drawdown is provided in **Table 19**.

Table 19
Summary of Maximum Predicted Drawdowns at Neighbouring Bores

Bore	Approval and Purpose	Depth (m)	Aquifers and Yield	Water Level (m)	Available Drawdown (m)	Predicted Maximum Drawdown at End of Extraction Stage 7 Year 45	Percentage of Available Drawdown
GW035166 Bridgewater	10WA109728 Stock & Domestic Basic Landholder Rights	65.2	56.0-65.1 (1 L/s)	40.8	20.0	< 0.3	< 1.5 %
GW037967	10CA111648 10AL111647 WAL25020 Irrigation	83.8	39.0-39.3 (0.3L/s) 65.5-68.0 (0.5L/s) 81.6-82.8 (1.2L/s)	30.4	30.0	< 0.3	< 1.0 %
GW068897	No information	61.0	0.0-35.0 (0.1 L/s) 35.0-61.0 (0.6 L/s)	20.0	40.0	< 0.4	< 1.0 %
GW101872 Bridgewater	Stock & Domestic Basic Landholder Rights	204.0	71.0-72.0 (0.3L/s) 89.0-90.0 (0.3L/s)	63.0	20	< 0.3	< 1.5 %

Given the depth of these bores, reported water levels and resultant available drawdown, the model indicates that any impacts would be insignificant. The amount of predicted drawdown in the four potentially affected bores as a proportion of available drawdown is predicted to be less than 1.5 %. No other private bores outside of the Site are impacted by the predicted cone of depression.

Regular monitoring of water levels in the network of on-site monitoring bores and selected off-site private bores during the life of the Proposal would provide valuable real-time data to assess the amount and degree of any impacts and compare against model predictions.

15.4 LOCAL CREEK FLOW

Coffey (2016) calculated the base flow attributable to groundwater to Long Swamp Creek to be approximately 2.01 ML/day (Coffey, 2016).

With private pumping bores active but extraction inactive, Coffey (2016) predicts that Long Swamp Creek has a modelled baseflow of 2.01 ML/day. With private pumping bores active and extraction active, Long Swamp Creek has a modelled baseflow of 1.97 ML/day.

With the surrounding groundwater bores operational and extraction operations in progress, the extraction area receives a long term modelled inflow of 0.14 ML/day. This is supplied by a maximum reduction of 0.04 ML/day in baseflow to Long Swamp Creek to Year 28 and 0.052 ML/day between Year 28 and Year 45. Coffey (2016) calculated that the reduction for Long Swamp Creek is approximately 2.6% of the modelled baseflow. This reduction in baseflow is considered to be within the range of natural variation in flows for this type of system.

Coffey (2016) notes that the lowest level of the proposed extraction area is a minimum of 10 m above the channel of Long Swamp Creek directly opposite.

15.5 GROUNDWATER CHEMISTRY

Any groundwater inflow into the extraction area is predicted to be low salinity, non-toxic and effectively diluted by rainwater. That is, the chemistry of any residual water retained in the final void would be dominated by rainwater.

It is also concluded that the proposed extraction area is predicted not to impact on the chemistry of the groundwater quality of any neighbouring bore.

15.6 GROUNDWATER DEPENDENT ECOSYSTEMS

The GDEs, regulatory framework policy and Director General’s requirements are detailed in Section 16. Potential impacts on Long Swamp, identified as a Temperate Highland Peat Swamp and GDE from the proposed extraction operations are also discussed.

15.7 ASSESSMENT OF PROPOSED QUARRY

Having regard to the presence of a semi-confined to confined porous sandstone aquifer system beneath the proposed extraction area, the key parameters for assessing minimal impact considerations for the extraction area are the potential adverse impacts from the extraction area on water pressure and water quality. In this regard, the transient numerical groundwater model predicts a maximum decline in water level in any surrounding water works to be less than 1 m. This is assessed to be a Level 1 impact at accordance with Table 1 of the AIP and therefore considered acceptable. Point 6, Section 2 of the Aquifer Interference Assessment Framework states that "Where the assessment determines that the impacts fall within the Level 1 impacts, the assessment should be 'Level 1 – Acceptable". The location of the extraction area and baseline groundwater chemistry indicates there is no evidence to suggest that a significant change in water quality would result from the aquifer interference activity.

The results of the transient groundwater model predict that at the end of the quarry life (45 years), baseflow to Long Swamp and Long Swamp Creek could be reduced by a maximum of 0.052 ML/day. This predicted base flow reduction equates to approximately 2.6% of the modelled baseflow of Long Swamp Creek. This base flow reduction is the maximum predicted impact at the end of the quarry life.

15.8 RISKS AND UNCERTAINTIES

The main uncertainties in the groundwater impact assessment are considered to be the degree of heterogeneity of the Hawkesbury Sandstone aquifer system on the local scale and hence the actual impact on the flow in Long Swamp Creek. In order to understand and assess how accurate the model predictions are, a program of ongoing monitoring of water levels, water quality and groundwater extraction (production and pit inflows) and reporting of these data would likely be required to ensure that the impacts are within the range predicted.

Groundwater Monitoring and reporting strategies would constitute an important part of a Management Plan to be developed as part of any development consent. A suggested outline for a monitoring and reporting strategy is provided in Sections 21.3 and 21.6. In addition, the transient groundwater model could be periodically updated during the life of the Proposal as additional information is acquired.

15.9 STRATEGIES TO MINIMISE ANY RISKS

Strategies to minimise the risks and uncertainties in the groundwater model predictions of impacts would depend on progressive monitoring results throughout the life of the Quarry. Strategies to mitigate any risks may include acquisition of additional water licences or exploring possible offsets.

16. GROUNDWATER DEPENDENT ECOSYSTEMS

16.1 INTRODUCTION

Sinclair Knight Mertz (2001) makes reference to the environmental water requirements of GDEs. They use the term 'proportional response' which they define as a *'progressive decline in ecological process as the actual water regime shifts away from the natural regime.' Sinclair Knight Mertz* (2001) further notes that *'Defining ecosystem responses to change in the water regime would be difficult for ecosystems whose ecological processes are poorly understood or whose water regimes are complex.'*

Field inspections and office-based studies identified evidence of modifications to the environment in the local area (and region) from 100 years of agricultural pursuits (clearing, soil improvements and cropping), grazing and sand extraction. In addition, extensive historic peat mining in some Temperate Highland Peat Swamps such as Long Swamp has caused considerable changes in those areas.

The hydrology and hydrodynamics of groundwater dependent ecosystems (GDEs) is complex. The New South Wales State *Groundwater Dependent Ecosystems Policy* (NSW Government 2002) identifies four types of GDEs in New South Wales which are supported by five broad types of aquifers (groundwater systems). The dominant type of GDE identified near the Site is Temperate Highland Peat Swamps Developed on Sandstone such as Long Swamp, in particular within natural depressions or along watercourses such as Long Swamp Creek, Hanging Rock Swamp and Stingray Swamp.

The other type of GDE that may be present near the Site is Terrestrial Vegetation which is *'supported by shallow groundwater either permanently or seasonally'*. The dominant type of groundwater system is Sedimentary Rock Groundwater Systems described as 'sedimentary rock aquifers includes sandstone shale and coal'.

Three GDEs are known in the area surrounding the Site, namely Long Swamp within the Long Swamp Creek system north and west of the Site, Hanging Rock Swamp to the south and Stingray Swamp located approximately 1.5 km south-east of the Site on the eastern watershed of Penrose State Forest (see Section 11.6).

By definition, these vegetation communities are identified as having a dependence on groundwater.

16.2 DIRECTOR-GENERAL'S REQUIREMENTS

The Director-General's Requirements (DGRs) relevant to this groundwater impact assessment are summarised in **Table 2** (Section 6) together with reference to where each requirement is addressed in this document. The DGRs specify the key biodiversity issues required to be addressed through a detailed assessment of the potential impact of the proposed development on groundwater dependent ecosystems (GDEs), riparian resource, threatened species and their habitats and native vegetation.

The key documents relevant to this assessment are the NSW State Groundwater Dependent Ecosystems Policy (NSW Government 2002) and the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources (2011).

16.3 ENVIRONMENTAL FLOWS INITIATIVE TECHNICAL REPORT NO.2

A useful reference providing non-site-specific details on the Environmental Water Requirements to maintain GDEs was issued by Environment Australia in 2001 titled Environmental Flows Initiative Technical Report No.2 (Environment Australia, 2001). The report identifies four key attributes:

- **Flux**: the rate of surface or sub-surface discharge of an aquifer;
- **Water Level**: depth to the water table (piezometric surface) which, in the case of the Proposal, is relevant for the GDEs immediately north and west of the extraction area;
- **Groundwater Pressure**: In confined aquifers has a similar role to water level in unconfined aquifers; and
- **Water Quality**: Typically measured in terms of electrical conductivity (EC), nutrient content and/or contaminations concentrations.

The report lists various forms of groundwater dependency and states that groundwater may not be the sole source of water exploited by many dependent ecosystems. Surface water, direct precipitation (rainfall) and soil water may be important contributing factors. The report also develops a three dimensional framework for GDE water usage:

- **Thresholds**: Within which one or more of the four key groundwater attributes listed above must remain for the ecosystem to be adequately maintained.
- **Rates of Use**: That indicates the consumptive use and/or requirements of dependent ecosystems.
- **Temporary Distribution of Use**: Patterns of water usage or requirements of dependent ecosystems.
- **Temporal Dimensions of Usage**: Timing, frequency, duration, episodicity must all be described to adequately determine the environmental water requirement.

16.4 NSW STATE GROUNDWATER DEPENDENT ECOSYSTEMS POLICY

The NSW State Groundwater Dependent Ecosystems Policy lists five management principles for GDEs which are listed below. The principles provide the foundations for a considered response regarding potential impacts on GDEs by the Proposal. In this regard, a discussion is provided addressing each of the principles.

16.4.1 Principle 1

The scientific, ecological, aesthetic and economic values of groundwater dependent ecosystems, and how threats to them may be avoided, should be identified and action taken to ensure that the most vulnerable and the most valuable ecosystems are protected.

16.4.2 Principle 2

Groundwater extractions should be managed within the sustainable yield of aquifer systems, so that the ecological processes and biodiversity of their dependent ecosystems are maintained and/or restored. Management may involve establishment of threshold levels that are critical for ecosystem health, and controls on extraction on the proximity of groundwater dependent ecosystems.

16.4.3 Principle 3

Priority should be given to ensuring that sufficient groundwater of suitable quality is available at the times when it is needed:

- *for protecting ecosystems which are known to be, or are most likely to be, groundwater dependent; and*
- *for groundwater dependent ecosystems which are under immediate or high degree of threat from groundwater related activities.*

16.4.4 Principle 4

Where scientific knowledge is lacking, the Precautionary Principle should be applied to protect groundwater dependent ecosystems. The development of adaptive management systems and research to improve understanding of these systems is essential to their management.

16.4.5 Principle 5

Planning, approval and management of developments and land use activities should aim to minimise adverse impacts on groundwater dependent ecosystems by:

- *maintaining, where possible, natural patterns of groundwater flow and not disrupting groundwater levels that are critical for ecosystems;*
- *not polluting or causing adverse changes in groundwater quality; and*
- *rehabilitation of degraded groundwater systems where practical.*

16.4.6 Potential Impacts on Long Swamp

Long Swamp is located on Long Swamp Creek approximately 200 m west, and downslope of, the western extremity of the proposed extraction operations (**Figure 8**).

The active extraction transient computer groundwater modelling scenario predicts a maximum baseflow reduction of 0.052 ML/day in Long Swamp Creek and Long Swamp over the 45 years of extraction. This equates to a reduction for Long Swamp Creek and Long Swamp of 2.6% of the modelled baseflow. This reduction in baseflow is considered to be within the range of natural variation in flows for this type of GDE.

In addition, the active extraction groundwater modelling scenario also predicts maximum drawdown of the water table at the eastern end of Long Swamp of less than 0.1 m at the end of Stage 5 - Year 28 and the same prediction at the end of Stage 7 - Year 45 (**Figures 23 and 24**).

In light of this assessment, the five principles listed above are considered to be satisfied.

17. INFLOW OF GROUNDWATER INTO PIT VOID

The factors affecting the rate of inflow of groundwater into an extraction void are the size, shape, location, rate of excavation and the hydrogeological properties of the host rock, in particular the effective permeability of the Hawkesbury Sandstone. The rate of inflow of groundwater into the progressively expanding extraction area will also be controlled by local geologic and structural elements.

As the extraction intercepts the piezometric surface, hydraulic gradients would begin to steepen toward the excavation, inducing flow towards the extraction area. A seepage face may develop on the walls of the extraction area. Therefore, dewatering of the extraction void would effectively lower the groundwater level in the sandstone aquifer proximal to the extraction area and reduce the pore pressures on the surrounding walls which, in some rock types, can improve slope stability.

The active extraction transient computer groundwater modelling scenario predicts an average inflow of 0.14 ML/day over the 45 years quarry life which equates to approximately 51 ML per annum. Groundwater inflow is predicted by Coffey (2016) to commence in Stages 0 and 1, at which time the water table may be impacted. Inflow is expected to be low at first increasing gradually over the remaining life of the Proposal reaching a predicted maximum of 0.2 ML/day.

18. WATER ACCESS LICENSING

18.1 PREDICTED QUARRY GROUNDWATER INFLOW

As noted in Section 17, the active extraction transient groundwater modelling scenario predicts average inflow to the extraction area of 0.14ML/day up to a maximum of 0.2ML/day which equates to approximately 51 ML per annum.

Subject to a successful application to CL&W for a change of purpose for WAL25051 from ‘irrigation’ to ‘industrial’ under the Water Management Act 2000, there is considered to be insufficient available water in the 45 ML allocation to account for the predicted inflow within the extraction area as well as supply supplementary make-up water, the latter of which is discussed in Section 18.2.

18.2 SUPPLEMENTARY MAKE-UP WATER

Calculations of the make-up water required to satisfy the water demands of the processing operations and dust suppression requirements of the Proposal indicate that approximately 33 ML per annum may be required in 50% of years to supplement water supplied under harvestable rights. In this regard, additional water supplies could be sourced from the allocation attached to bore GW104765.

It is not uncommon in these circumstances for the Applicant to seek acquisition of additional groundwater entitlement through water trading. However, as can be seen in **Table 20**, the current water entitlement for the Site (GW104765) is 45 ML. This allocation is attached to Water Access Licence WAL25051 for the purpose of irrigation. Condition 3 of the licence restricts the pumping rate to less than 2.0 L/s.

Subject to the receipt of development consent, the applicant should apply to CL&W for a change of purpose for WAL25051 from ‘irrigation’ to ‘industrial’ under the Water Management Act 2000. The details of the production bore, available drawdown and indicative yield provided in **Table 3** and 45 ML allocation indicate that it is a useful potential supply of supplementary water for the Proposal. However, an additional allocation will likely be required to satisfy the demands during ‘dry’ periods and the average 51 ML/year groundwater inflow into the extraction area.

18.2.1 Current Approvals and Licences – The Site

The water resources of the Site are covered by the Water Sharing Plan (WSP) for the Greater Metropolitan Region Groundwater Sources. The two bores on Lot 4 DP 253435 (GW101872 and GW104765) have current approvals as documented in **Table 20**. The landowner holds a Water Access Licence for bore GW104765 under the Water Management Act 2000 and the applicant holds an agreement for usage of this allocation for the Proposal.

Table 20
Current Approvals and Licences – Registered Bores on Site

Bore	Approval	Licence/s	Term	Authorised Purpose	Share Component	Licence Conditions
GW101872	10WA110379	Basic Rights	1/7/11-	Stock & Domestic	N/A	N/A
GW104765	10CA112020	10AL112019 WAL25051	1/7/11- 30/6/24	Irrigation	45 ML	Pumping ≤ 2.0 L/s

19. IMPACT MITIGATION STRATEGIES

19.1 INTRODUCTION

Recognition of the important and dynamic interrelationship between surface water, groundwater systems and land use in the hydrologic cycle of landscapes suggests that an integrated approach to water management for the Proposal is required especially given the presence and documented importance of GDEs in the catchment. This concept is developed in the following sub sections.

A strategy for the management of monitoring data and in-house and regulatory reporting would also be required as part of any Water Management Plan (WMP). A suggested approach is provided in sections 19.3 to 19.6.

19.2 INTEGRATED APPROACH TO WATER MANAGEMENT

The importance of the link between surface water and groundwater systems has been widely documented in the recent scientific literature. The combination of sheeted ‘stacked’ sandstone aquifers and deeply dissected valley systems resulting in tiered topography, and widespread occurrence of high priority GDEs suggests that an integrated approach to water management is required for the Proposal. The WMP would integrate the results of the groundwater studies presented herein and surface water assessments.

19.3 GROUNDWATER MONITORING PROGRAM

Automated measurements of water level should be continued in the monitoring network in order to build on the existing dataset. An ongoing long-term program of regular water level (measurements and manual readings) and water quality sampling and analysis in a strategically designed monitoring network is recommended in order to collect additional hydrogeological data.

Monitoring data would be statistically analysed to establish any natural variation in water levels water quality in monitoring bores and neighbouring production bores within the outwardly migrating cone of depression surrounding the expanding quarry to compare as predicted by the transient computer groundwater model. The recommended monitoring network includes on-site and neighbouring bores as listed in **Table 21**.

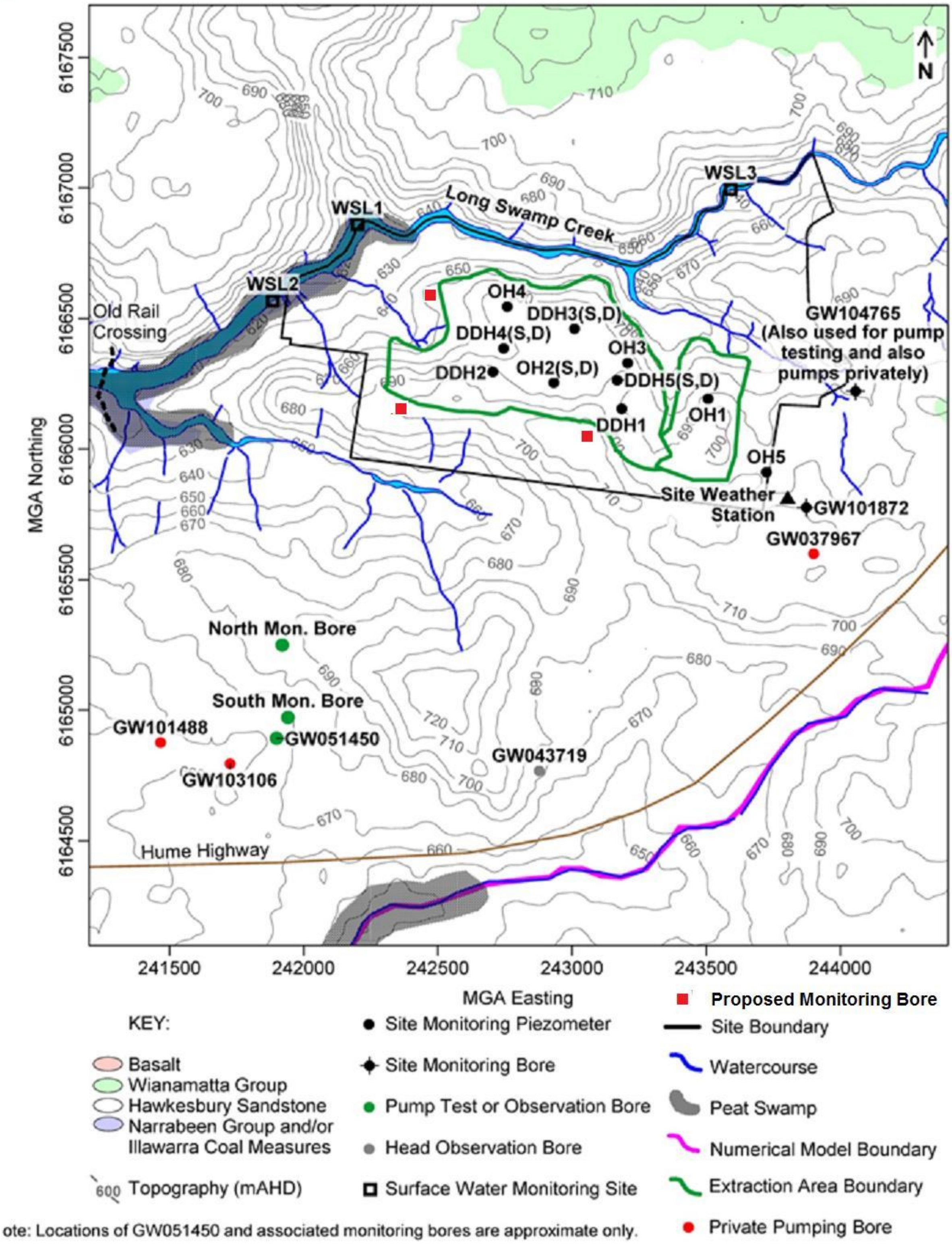
As extraction operations progress, the monitoring network would need to be supplemented in the longer term with additional monitoring bores being established as existing bores are removed. The results of the hydrogeological investigations indicate that no impacts on the water table would occur until about the end of Year 3 (Stages 0 and 1). The proposed locations of the three additional monitoring bores are shown in **Figure 25**.

Table 21
Recommended Monitoring Bore Network

Bore	Bore Type	Monitoring Type
SQF DDH 1	On-site Monitoring Bore	Water level measurements and water quality testing
SQF DDH 2	On-site Monitoring Bore	Water level measurements and water quality testing
SQF DDH 3D	On-site Monitoring Bore	Water level measurements and water quality testing
SQF DDH 3S	On-site Monitoring Bore	Water level measurements and water quality testing
SQF DDH 4D	On-site Monitoring Bore	Water level measurements and water quality testing
SQF DDH 4S	On-site Monitoring Bore	Water level measurements and water quality testing
SQF DDH 5D	On-site Monitoring Bore	Water level measurements and water quality testing
SQF DDH 5S	On-site Monitoring Bore	Water level measurements and water quality testing
SQF OH 1	On-site Monitoring Bore	Water level measurements and water quality testing
SQF OH 2D	On-site Monitoring Bore	Water level measurements and water quality testing
SQF OH 2S	On-site Monitoring Bore	Water level measurements and water quality testing
SQF OH 3	On-site Monitoring Bore	Water level measurements and water quality testing
SQF OH 4	On-site Monitoring Bore	Water level measurements and water quality testing
SQF OH 5	On-site Monitoring Bore	Water level measurements and water quality testing
SQF OH 6*	On-site Monitoring Bore	Water level measurements and water quality testing
SQF OH7*	On-site Monitoring Bore	Water level measurements and water quality testing
SQF OH8*	On-site Monitoring Bore	Water level measurements and water quality testing
GW101872	Registered Production Bore	Water level measurements and water quality testing
GW104765	Registered Production Bore	Water level measurements and water quality testing

Note: * denotes new proposed monitoring bores peripheral to extraction area

Figure 25 Proposed Monitoring Bore Network



It is noted that measurements of water level are currently collected using automated water level sensors/data loggers and recorders (with telemetry) in six on-site monitoring bore with the data being downloaded on a weekly basis.

Manual measurements of water level should be collected on a monthly basis in selected monitoring bores.

It is recommended that sampling and analysis of groundwater quality in the monitoring bores should be carried out on a quarterly (3 monthly) basis for an initial period of 24 months. In this way, analysis of the results would establish any trends in water quality and establish any natural variation. Careful analysis and progressive assessment of the results may lead to the reduction of the number of analytes determined and the frequency of sampling. A set of indicator analytes can be developed which would alert the Quarry Manager of any significant changes in water quality that may require action. The recommended list of analytes and tests for quarterly sampling is provided in **Table 22**. It is recommended that the water quality data is reviewed every year to ensure only meaningful data is being collected.

Table 22
Recommended List of Analytes and Tests

Tests and TDS
pH
Electrical Conductivity (EC)
Total Dissolved Solids (TDS)
Cations
Sodium (Na)
Calcium (Ca)
Potassium (K)
Magnesium (Mg)
Ammonia (NH4-N)
Anions
Chloride (Cl)
Sulphate (SO4)
Carbonate Alkalinity (as CaCO3)
Bicarbonate Alkalinity (as CaCO3)
Hydroxide Alkalinity (OH^-) as CaCO3)
Total Alkalinity (as CaCO3)
Metals
Arsenic (As)
Cadmium (Cd)
Chromium (Cr)
Copper (Cu)
Lead (Pb)
Zinc (Zn)
Nickel (Ni)

Rainfall data should continue to be collected within the Site at the on-site meteorological station. The data should be collated in an electronic database for evaluation with the groundwater and surface water data.

A recommended monitoring program is provided in **Table 23**.

Table 23
Recommended Monitoring Program

Monitoring Type	Activity	Sample Frequency	Comment
Water Level	Automatic water level measurements using data logger in monitoring bores	• *Initial* 12-hourly (1 sample every 12 hours) • *Assess* data after 12 months • *Depending* on results and trends, decrease frequency to 24-hourly (1 sample every 24 hours)	This sample frequency is designed to provide adequate, real time water level data, optimise the logger battery life and optimise logger memory. Telemetry may be useful and cost effective in the long-term.
Water Quality	Groundwater sampling analysis representative monitoring bores	• *Initial* 3-monthly (1 sample per bore) for 24 months • *Assess* data after 24 months	This sample frequency is designed to provide adequate water quality data to detect any significant changes in groundwater chemistry.
Rainfall	Automatic rainfall measurements in *tipping bucket rain gauge* data logger on site	• *Continuous* logging at every 0.2 mm tip with time/date recorded	This sample frequency is designed to provide adequate, real time good quality rainfall data, optimise the logger battery life and optimise logger memory.

19.4 DATA MANAGEMENT

The recommended protocol for data management would be incorporated in a WMP. A suggested protocol is summarised as follows.

- The water level data downloaded from the water level data loggers in the monitoring bores is presently imported into an electronic database or spreadsheet via telemetry and viewed weekly to ensure the operational integrity of the sensors. This process would ensure that a progressive record of the data is stored and maintained, and the integrity/quality of the data can be checked on a regular basis.
- Maintain the existing electronic water quality database
- Develop and maintain Site rainfall database.

19.5 DEVELOPMENT OF TRIGGER LEVELS

At this stage, with available monitoring data, it is considered premature to establish a set of absolute water levels, bore yield or water quality trigger values that if ‘exceeded’ may indicate that. The results of the Coffey numerical groundwater modelling assessment indicate that no impacts on the water table would occur within the first three years of extraction. This timeframe would allow for collection and assessment of regularly acquired water level and water quality monitoring data from the monitoring bore network (as proposed in Section 21.3) and development of meaningful trigger levels. Ranges will be established that take into account, natural variation and fluctuations in climate and rainfall, and possible artificial changes induced by pumping from the network of existing district and neighbouring bores.

It is recognised that any significant decrease in water level and/or changes in water quality in monitoring bores and monitoring sites may be a consequence of several factors including but not necessarily limited to reduced rainfall and aquifer recharge, pumping interference from neighbouring bores or interference from extraction operations.

The development of a set of trigger levels is considered an important component of on-going long-term assessment of any potential impacts from extraction operations on the local groundwater systems and environment.

In the event that the established trigger water levels in monitoring bores are ‘exceeded’ and an impact is indicated, action would include an immediate assessment of rainfall data and water level fluctuations in other monitoring bores to establish trends and ascertain whether there is a correlation or otherwise with quarrying.

Any mitigation measures would depend on the degree of fluctuations in water levels in the monitoring bores, and the assessment of the significance of any impacts. Additional mitigation measures may need to be developed depending on the nature and degree of any impacts that may be revealed at the end of the review stages.

19.6 REPORTING

A protocol for reporting would be incorporated in a WMP. A suggested protocol for reporting is summarised as follows:

- All water level data and any groundwater quality monitoring results should be recorded, collated and duly reported in-house on at least a six-monthly basis for the first 12 months then on an annual basis. The data should be reviewed annually with the aim to assess any changes in water levels or groundwater chemistry and identify reasons for the changes if they occur. The monitoring schedule should be reviewed annually and changed if deemed appropriate by the hydrogeological consultant.
- Annual review of the results of the statistical analysis of monitoring data in order to detect any imminent or occurring impacts.
- A complete set of results of the production and monitoring program including a review and assessment of the statistical analysis should be formally reported in the Quarry’s Annual Review for circulation to relevant government agencies including CL&W.

The report should include but not necessarily be limited to:

- a figure showing the locations of the monitoring bore network
- a set of hydrographs;
- rainfall data correlations;
- progressive assessment of any trends in water level fluctuations;
- analytical results and progressive assessment of any trends in water quality;
- progressive assessment of any statistical trends; and,
- conclusions and recommendations

19.7 MITIGATION OF ANY IMPACTS TO NEIGHBOURING WATER USERS

The water table at private bores surrounding the Site is predicted to draw down by 0.5 m or less over the 45 year life of the extraction operations. Given the depth of the bores and reported water levels, this is unlikely to result in any significant impacts. However, if there is a scientifically and independently demonstrated significant impact on any neighbouring water users surrounding the Site, for example, a fall in bore water level, bore performance (bore yield) or water quality that can, with the available scientific data, be attributed to extraction operations, the following options are presented for consideration in a WMP subject to any agreement/s between the property owner and the Applicant.

- Supply groundwater supplies to the property/s with a minimum flow equivalent to the measured and documented losses with water quality commensurate with the present bore supply, or better.
- Deepen the affected bore, if feasible.
- Drill a new test bore for the owner in order to replace or improve the bore yield of the existing registered bore. The water quality must be similar to the existing bore water quality or suitable for the intended purpose.
- Agree to another arrangement mutually acceptable to the property owner and the Applicant.

20. CONCLUSIONS

The results of the transient computer groundwater modelling assessment indicate the following:

- The local water table will not be intersected by the expanding extraction area until about the end of Year 3 (Stages 0 and 1).
- Inflows into the pit would commence once extraction occurs below 665 m AHD in stages 0 and 1 and reach a maximum of approximately 0.2 ML/day in the early part of Stage 6. The total average groundwater inflow to the pit void over 45 years is estimated to be about 0.14 ML/day. This equates to approximately 51 ML per annum.
- The transient groundwater modelling assessment predicts that the cone of depression surrounding the extraction area arising from the inflow of groundwater into the progressively expanding extraction area is asymmetrical and extends up to approximately 1 km to the south and up to 750 m to the east. The modelled contour of 0.2 m drawdown of the water table (due to extraction operations) extends a maximum of about 1 km from the extraction area at the end of Stage 5 (Year 28) and about 1.2 km at the end of Stage 7 (end of extraction operations, Year 45).
- The predicted intercepted baseflow to Long Swamp Creek and its tributaries due to extraction is a maximum of about 2.6% compared to the calculated long-term average baseflow.
- The maximum modelled drawdown of the water table at the end of extraction operations (Year 45) at each private bore is less than 0.5 m. The maximum modelled drawdown of the water table (due to extraction operations) at Year 45

(end of extraction operations) in the vicinity of the four closest private bores to the extraction area is as follows:

- GW035166: < 0.3 m
- GW037967: < 0.3 m
- GW068897: < 0.5 m
- GW101872: < 0.3 m

- The amount of predicted drawdown in the four closest private bores as a proportion of available drawdown is predicted to be less than 1.5 %. This degree of water table drawdown is unlikely to create any significant problems.
- Given the depths of the four closest private bores to the extraction area, and their recorded water levels, this is unlikely to cause significant loss of available groundwater at these locations and is within drawdown limits set in the Aquifer Interference Policy.
- Private bores are unlikely to be influenced by the proposed extraction operation.
- Industrial mineral water extraction bores, including the Coca Cola Amatil bores located between approximately 1.3 km to 2 km south west of the extraction area are unlikely to be influenced by the proposed extraction regime.
- Placement of fines in the extraction area would predictably impede and possibly reduce direct recharge from rainfall but aid in the recovery (equilibration) of the water table surrounding the extraction area
- The long-term average groundwater discharge from the backfill in the extraction area is calculated as 0.002 ML/day. This is likely to be consumed by evaporation before being able to freely discharge. Where increased discharge occurs (during higher rainfall periods), the discharge (where not consumed by surface evaporation) will exit the area as surface flow.
- Potential impacts on Long Swamp (identified as a Temperate Highland Peat Swamp and GDE) from the proposed extraction operations were assessed.
- The transient groundwater modelling assessment predicts a maximum reduction of 0.052 ML/day in baseflow to Long Swamp Creek over the 45 years of extraction. This equates to a base flow reduction for Long Swamp Creek of 2.6% of the calculated average annual base flow which is considered to be a minimal impact and within the range of natural variation in flows for this type of GDE.
- The transient groundwater modelling assessment predicts maximum drawdown of the water table at the eastern end of Long Swamp of less than 0.1 m at the end of Stage 5 - Year 28 and the same prediction at the end of Stage 7 – Year 45. This amount of drawdown is not considered significant and within the range of natural variation.
- Calculations of the make-up water required to satisfy the water demands of the sand processing operations and dust suppression activities indicate that approximately 33 ML per annum will, be required to supplement water supplies in 50% of years. Supplementary water would either be sourced from groundwater or commercial supply arrangements. The numerical groundwater modelling assessment incorporated 67% abstraction of the annual allocation of surrounding production bores including bore GW104765 to predict impacts on the local water table associated with the extraction. That is, the use of any supplementary groundwater from bore GW104765 would not result in any additional impacts on the groundwater system.

- An additional water licence will be required to satisfy the average 51 ML/year groundwater inflow into the extraction area predicted by the numerical groundwater model. The additional source of water could include an additional groundwater entitlement obtained by water trading in the same groundwater source. In this regard, calculations of the safe long-term yield for bore GW104765 indicate a sustainable flow rate of 2.1 L/s which equates to an annual production volume of 67 ML/year.
- Regular monitoring of water levels (and water quality) in the network of on-site monitoring bores and selected off-site private bores during the life of the Proposal will provide valuable real-time data to assess the amount and degree of any impacts and enable comparison against transient groundwater model predictions.

21. REFERENCES

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GLOSSARY OF TERMS

ALLUVIUM--Unconsolidated clay, silt, sand, or gravel deposited during recent geologic time by running water in the bed of a watercourse or on its floodplain.

ANISOTROPY--condition of having different properties in different directions.

AQUICLUDE--A saturated geologic unit that is incapable of transmitting significant quantities of water under ordinary hydraulic gradients.

AQUIFER--A geologic formation (or one or more geologic formations) that is porous enough and permeable enough to transmit water at a rate sufficient to feed a spring or a well. An aquifer transmits more water than an aquitard. A saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients.

AQUIFER SYSTEM--heterogeneous body of interbedded permeable and poorly permeable material that functions regionally as a water-yielding unit; it comprises two or more permeable beds separated at least locally by confining beds that impede vertical ground water movement but do not greatly affect the regional hydraulic continuity of the system; includes both saturated and unsaturated parts of permeable materials.

AQUIFER YIELD--Maximum rate of withdrawal that can be sustained by an aquifer. See YIELD.

AQUITARD--A part of a geologic formation (or one or more geologic formations) that is of much lower permeability than an aquifer and would not transmit water at a rate sufficient to feed a spring or for economic extraction by a well. A saturated geologic unit that transmits water in quantities insufficient for economic use.

BEDROCK--The solid rock that underlies any unconsolidated sediment or soil.

BICARBONATE--The anionic constituent HCO3 that has a single negative charge as dissolved in water. Nearly all of the alkalinity in water is composed of bicarbonate. An alkalinity value (reported as mg/L CaCO3) for a water can be converted to the equivalent bicarbonate concentration in mg/L by multiplying by 1.219.

BOUNDARY CONDITION--mathematical expression of a state of the physical system that constrains the equations of the mathematical model.

CALCIUM--The element Ca that occurs as a cation with a double positive charge when dissolved in water; the major dissolved constituent constituting hardness in water.

CALIBRATION (model application)--process of refining the model representation of the hydrogeologic framework, hydraulic properties, and boundary conditions to achieve a desirable degree of correspondence between the model simulation and observations of the ground-water system.

CARBONATE--The anionic constituent CO3 that has two negative charges as dissolve din water or present in a mineral.

CASING RADIUS--Radius of unperforated portion of well casing.

CHLORIDE--The anionic form of the element chlorine (Cl) that has a single negative charge as dissolved in water.

CLAY--A very fine grained material, smaller than silt (clay has a diameter of less than 1/256 mm). Clay is formed by the weathering and breaking down of rocks and minerals.

CONCEPTUAL MODEL--interpretation or working description of the characteristics and dynamics of the physical system.

CONE OF DEPRESSION--A cone-shaped depression in the water table around a well or a group of wells. The cone is created by withdrawing ground water more quickly than it can be replaced.

CONFINED AQUIFER--An aquifer that is bounded above and below by confining layers. Because of the pressure created in a confined aquifer, the water level in a well drilled into a confined aquifer would rise above the top of the aquifer and, in some instances, above the land's surface. An aquifer with upper and lower boundaries consisting of aquicludes.

CONTACT SPRING--A type of gravity spring whose water flows to the land surface from permeable rocks that are underlain by less permeable rocks, preventing the downward movement of water.

DEPTH TO WATER--The depth of the water table below the earth's surface.

DISCHARGE--Movement of ground water from the subsurface to the land surface, usually from a spring or to a marsh, river, or watercourse.

DISCHARGE AREA--An area where ground water is lost naturally from an aquifer through springs, seeps, or hydraulic connection to other aquifers. The water leaving the aquifer is called discharge.

DOMESTIC USE--Water used for drinking and other purposes by a household such as from a rural well.

DOUBLE-POROSITY FRACTURED AQUIFER--An aquifer represented by a double porosity system consisting of low-permeability, primary porosity blocks and high-permeability, secondary porosity fissures.

DOWNGRADIENT--In reference to the movement of ground water, the "downstream" direction from a point of reference (e.g. a well).

DRAWDOWN--Lowering of the ground-water surface or the piezometric pressure caused by pumping, measured as the difference between the original ground-water level and the current pumping level after a period of pumping. Change in water level relative to static condition due to pumping or slug withdrawal during an aquifer test.

ELEVATION HEAD--see hydraulic head.

EPHEMERAL FLOW--when water flows in a channel only after precipitation.

FAULT--A fracture or break in underground rock usually resulting from tectonic stresses along which one or both sides move. Movement along faults may produce earthquakes; most faults are relatively minor with movement involving only a few feet.

FINITE-DIFFERENCE METHOD--numerical technique for solving a system of equations using a rectangular mesh representing the aquifer and solving for the dependent variable in a piece-wise manner.

FINITE-ELEMENT METHOD--numerical technique for solving a system of equations using an irregular triangular or quadrilateral mesh representing the aquifer and solving for the dependent variable in a continuous manner.

FLUX--refers to the rate of flow; it is the quantity of material or energy transferred through a system or a portion of a system in a unit time and is called mass flux. If the moving matter is a fluid, the flux may be measured as volume of fluid moving through a system in a unit time and is called volume flux. For most applications, we desire to know the flux per unit area of a system rather than the flux of the entire system; the flux per unit area is called the flux density.

FORMATION--A body of rock identified by physical characteristics and stratigraphic position and mappable at the earth's surface or traceable in the subsurface. The formation is the fundamental unit in lithostratigraphic classification. Formations can be subdivided into members or lumped together into groups.

GEOLOGY--The study of the earth, what it's made of, and how it changes over time.

GEOLOGIC STRUCTURES--Features produced by deformation or displacement of the rocks, such as folds, faults, and fractures.

GRAVEL PACK--Coarse sand and gravel placed in the annular space between the borehole and the well casing in the vicinity of the well screen. The purpose of the gravel pack is to minimize the entry of fine sediment into the well, stabilize the borehole, and allow the flow of ground water into the well.

GROUND WATER--Underground water that is generally found in the pore space of rocks or sediments and that can be collected with wells, tunnels, or drainage galleries, or that flows naturally to the earth's surface via seeps or springs.

GROUND-WATER-FLOW MODEL--application of a mathematical model to represent a site-specific ground-water flow system.

GROUND-WATER FLOW SYSTEM--set of ground-water flow paths with common recharge and discharge areas. Flow systems are dependent on both the hydrogeologic characteristics of the soil/rock material and landscape position. Areas of steep or undulating (hummocky) relief tend to have dominant local-flow systems (discharging in nearby topographic lows such as a pond or watercourse) Areas of gently sloping or nearly flat relief tend to have dominant regional-flow systems (discharging at much greater distances than local systems in major basin topographic lows or oceans.)

GROUND-WATER HYDROGRAPH--see hydrograph.

GROUND-WATER STORAGE--(1) quantity of water in the saturated zone, or (2) water available only from the storage as opposed to capture.

HARDNESS—(1) Water-quality parameter that indicates the level of alkaline salts, principally calcium and magnesium, and expressed as equivalent calcium carbonate (CaCO3). Hard water is commonly recognized by the increased quantities of soap, detergent, or shampoo necessary to lather. (2) In mineralogy, the degree of hardness of a mineral is an aid in identification. Geologists have assigned numbers to the hardness of several minerals; in this hardness scale, softer minerals are assigned a low mineral and the harder minerals a higher number.

HEAD--see hydraulic head.

HEAD LOSS--see hydraulic head.

HECTARE (ha)--One hectare equals 2.47 acres. One square kilometre equals 100 hectares. One square mile equals 259 hectares.

HETEROGENEOUS--material property that varies with the location within the material. See also homogeneous.

HOMOGENEOUS--material is homogeneous if its hydrologic properties are identical everywhere.

HYDRAULIC CONDUCTIVITY--Factor of proportionality in Darcy's equation relating flow velocity to hydraulic gradient having units of length per unit of time. A property of the porous medium and the fluid (water content of the medium). The volume of water moving through a unit area of aquifer perpendicular to the direction of flow in unit time under a unit hydraulic gradient.

HYDRAULIC GRADIENT--slope of the water table or potentiometric surface. The change is static head per unit of distance in a given direction. If not specified, the direction generally is understood to be that of the maximum rate of decrease in head.

HYDRAULIC HEAD OR (STATIC) HEAD--Height that water in an aquifer can raise itself above an (arbitrary) reference level (or datum), and is generally measured in feet. When a borehole is drilled into an aquifer, the level at which the water stands in the borehole (measured with reference to a horizontal datum such as sea level) is, for most purposes, the hydraulic head of water in the aquifer. This term defines how much energy water possesses. Ground water possesses energy mainly by virtue of its elevation (elevation head) and of its pressure (pressure head). See also hydrostatic head. When ground water moves, some energy is dissipated and therefore a head loss occurs.

HYDRAULICALLY CONNECTED--A condition in which ground water moves easily between aquifers that are in direct contact. An indication of this condition is that the water levels in both aquifers are approximately equal.

HYDROGEOLOGY--The study of ground water and its relationship to geology. Also sometimes known as geohydrology.

HYDROGRAPH--graph showing stage, flow, velocity, or other characteristics of water with respect to time. A watercourse hydrograph commonly shows rate of flow; a ground-water hydrograph shows water level or head.

HYDROLOGIC BUDGET OR BALANCE--Accounting of the inflow to, outflow from, and storage in a hydrologic unit such as a watercourse basin, aquifer, soil zone, lake, or reservoir; the relationship between evaporation, precipitation, runoff, and the change in water storage, expressed by the hydrologic equation.

HYDROLOGIC CYCLE--The complete cycle that water can pass through, beginning as atmospheric water vapour, turning into precipitation and falling to the earth's surface, moving into aquifers or surface water, and then returning to the atmosphere via evapotranspiration.

HYDROLOGY--The study of the characteristics and occurrence of water, and the hydrologic cycle. Hydrology concerns the science of surface and ground waters, whereas hydrogeology principally focuses on ground water.

HYDROSTATIC HEAD--height above a standard datum of the surface of a column of water or other liquid that can be supported by the (hydro) static pressure at a given point.

HYDROSTATIC PRESSURE--Pressure exerted by water at any given point in a body of water at rest.

IGNEOUS ROCK--Rock that forms when a hot liquid (magma) cools and hardens.

IRRIGATION USE--Water applied to the soil surface by centre pivots, ditches or other means, or to the soil subsurface by tubes to add to the water available for plant growth.

ISOTROPIC--said of a medium whose properties are the same in all directions. See anisotropy.

JOINT--In geologic terms, a natural fracture, usually vertical, in a rock. Joints are common in limestone, and caves usually form along joints and bedding planes.

LEAKY AQUIFER--An aquifer with upper and lower boundaries of one aquitard and one aquiclude or two aquitards.

LITHOLOGY--(1) The description of rocks on the basis of physical characteristics, such as colour and mineral composition. (2) The physical character of a rock.

MAGNESIUM--The cationic form of the element magnesium (Mg) that has a double positive charge as dissolved in water; along with calcium, a major dissolved constituent constituting hardness in water.

MAGNESIUM-BICARBONATE TYPE--The constituents with the largest concentrations in this type of water are calcium (Ca) and bicarbonate (HCO3).

MAJOR DISSOLVED CONSTITUENTS--The substances in largest concentration that are dissolved in waters are calcium, magnesium, sodium, bicarbonate, chloride, sulphate, and silica, although nitrate can sometimes be a major constituent.

mg/L--Milligrams of a substance dissolved in one litre of water. The value is essentially the same as a part per million in freshwater because one litre of distilled water weighs one million milligrams (one kilogram).

MILLIGRAMS PER LITRE (mg/L)--Milligrams per litre of water. This measure is equivalent to parts per million (ppm).

MODEL--Assembly of concepts in the form of mathematical equations that portray understanding of a natural phenomenon.

MODELLING--Investigative technique that uses a mathematical or physical representation of a system or theory that accounts for all or some of its known properties. Models are often used to test the effects of changes of system components on the overall performance of the system.

MONITORING WELL--Non-pumping well used primarily for drawing water-quality samples; also for measuring ground-water levels.

NATURAL RECHARGE--Naturally occurring water added to an aquifer. Natural recharge generally comes from snowmelt and precipitation or storm runoff.

NUMERICAL METHODS--set of procedures used to solve the equations of a mathematical model in which the applicable partial differential equations are replaced by a set of algebraic equations written in terms of discrete values of state variables at discrete points in space and time. There are many numerical methods. Those in common use in ground-water models are the finite-difference method, the finite-element method, the boundary-element method, and the analytical-element method.

NUMERICAL MODEL--model that uses numerical methods to solve the governing equations of the applicable problem.

OBSERVATION WELL--non-pumping well used primarily for observing the elevation of the water table or the piezometric pressure; also to obtain water-quality samples.

OUTCROP--That part of a rock unit that is exposed at the earth's surface.

PARTS PER MILLION (ppm)--See milligrams per litre.

PERCHED WATER TABLE--Water table of a relatively small ground-water body lying above the general ground-water body.

PERCHING HORIZON--A relatively impermeable (i.e., incapable of transmitting fluids) lens or layer of clay or bedrock in otherwise permeable sediments that slows or prevents the downward movement of water.

PERENNIAL FLOW--year-round flow.

PERIOD--A unit of geologic time. Several periods make up an era.

PERMEABLE--Permeability is a measure of the ease with which a fluid would move through a porous material (e.g., sand and gravel or rock). A geologic unit is permeable if ground water moves easily through it.

PERMEABILITY--(1) Ability of a material (generally an earth material) to transmit fluids (water) through its pores when subjected to pressure or a difference in head. Expressed in units of volume of fluid (water) per unit time per cross section area of material for a given hydraulic head; (2) description of the ease with which a fluid may move through a porous medium; abbreviation of intrinsic permeability. It is a property of the porous medium only, in contrast to hydraulic conductivity, which is a property of both the porous medium and the fluid content of the medium.

pH--measure of the relative acidity or alkalinity of water. Defined as the negative log (base 10) of the hydrogen ion concentration. Water with a pH of 7 is neutral; lower pH levels indicate an increasing acidity, while pH levels above 7 indicate increasingly basic solutions.

PIEZOMETER--small-diameter well open at a point or short length in the aquifer to allow measurement of hydraulic head at that point or short length. An open-ended pipe installed in an aquifer to measure hydraulic head at a specific depth.

PIEZOMETRIC PRESSURE--pressure corresponding to the height to which water would rise in an observation well penetrating an aquifer.

PIEZOMETRIC SURFACE--surface defined by a pressure head and position (elevation above a standard datum, such as sea level). For an unconfined aquifer, it is equal to the elevation of the water table. For a confined aquifer, it is equal to the elevation to which water would rise in a well penetrating and open to the aquifer. This term is now replaced by potentiometric surface.

POROSITY--Fraction of bulk volume of a material consisting of pore space. Porosity determines the capacity of a rock formation to absorb and store ground water. The ratio of void volume to total volume in an unconsolidated material.

POROUS--Geologically, this term describes rock that permits movement of fluids through small, often microscopic openings, much as water moving through a sponge. Porous rocks may contain gas, oil, or water.

POTENTIOMETRIC SURFACE--Imaginary surface representing the static head of ground water and defined by the level to which water would rise in a well. The water table is a particular potentiometric surface.

PRECIPITATION--Water in some form that falls from the atmosphere. It can be in the form of liquid (rain or drizzle) or solid (snow, hail, sleet).

QUARTZ--An important rock-forming mineral, crystalline silica (SiO2) occurs either in transparent hexagonal crystals or in crystalline or cryptocrystalline masses. Quartz is the commonest mineral next to feldspar and forms the majority of most sands. It is widely distributed in igneous, sedimentary, and metamorphic rocks. It has a hardness of 7 on the Mohs scale.

RECHARGE--The replenishment of ground water in an aquifer. It can be either natural, through the movement of precipitation into an aquifer, or artificial-the pumping of water into an aquifer.

RECHARGE AREA--A geographic area where water enters (recharges) an aquifer. Recharge areas usually coincide with topographically elevated regions where aquifer units crop out at the surface. In these areas infiltrated precipitation is the primary source of recharge. The recharge area may also coincide with the area of hydraulic connection where one aquifer receives flow from another adjacent aquifer.

SAFE YIELD--(1) Rate of surface-water diversion or ground- water extraction from a basin for consumptive use over an indefinite period of time that can be maintained without producing negative effects; (2) the annual extraction from a ground-water unit which would not, or does not, exceed the average annual recharge; ii. so lower the water table that permissible cost of pumping is exceeded; iii. so lower the water table as to permit intrusion of water of undesirable quality; or iv. so lower the water table as to infringe upon existing water rights; (3) the attainment and maintenance of a long-term balance between the amount of ground water withdrawn annually and the annual amount of recharge; (4) the maximum quantity of water that can be guaranteed from a reservoir during a critical dry period. Synonymous to firm yield.

SALINE WATER--Water containing more than 10,000 parts per million (ppm) of dissolved solids of any type. Brackish water contains between 1,000 and 10,000 ppm of dissolved solids.

SALINITY--The total quantity of dissolved salts in water, usually measured by weight in milligrams per litre (mg/L) or parts per million (ppm). The upper limit for freshwater is 1,000 mg/L; natural seawater has a salinity of approximately 35,000 mg/L.

SAND--A rock fragment or mineral particle smaller than a granule and larger than a coarse silt grain. Its diameter ranges from 1/16 to 2 mm.

SATURATED THICKNESS--The vertical thickness of an aquifer that is full of water. The upper surface is the water table. The height of the hydrogeologically defined aquifer unit in which the pore spaces are filled (saturated) with water. For the High Plains aquifer and similar unconfined, unconsolidated aquifers, the saturated thickness is equal to the difference in elevation between the bedrock surface and the water table. The predevelopment saturated thickness is based on the best available estimate of the elevation of the water table prior to human alteration by groundwater pumping. Vertical distance measured from the top of an aquifer (confining layer or water table) to the base of the aquifer.

SATURATED ZONE--That portion of soil or an aquifer in which all of the pore space is filled with water.

SEEP--A discharge of water that "oozes out of the soil or rock over a certain area without distinct trickles or rivulets" (from H. Bouwer, 1978, Groundwater Hydrology: New York, McCraw-Hill, 480 p.).

SIMULATION--in ground-water-flow modelling, one complete execution of a ground-water-modelling computer program, including input and output.

SODIUM--The cationic form of the element sodium (Na) that has a single positive charge as dissolved in water.

SPECIFIC DISCHARGE--for ground water, the rate of discharge of ground water per unit area measured at right angles to the direction of flow.

SPECIFIC RETENTION--ratio of the volume of water that a given body of rock or soil would hold against the pull of gravity to the volume of the body itself. It is usually expressed as a percentage. Compare with field capacity.

SPECIFIC STORAGE--volume of water released from or taken into storage per unit volume of the porous medium per unit change in head. It is the three-dimensional equivalent of storage coefficient or storativity, and is equal to storativity divided by aquifer saturated thickness. The volume of water released from storage by a unit volume of confined aquifer per unit decline in hydraulic head.

SPECIFIC YIELD--The quantity of water given up by a unit volume of a substance when drained by gravity. The volume of water released from storage per unit surface area of an unconfined aquifer per unit decline of the water table.

SPRING--A place where ground water flows naturally from the earth into a body of surface water or onto the land surface, at a rate sufficient to form a current.

STEADY-STATE FLOW--characteristic of a flow system where the magnitude and direction of specific discharge are constant in time at any point.

STORATIVITY or STORAGE COEFFICIENT--volume of water released per unit area of aquifer and per unit drop in head. Storage coefficient is a function of the compressive qualities of water and matrix structures of the porous material. A confined aquifer's ability to store water is measured by its storage coefficient. Storativity is a more general term encompassing both or either storage coefficient and/or specific yield. The volume of water released from storage per unit surface area of a confined aquifer per unit decline in hydraulic head.

SUBSURFACE--Underground. Below the earth's surface.

SUBSURFACE WATER--all water below the land surface, including soil moisture, capillary fringe water in the vadose zone, and ground water.

SULPHATE--The anionic constituent SO4 that has two negative charges as dissolved in water.

SURFACE WATER--Water found at the earth's surface, usually in watercourses or lakes.

SUSTAINABLE YIELD--volume of ground water that can be extracted annually from a ground water basin without causing adverse effects.

TOPOGRAPHIC MAP--A map that shows natural human-made features of an area using contour lines (lines of equal elevation) to portray the size, shape, and elevation of the features.

TOPOGRAPHY--Physical features, such as hills, valleys, and plains that shape the surface of the Earth.

TOTAL DISSOLVED SOLIDS (TDS)--The total quantity of minerals (salts) in water, usually measured by weight in milligrams per litre (mg/L) or parts per million (ppm).

TRANSMISSIVITY--flow capacity of an aquifer measured in volume per unit time per unit width. Equal to the product of hydraulic conductivity times the saturated thickness of the aquifer. Transmissivity is the rate of flow under a unit hydraulic gradient through a cross-section of aquifer having a unit width and full saturated thickness. Also expressed as the product of hydraulic conductivity times saturated thickness.

TRIASSIC PERIOD--The interval of geologic time between approximately 248.2 and 205.7 million years ago.

UNCONFINED AQUIFER--An aquifer that is not bounded above by an aquitard; water levels in wells screened in an unconfined aquifer coincide with the elevation of the water table. An aquifer with an unrestricted (free) upper boundary and an impermeable lower boundary (aquiclude).

UPGRADIENT--In reference to the movement of ground water, the "upstream" direction from a point of reference (e.g., a well).

VADOSE ZONE--unsaturated (not completely filled with water) zone lying between the earth's surface and the top of the ground water. Also known as unsaturated zone and zone of aeration.

VOID--pore space or other openings in rock. The openings can be very small to cave size and are filled with water below the water table.

WATER BALANCE--A mathematical construction that shows the amount of water leaving and entering a given watershed or aquifer.

WATER QUALITY--physical, chemical, and biological characteristics of water and how

WATERSHED--The area drained by a single watercourse or river.

WATER TABLE--A fluctuating demarcation line between the unsaturated (vadose) zone and the saturated (phreatic) zone that forms an aquifer. It may rise or fall depending on precipitation (rainfall) trends. The water table is semi parallel to the land surface above but is not always a consistent straight line. Because of impervious beds of shale, etc., local water tables can be perched above the area's average water table.

WELL--A vertical excavation into an underground rock formation.

WELLBORE RADIUS--Radius of well boring (adjacent to well intake or screen).

WELL SCREEN--A slotted section of pipe usually placed in the borehole adjacent to the main aquifer unit or units that supplies the well with water.

WELL YIELD--Maximum pumping rate that can be supplied by a well without drawing the water level in the well below the pump intake. See YIELD.

YIELD--amount of water that can be supplied from a reservoir, aquifer, basin, or other system during a specified interval of time. This time period may vary from a day to several years depending upon the size of the system involved.

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Annexures

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Annexure 1

Water Level Measurements

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Annexure 1 Sutton Forest Quarry - Water Level Measurements

Monitoring Bore	Coordinates (AMG Grid)		Bore Details			
	Easting (m)	Northing (m)	Depth (m)	Elevation NS (m AHD)	Elevation Base of Bore (m AHD)	Stickup (m AGL)
SQF DDH 1	243185	6166154	51.10	692.7	641.6	0.46
SQF DDH 2	242705	6166295	40.50	682.0	641.5	0.57
SQF DDH 3	243009	6166460	38.90	688.0	649.1	0.65
SQF OH 1	243507	6166192	32.00	690.0	658.0	0.58
SQF OH 2	242932	6166254	36.00	685.2	649.2	0.81
SQF OH 3	243207	6166329	39.00	684.5	645.5	1.30
SQF OH 4	242758	6166545	40.70	686.0	645.3	0.73
SQF OH5 *	243724	6165912	42.00	687.0	645.0	0.63

Water Level Measurements

Monitoring Bore	24/10/12			20/12/12			16/01/13			10/02/13			17/04/13			21/06/13		
	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)
SQF DDH 1	43.50	43.04	649.66	43.76	43.30	649.40	44.56	44.10	648.60	44.39	43.93	648.77	44.17	43.71	648.99	45.1	44.64	648.06
SQF DDH 2	26.66	26.09	655.91	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
SQF DDH 3	38.14	37.49	650.51	37.31	36.66	651.34	37.38	36.73	651.27	37.49	36.84	651.16	36.52	35.87	652.13	36.94	36.29	651.71
SQF OH 1	31.98	31.40	658.60	32.67	32.09	657.91	32.80	32.22	657.78	32.90	32.32	657.68	33.12	32.54	657.46	32.75	32.17	657.83
SQF OH 2	29.90	29.09	656.11	29.50	28.69	656.51	29.52	28.71	656.49	29.63	28.82	656.38	29.41	28.6	656.60	28.67	27.86	657.34
SQF OH 3	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
SQF OH 4	40.45	39.72	646.28	40.45	39.72	646.28	40.25	39.52	646.48	40.49	39.76	646.24	39.82	39.09	646.91	39.75	39.02	646.98
SQF OH5 *				40.30	39.67	647.33	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry

* Control Bore

Monitoring Bore	6/08/13			5/11/13			5/02/14			24/04/14			10/06/14			23/07/14		
	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)
SQF DDH 1	45.34	44.88	647.82	44.55	44.09	648.61	45.26	44.8	647.9	46.12	45.66	647.04	46.91	46.84	645.86	48	47.54	645.16
SQF DDH 2	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
SQF DDH 3	37.46	36.81	651.19	36.84	36.19	651.81	37.31	36.66	651.34	37.15	36.5	651.5	36.82	36.17	651.83	37.42	36.77	651.23
SQF OH 1	33.14	32.56	657.44	31.96	31.38	658.62	32.46	31.88	658.12	32.4	31.82	658.18	Collapsed	Collapsed	Collapsed	31.22	30.76	659.24
SQF OH 2	29.31	28.5	656.70	28.88	28.07	657.13	27.92	27.11	658.09	28.12	27.31	657.89	Collapsed	Collapsed	Collapsed	26.47	25.99	659.21
SQF OH 3	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Collapsed	Collapsed	Collapsed	39.7	39.06	645.44
SQF OH 4	39.89	39.16	646.84	40.21	39.48	646.52	39.4	38.67	647.33	39.56	38.83	647.17	Collapsed	Collapsed	Collapsed	37.85	37.12	648.88
SQF OH5 *	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	41.42	40.79	646.21

Annexure 1 Sutton Forest Quarry - Water Level and Field Water Quality Measurements

Monitoring Bore	Coordinates (AMG Grid)		Bore Details			
	Easting (m)	Northing (m)	Depth (m)	Elevation NS (m AHD)	Elevation Base of Bore (m AHD)	Stickup (m AGL)
SQF DDH 1	243185	6166154	51.10	692.7	641.6	0.46
SQF DDH 2	242705	6166295	40.50	682.0	641.5	0.57
SQF DDH 3	243009	6166460	38.90	688.0	649.1	0.65
SQF OH 1	243507	6166192	32.00	690.0	658.0	0.58
SQF OH 2	242932	6166254	36.00	685.2	649.2	0.81
SQF OH 3	243207	6166329	39.00	684.5	645.5	1.30
SQF OH 4	242758	6166545	40.70	686.0	645.3	0.73
SQF OH5 [1]	243724	6165912	42.00	687.0	645.0	0.63

1 Control Bore

Water Level Measurements

Monitoring Bore	24/10/12			20/12/12			16/01/13			10/02/13			17/04/13			21/06/13		
	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)
SQF DDH 1	43.50	43.04	649.66	43.76	43.30	649.40	44.56	44.10	648.60	44.39	43.93	648.77	44.17	43.71	648.99	45.1	44.64	648.06
SQF DDH 2	26.66	26.09	655.91	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
SQF DDH 3	38.14	37.49	650.51	37.31	36.66	651.34	37.38	36.73	651.27	37.49	36.84	651.16	36.52	35.87	652.13	36.94	36.29	651.71
SQF OH 1	31.98	31.40	658.60	32.67	32.09	657.91	32.80	32.22	657.78	32.90	32.32	657.68	33.12	32.54	657.46	32.75	32.17	657.83
SQF OH 2	29.90	29.09	656.11	29.50	28.69	656.51	29.52	28.71	656.49	29.63	28.82	656.38	29.41	28.6	656.60	28.67	27.86	657.34
SQF OH 3	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
SQF OH 4	40.45	39.72	646.28	40.45	39.72	646.28	40.25	39.52	646.48	40.49	39.76	646.24	39.82	39.09	646.91	39.75	39.02	646.98
SQF OH5 [1]				40.30	39.67	647.33	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry

Monitoring Bore	6/08/13			5/11/13			5/02/14			24/04/14			10/06/14			23/07/14		
	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)	SWL (m TOC)	SWL (m BGL)	SWL (m AHD)
SQF DDH 1	45.34	44.88	647.82	44.55	44.09	648.61	45.26	44.8	647.9	46.12	45.66	647.04	46.91	46.84	645.86	48	47.54	645.16
SQF DDH 2	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
SQF DDH 3	37.46	36.81	651.19	36.84	36.19	651.81	37.31	36.66	651.34	37.15	36.5	651.5	36.82	36.17	651.83	37.42	36.77	651.23
SQF OH 1	33.14	32.56	657.44	31.96	31.38	658.62	32.46	31.88	658.12	32.4	31.82	658.18	Collapsed	Collapsed	Collapsed	31.22	30.76	659.24
SQF OH 2	29.31	28.5	656.7	28.88	28.07	657.13	27.92	27.11	658.09	28.12	27.31	657.89	Collapsed	Collapsed	Collapsed	26.47	25.99	659.21
SQF OH 3	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Collapsed	Collapsed	Collapsed	39.7	39.06	645.44
SQF OH 4	39.89	39.16	646.84	40.21	39.48	646.52	39.4	38.67	647.33	39.56	38.83	647.17	Collapsed	Collapsed	Collapsed	37.85	37.12	648.88
SQF OH5 [1]	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	41.42	40.79	646.21

Field Water Quality Testing

Monitoring Bore	24/10/2012		20/12/2012		16/01/2013		10/02/2013		17/04/2013		21/06/2013	
	pH	EC (µS/cm)	pH	EC (µS/cm)	pH	EC (µS/cm)	pH	EC (µS/cm)	pH	EC (µS/cm)	pH	EC (µS/cm)
SQF DDH 1	nt	nt	5.9	94	5.8	113	5.7	106	5.8	121	6.0	102
SQF DDH 2	Dry		Dry		Dry		Dry		Dry		Dry	
SQF DDH 3	nt	nt	6.2	85	6.1	94	5.9	102	6.0	115	5.9	98
SQF OH 1	nt	nt	iw	iw	iw	iw	iw	iw	iw	iw	iw	iw
SQF OH 2	nt	nt	5.8	114	6.3	98	6.1	106	6.2	103	5.9	101
SQF OH 3	Dry		Dry		Dry		Dry		Dry		Dry	
SQF OH 4	nt	nt	6.0	102	5.6	124	5.9	119	6.0	98	5.7	79
SQF OH5 *	Dry		Dry		Dry		Dry		Dry		Dry	

Monitoring Bore	6/08/2013		5/11/2013		5/02/2014		24/04/2014		10/06/2014		23/07/2014	
	pH	EC (µS/cm)	pH	EC (µS/cm)	pH	EC (µS/cm)	pH	EC (µS/cm)	pH	EC (µS/cm)	pH	EC (µS/cm)
SQF DDH 1	5.8	96	5.9	98	5.8	106	6.0	85	5.9	84	5.8	105
SQF DDH 2	Dry		Dry		Dry		Dry		Dry		Dry	
SQF DDH 3	6.1	102	6.1	99	6.0	113	5.9	102	5.9	94	6.0	114
SQF OH 1	iw	iw	iw	iw	iw	iw	iw	iw	Collapsed	Collapsed	7.4	644
SQF OH 2	6.1	94	5.9	124	6.1	106	6.1	98	Collapsed	Collapsed	7.5	429
SQF OH 3	Dry		Dry		Dry		Dry		Collapsed	Collapsed	6.8	332
SQF OH 4	5.9	123	6.1	117	5.9	82	6.1	98	Collapsed	Collapsed	5.8	82
SQF OH5 *	Dry		Dry		Dry		Dry		Dry		iw	iw

Legend:
nt: not tested
iw: insuffucicient water

Annexure 2

Slug Test Models

(Total No. of pages including blank pages = 20)

Note: This Annexure is only available on the digital version of this document

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DRAWDOWN ANALYSIS DATA

SLUG TEST

Test Date :	9.2.13	**Project :**	Sutton Forest Quarry Project
Test Type:	Rising Head	**Client :**	Sutton Forest quarries Pty Ltd
Bore Depth :	51.10 m	**Job No :**	13017
Start Time :	1140	**Bore ID :**	SFQ DDH 1
End of Test	1145	**Coordinates:**	MGA Grid - 243185 E 616654 N
Hole ID :	98 mm		
Casing ID :	50 mm	**Static Water Level:**	45.00 m BGL
Tested by :	LCC	**SWL at Start of Test :**	50.71 m BGL
		SWL at End of Test :	45.41 m BGL

Real Time	Elapsed Time		Water Level (m)	Change in Water Level (h) (m)	h/h_o	SWL =	45.00
	Minutes	Seconds				h_o =	5.71
1140		0	50.71	5.71	1.00		
		1	50.58	5.58	0.98		
		2	50.47	5.47	0.96		
		3	50.28	5.28	0.92		
		4	50.11	5.11	0.90		
		5	49.91	4.91	0.86		
		6	49.80	4.80	0.84		
		7	49.61	4.61	0.81		
		8	49.48	4.48	0.79		
		9	49.35	4.35	0.76		
		10	49.22	4.22	0.74		
		11	49.11	4.11	0.72		
		12	49.00	4.00	0.70		
		13	48.89	3.89	0.68		
		14	48.80	3.80	0.67		
		15	48.72	3.72	0.65		
		16	48.60	3.60	0.63		
		17	48.51	3.51	0.61		
		18	48.43	3.43	0.60		
		19	48.33	3.33	0.58		
		20	48.26	3.26	0.57		
		21	48.18	3.18	0.56		
		22	48.10	3.10	0.54		
		23	48.03	3.03	0.53		
		24	47.95	2.95	0.52		
		25	47.88	2.88	0.50		
		26	47.82	2.82	0.49		
		27	47.75	2.75	0.48		
		28	47.69	2.69	0.47		
		29	47.61	2.61	0.46		
		30	47.57	2.57	0.45		
		31	47.49	2.49	0.44		
		32	47.44	2.44	0.43		
		33	47.38	2.38	0.42		
		34	47.32	2.32	0.41		
		35	47.27	2.27	0.40		
		36	47.22	2.22	0.39		
		37	47.18	2.18	0.38		
		38	47.14	2.14	0.37		

		39	47.08	2.08	0.36		
		40	47.04	2.04	0.36		
		41	46.99	1.99	0.35		
		42	46.95	1.95	0.34		
		43	46.90	1.90	0.33		
		44	46.88	1.88	0.33		
		45	46.83	1.83	0.32		
		46	46.79	1.79	0.31		
		47	46.75	1.75	0.31		
		48	46.74	1.74	0.30		
		49	46.68	1.68	0.29		
		50	46.63	1.63	0.29		
		51	46.61	1.61	0.28		
		52	46.58	1.58	0.28		
		53	46.53	1.53	0.27		
		54	46.51	1.51	0.26		
		55	46.48	1.48	0.26		
		56	46.45	1.45	0.25		
		57	46.42	1.42	0.25		
		58	46.39	1.39	0.24		
		59	46.36	1.36	0.24		
		60	46.34	1.34	0.23		
		61	46.32	1.32	0.23		
		62	46.28	1.28	0.22		
		63	46.27	1.27	0.22		
		64	46.24	1.24	0.22		
		65	46.22	1.22	0.21		
		66	46.20	1.20	0.21		
		67	46.18	1.18	0.21		
		68	46.16	1.16	0.20		
		69	46.13	1.13	0.20		
		70	46.13	1.13	0.20		
		71	46.10	1.10	0.19		
		72	46.08	1.08	0.19		
		73	46.06	1.06	0.19		
		74	46.05	1.05	0.18		
		75	46.04	1.04	0.18		
		76	46.01	1.01	0.18		
		77	45.98	0.98	0.17		
		78	45.97	0.97	0.17		
		79	45.97	0.97	0.17		
		80	45.95	0.95	0.17		
		81	45.93	0.92	0.16		
		82	45.92	0.92	0.16		
		83	45.91	0.91	0.16		
		84	45.90	0.90	0.16		
		85	45.88	0.88	0.15		
		86	45.88	0.88	0.15		
		87	45.84	0.84	0.15		
		88	45.85	0.84	0.15		
		89	45.83	0.83	0.14		
		90	45.82	0.82	0.14		
		91	45.80	0.80	0.14		
		92	45.78	0.78	0.14		
		93	45.79	0.79	0.14		
		94	45.77	0.77	0.13		

		95	45.75	0.75	0.13		
		96	45.74	0.74	0.13		
		97	45.73	0.73	0.13		
		98	45.74	0.74	0.13		
		99	45.72	0.72	0.13		
		100	45.71	0.71	0.12		
		101	45.69	0.69	0.12		
		102	45.68	0.68	0.12		
		103	45.69	0.69	0.12		
		104	45.68	0.67	0.12		
		105	45.67	0.67	0.12		
		106	45.66	0.66	0.12		
		107	45.65	0.65	0.11		
		108	45.64	0.64	0.11		
		109	45.64	0.64	0.11		
		110	45.63	0.63	0.11		
		111	45.62	0.62	0.11		
		112	45.61	0.61	0.11		
		113	45.62	0.62	0.11		
		114	45.62	0.61	0.11		
		115	45.60	0.60	0.10		
		116	45.59	0.59	0.10		
		117	45.59	0.59	0.10		
		118	45.58	0.58	0.10		
		119	45.58	0.58	0.10		
		120	45.58	0.58	0.10		
		121	45.57	0.57	0.10		
		122	45.56	0.56	0.10		
		123	45.56	0.56	0.10		
		124	45.55	0.55	0.10		
		125	45.56	0.56	0.10		
		126	45.56	0.56	0.10		
		127	45.55	0.55	0.10		
		128	45.54	0.54	0.10		
		129	45.53	0.53	0.09		
		130	45.53	0.53	0.09		
		131	45.53	0.53	0.09		
		132	45.53	0.53	0.09		
		133	45.52	0.52	0.09		
		134	45.52	0.52	0.09		
		135	45.53	0.53	0.09		
		136	45.52	0.52	0.09		
		137	45.51	0.51	0.09		
		138	45.51	0.51	0.09		
		139	45.51	0.51	0.09		
		140	45.52	0.52	0.09		
		141	45.51	0.51	0.09		
		142	45.51	0.51	0.09		
		143	45.51	0.51	0.09		
		144	45.52	0.52	0.09		
		145	45.50	0.50	0.09		
		146	45.50	0.50	0.09		
		147	45.50	0.49	0.09		
		148	45.50	0.50	0.09		
		149	45.49	0.49	0.09		
		150	45.50	0.50	0.09		

		151	45.49	0.49	0.09		
		152	45.50	0.50	0.09		
		153	45.49	0.49	0.09		
		154	45.50	0.50	0.09		
		155	45.49	0.49	0.09		
		156	45.48	0.48	0.08		
		157	45.48	0.47	0.08		
		158	45.48	0.48	0.08		
		159	45.48	0.48	0.08		
		160	45.48	0.48	0.08		
		161	45.47	0.47	0.08		
		162	45.48	0.48	0.08		
		163	45.48	0.48	0.08		
		164	45.47	0.47	0.08		
		165	45.47	0.47	0.08		
		166	45.48	0.48	0.08		
		167	45.48	0.47	0.08		
		168	45.48	0.48	0.08		
		169	45.47	0.47	0.08		
		170	45.48	0.48	0.08		
		171	45.47	0.47	0.08		
		172	45.48	0.47	0.08		
		173	45.47	0.47	0.08		
		174	45.45	0.45	0.08		
		175	45.46	0.46	0.08		
		176	45.47	0.47	0.08		
		177	45.46	0.46	0.08		
		178	45.46	0.46	0.08		
		179	45.46	0.46	0.08		
		180	45.46	0.46	0.08		
		181	45.46	0.46	0.08		
		182	45.45	0.45	0.08		
		183	45.45	0.45	0.08		
		184	45.46	0.46	0.08		
		185	45.47	0.47	0.08		
		186	45.46	0.45	0.08		
		187	45.45	0.45	0.08		
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		189	45.46	0.46	0.08		
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		200	45.45	0.45	0.08		
		201	45.44	0.44	0.08		
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		203	45.44	0.44	0.08		
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		205	45.43	0.43	0.08		
		206	45.45	0.45	0.08		

		207	45.45	0.45	0.08		
		208	45.42	0.42	0.07		
		209	45.45	0.45	0.08		
		210	45.44	0.44	0.08		
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		213	45.44	0.44	0.08		
		214	45.43	0.43	0.08		
		215	45.45	0.45	0.08		
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		217	45.44	0.44	0.08		
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		243	45.41	0.41	0.07		
		244	45.41	0.41	0.07		
		245	45.43	0.43	0.08		
		246	45.43	0.43	0.07		
		247	45.42	0.42	0.07		
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		252	45.41	0.41	0.07		
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		261	45.43	0.43	0.08		
		262	45.41	0.41	0.07		

		263	45.42	0.41	0.07		
		264	45.42	0.42	0.07		
		265	45.42	0.42	0.07		
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		268	45.42	0.41	0.07		
		269	45.43	0.42	0.07		
		270	45.40	0.40	0.07		
		271	45.43	0.43	0.07		
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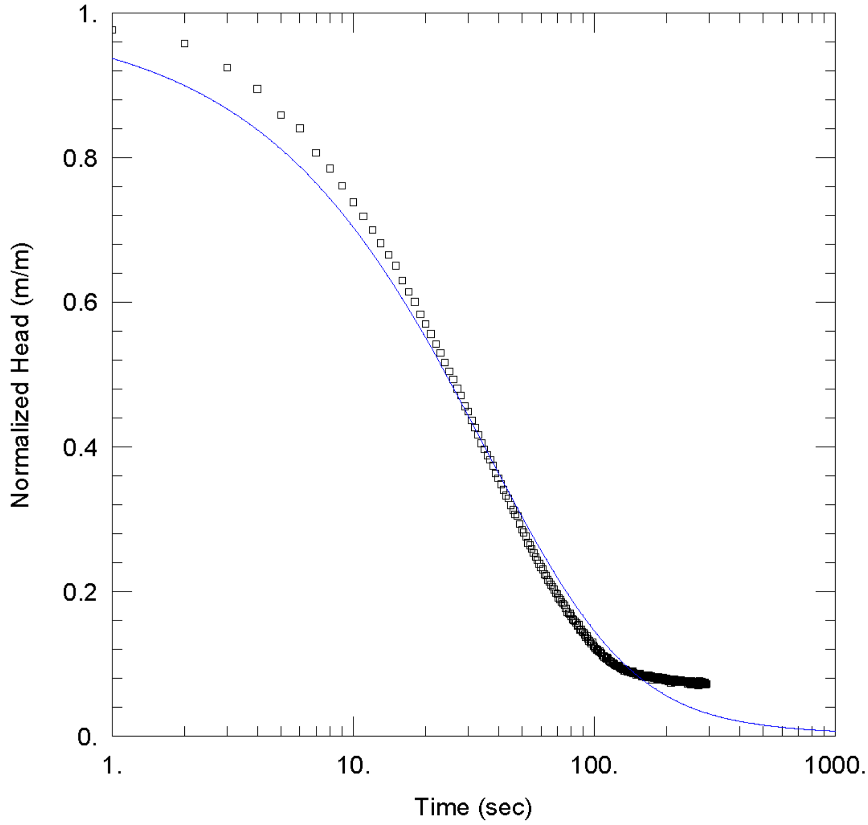
		275	45.43	0.43	0.07		
		276	45.42	0.42	0.07		
		277	45.42	0.42	0.07		
		278	45.43	0.43	0.08		
		279	45.42	0.42	0.07		
		280	45.41	0.41	0.07		
		281	45.42	0.42	0.07		
		282	45.41	0.41	0.07		
		283	45.41	0.41	0.07		
		284	45.41	0.41	0.07		
		285	45.42	0.42	0.07		
		286	45.42	0.42	0.07		
		287	45.42	0.42	0.07		
		288	45.42	0.42	0.07		
		289	45.41	0.41	0.07		
		290	45.41	0.41	0.07		
		291	45.41	0.41	0.07		



WELL TEST ANALYSIS

Data Set: C:\...\SFQ DDH 1-KGS.aqt
Date: 07/30/14 Time: 15:30:35

PROJECT INFORMATION

Company: Larry Cook Consulting
Client: Sutton Forest Quarries
Location: Sutton Forest
Test Well: SFQ DDH 1
Test Date: 9 February 2013

AQUIFER DATA

Saturated Thickness: 6.1 m

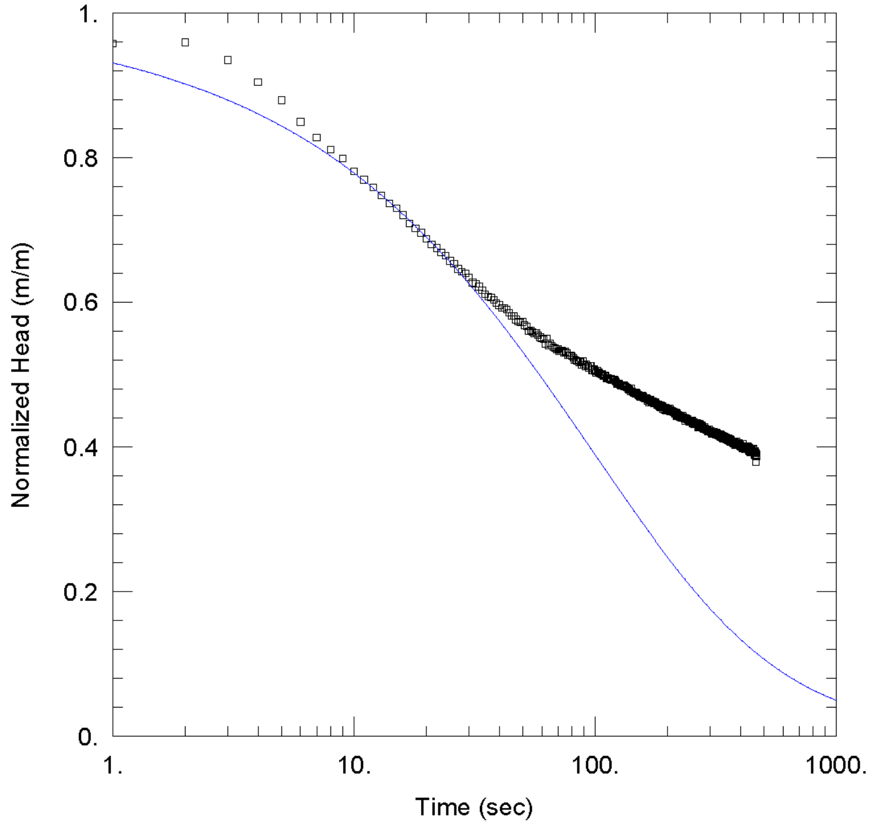
WELL DATA (SFQ DDH 1)

Initial Displacement: 5.71 m
Total Well Penetration Depth: 6.1 m
Casing Radius: 0.025 m
Static Water Column Height: 6.1 m
Screen Length: 6. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 4.071E-6 m/sec
Kz/Kr = 1.
Ss = 0.0002662 m^{-1}



WELL TEST ANALYSIS

Data Set: C:\...\SFQ OH2-KGS.aqt
Date: 07/30/14
Time: 15:27:32

PROJECT INFORMATION

Company: Larry Cook Consulting
Client: Sutton Forest Quarries
Location: Sutton Forest
Test Well: SFQ OH 2
Test Date: 9 February 2013

AQUIFER DATA

Saturated Thickness: 7.2 m

WELL DATA (SFQ OH 2)

Initial Displacement: 4.66 m
Total Well Penetration Depth: 6.2 m
Casing Radius: 0.025 m
Static Water Column Height: 7.2 m
Screen Length: 6. m
Well Radius: 0.046 m

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 6.304E-7 m/sec
Kz/Kr = 1.
Ss = 0.007008 m^{-1}

DRAWDOWN ANALYSIS DATA

SLUG TEST

Test Date :	9.2.13	**Project :**	Sutton Forest Quarry Project
Test Type:	Rising Head	**Client :**	Sutton Forest Quarries Pty Ltd
Bore Depth :	36.00 m	**Job No :**	13017
Start Time :	1310	**Bore ID :**	SFQ OH 2
End of Test	1318	**Coordinates:**	MGA Grid GPS - 242932 E 6166254 N
Hole ID :	96 mm		
Casing ID :	nil	**Static Water Level:**	28.80 m BGL
Tested by :	LCC	**SWL at Start of Test :**	33.46 m BGL
		SWL at End of Test :	30.60m BGL

Real Time	Elapsed Time		Water Level (m)	Change in Water Level (h) (m)	h/h_o	SWL =	28.8
	Minutes	Seconds				h_o =	4.66
1310		0	33.46	4.66	1.00		
		1	33.26	4.46	0.96		
		2	33.27	4.47	0.96		
		3	33.16	4.36	0.94		
		4	33.02	4.22	0.91		
		5	32.90	4.10	0.88		
		6	32.76	3.96	0.85		
		7	32.66	3.86	0.83		
		8	32.58	3.78	0.81		
		9	32.52	3.72	0.80		
		10	32.44	3.64	0.78		
		11	32.39	3.59	0.77		
		12	32.34	3.54	0.76		
		13	32.29	3.49	0.75		
		14	32.24	3.44	0.74		
		15	32.20	3.40	0.73		
		16	32.16	3.36	0.72		
		17	32.11	3.31	0.71		
		18	32.08	3.28	0.70		
		19	32.05	3.25	0.70		
		20	32.01	3.21	0.69		
		21	31.97	3.17	0.68		
		22	31.95	3.15	0.68		
		23	31.92	3.12	0.67		
		24	31.90	3.10	0.66		
		25	31.87	3.07	0.66		
		26	31.85	3.05	0.65		
		27	31.81	3.01	0.65		
		28	31.79	2.99	0.64		
		29	31.79	2.99	0.64		
		30	31.76	2.96	0.63		
		31	31.73	2.93	0.63		
		32	31.72	2.92	0.63		
		33	31.70	2.90	0.62		
		34	31.67	2.87	0.62		
		35	31.65	2.85	0.61		
		36	31.63	2.83	0.61		
		37	31.63	2.83	0.61		
		38	31.61	2.81	0.60		

		39	31.59	2.79	0.60		
		40	31.58	2.78	0.60		
		41	31.56	2.76	0.59		
		42	31.56	2.76	0.59		
		43	31.55	2.75	0.59		
		44	31.53	2.73	0.59		
		45	31.51	2.71	0.58		
		46	31.51	2.71	0.58		
		47	31.49	2.69	0.58		
		48	31.47	2.67	0.57		
		49	31.47	2.67	0.57		
		50	31.47	2.67	0.57		
		51	31.45	2.65	0.57		
		52	31.44	2.64	0.57		
		53	31.41	2.61	0.56		
		54	31.42	2.62	0.56		
		55	31.41	2.61	0.56		
		56	31.40	2.60	0.56		
		57	31.40	2.60	0.56		
		58	31.39	2.59	0.55		
		59	31.37	2.57	0.55		
		60	31.37	2.57	0.55		
		61	31.36	2.56	0.55		
		62	31.33	2.53	0.54		
		63	31.37	2.57	0.55		
		64	31.32	2.52	0.54		
		65	31.34	2.54	0.54		
		66	31.32	2.52	0.54		
		67	31.31	2.51	0.54		
		68	31.30	2.50	0.54		
		69	31.30	2.50	0.54		
		70	31.30	2.50	0.54		
		71	31.28	2.48	0.53		
		72	31.28	2.48	0.53		
		73	31.29	2.49	0.53		
		74	31.27	2.47	0.53		
		75	31.28	2.48	0.53		
		76	31.27	2.47	0.53		
		77	31.26	2.46	0.53		
		78	31.26	2.46	0.53		
		79	31.26	2.46	0.53		
		80	31.25	2.45	0.53		
		81	31.24	2.44	0.52		
		82	31.23	2.43	0.52		
		83	31.23	2.43	0.52		
		84	31.22	2.42	0.52		
		85	31.22	2.42	0.52		
		86	31.21	2.41	0.52		
		87	31.21	2.41	0.52		
		88	31.20	2.40	0.51		
		89	31.22	2.42	0.52		
		90	31.20	2.40	0.51		
		91	31.18	2.38	0.51		
		92	31.20	2.40	0.51		
		93	31.18	2.38	0.51		
		94	31.17	2.37	0.51		

		95	31.19	2.39	0.51		
		96	31.19	2.39	0.51		
		97	31.16	2.36	0.51		
		98	31.16	2.36	0.51		
		99	31.17	2.37	0.51		
		100	31.15	2.35	0.50		
		101	31.14	2.34	0.50		
		102	31.16	2.36	0.51		
		103	31.15	2.35	0.50		
		104	31.15	2.35	0.50		
		105	31.14	2.34	0.50		
		106	31.13	2.33	0.50		
		107	31.13	2.33	0.50		
		108	31.12	2.32	0.50		
		109	31.12	2.32	0.50		
		110	31.13	2.33	0.50		
		111	31.11	2.31	0.50		
		112	31.11	2.31	0.50		
		113	31.11	2.31	0.50		
		114	31.11	2.31	0.50		
		115	31.10	2.30	0.49		
		116	31.10	2.30	0.49		
		117	31.09	2.29	0.49		
		118	31.09	2.29	0.49		
		119	31.10	2.30	0.49		
		120	31.10	2.30	0.49		
		121	31.09	2.29	0.49		
		122	31.08	2.28	0.49		
		123	31.07	2.27	0.49		
		124	31.07	2.27	0.49		
		125	31.07	2.27	0.49		
		126	31.08	2.28	0.49		
		127	31.06	2.26	0.49		
		128	31.06	2.26	0.48		
		129	31.06	2.26	0.48		
		130	31.06	2.26	0.49		
		131	31.06	2.26	0.49		
		132	31.06	2.26	0.48		
		133	31.06	2.26	0.48		
		134	31.05	2.25	0.48		
		135	31.05	2.25	0.48		
		136	31.05	2.25	0.48		
		137	31.04	2.24	0.48		
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		139	31.04	2.24	0.48		
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		145	31.01	2.21	0.47		
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		148	31.02	2.22	0.48		
		149	31.01	2.21	0.47		
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		185	30.92	2.12	0.46		
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		196	30.92	2.12	0.45		
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		205	30.90	2.10	0.45		
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		216	30.89	2.09	0.45		
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		218	30.88	2.08	0.45		
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		259	30.82	2.02	0.43		
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		266	30.81	2.01	0.43		
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		270	30.80	2.00	0.43		
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		272	30.79	1.99	0.43		
		273	30.81	2.01	0.43		
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		275	30.79	1.99	0.43		
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		280	30.78	1.98	0.43		
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		283	30.80	2.00	0.43		
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		291	30.77	1.97	0.42		
		292	30.77	1.97	0.42		
		293	30.76	1.96	0.42		
		294	30.77	1.97	0.42		
		295	30.77	1.97	0.42		
		296	30.78	1.98	0.42		
		297	30.76	1.96	0.42		
		298	30.77	1.97	0.42		
		299	30.76	1.96	0.42		
		300	30.77	1.97	0.42		
		301	30.77	1.97	0.42		
		302	30.76	1.96	0.42		
		303	30.76	1.96	0.42		
		304	30.75	1.95	0.42		
		305	30.75	1.95	0.42		
		306	30.76	1.96	0.42		
		307	30.76	1.96	0.42		
		308	30.76	1.96	0.42		
		309	30.75	1.95	0.42		
		310	30.76	1.96	0.42		
		311	30.76	1.96	0.42		
		312	30.75	1.95	0.42		
		313	30.76	1.96	0.42		
		314	30.76	1.96	0.42		
		315	30.75	1.95	0.42		
		316	30.74	1.94	0.42		
		317	30.76	1.96	0.42		
		318	30.75	1.95	0.42		

		319	30.74	1.94	0.42		
		320	30.75	1.95	0.42		
		321	30.75	1.95	0.42		
		322	30.75	1.95	0.42		
		323	30.74	1.94	0.42		
		324	30.74	1.94	0.42		
		325	30.74	1.94	0.42		
		326	30.74	1.94	0.42		
		327	30.74	1.94	0.42		
		328	30.74	1.94	0.42		
		329	30.74	1.94	0.42		
		330	30.75	1.95	0.42		
		331	30.73	1.93	0.41		
		332	30.73	1.93	0.41		
		333	30.74	1.94	0.42		
		334	30.73	1.93	0.41		
		335	30.73	1.93	0.41		
		336	30.74	1.94	0.42		
		337	30.74	1.94	0.42		
		338	30.73	1.93	0.42		
		339	30.72	1.92	0.41		
		340	30.72	1.92	0.41		
		341	30.73	1.93	0.41		
		342	30.72	1.92	0.41		
		343	30.72	1.92	0.41		
		344	30.73	1.93	0.41		
		345	30.73	1.93	0.41		
		346	30.72	1.92	0.41		
		347	30.72	1.92	0.41		
		348	30.72	1.92	0.41		
		349	30.73	1.93	0.41		
		350	30.71	1.91	0.41		
		351	30.72	1.92	0.41		
		352	30.72	1.92	0.41		
		353	30.72	1.92	0.41		
		354	30.72	1.92	0.41		
		355	30.71	1.91	0.41		
		356	30.71	1.91	0.41		
		357	30.71	1.91	0.41		
		358	30.72	1.92	0.41		
		359	30.71	1.91	0.41		
		360	30.71	1.91	0.41		
		361	30.70	1.90	0.41		
		362	30.70	1.90	0.41		
		363	30.72	1.92	0.41		
		364	30.70	1.90	0.41		
		365	30.70	1.90	0.41		
		366	30.71	1.91	0.41		
		367	30.70	1.90	0.41		
		368	30.70	1.90	0.41		
		369	30.70	1.90	0.41		
		370	30.70	1.90	0.41		
		371	30.70	1.90	0.41		
		372	30.70	1.90	0.41		
		373	30.69	1.89	0.41		
		374	30.69	1.89	0.41		

		375	30.69	1.89	0.41		
		376	30.69	1.89	0.41		
		377	30.69	1.89	0.41		
		378	30.69	1.89	0.40		
		379	30.69	1.89	0.41		
		380	30.69	1.89	0.41		
		381	30.68	1.88	0.40		
		382	30.69	1.89	0.40		
		383	30.68	1.88	0.40		
		384	30.70	1.90	0.41		
		385	30.69	1.89	0.41		
		386	30.69	1.89	0.40		
		387	30.68	1.88	0.40		
		388	30.69	1.89	0.41		
		389	30.68	1.88	0.40		
		390	30.68	1.88	0.40		
		391	30.68	1.88	0.40		
		392	30.68	1.88	0.40		
		393	30.69	1.89	0.41		
		394	30.68	1.88	0.40		
		395	30.68	1.88	0.40		
		396	30.68	1.88	0.40		
		397	30.68	1.88	0.40		
		398	30.67	1.87	0.40		
		399	30.68	1.88	0.40		
		400	30.67	1.87	0.40		
		401	30.67	1.87	0.40		
		402	30.67	1.87	0.40		
		403	30.67	1.87	0.40		
		404	30.67	1.87	0.40		
		405	30.67	1.87	0.40		
		406	30.66	1.86	0.40		
		407	30.65	1.85	0.40		
		408	30.67	1.87	0.40		
		409	30.69	1.89	0.40		
		410	30.67	1.87	0.40		
		411	30.66	1.86	0.40		
		412	30.66	1.86	0.40		
		413	30.67	1.87	0.40		
		414	30.67	1.87	0.40		
		415	30.66	1.86	0.40		
		416	30.65	1.85	0.40		
		417	30.65	1.85	0.40		
		418	30.67	1.87	0.40		
		419	30.66	1.86	0.40		
		420	30.66	1.86	0.40		
		421	30.65	1.85	0.40		
		422	30.66	1.86	0.40		
		423	30.67	1.87	0.40		
		424	30.66	1.86	0.40		
		425	30.67	1.87	0.40		
		426	30.66	1.86	0.40		
		427	30.65	1.85	0.40		
		428	30.67	1.87	0.40		
		429	30.66	1.86	0.40		
		430	30.66	1.86	0.40		

		431	30.67	1.87	0.40		
		432	30.65	1.85	0.40		
		433	30.64	1.84	0.40		
		434	30.65	1.85	0.40		
		435	30.66	1.86	0.40		
		436	30.64	1.84	0.39		
		437	30.63	1.83	0.39		
		438	30.65	1.85	0.40		
		439	30.63	1.83	0.39		
		440	30.63	1.83	0.39		
		441	30.64	1.84	0.39		
		442	30.63	1.83	0.39		
		443	30.64	1.84	0.40		
		444	30.63	1.83	0.39		
		445	30.64	1.84	0.39		
		446	30.64	1.84	0.39		
		447	30.64	1.84	0.40		
		448	30.64	1.84	0.39		
		449	30.64	1.84	0.39		
		450	30.63	1.83	0.39		
		451	30.65	1.85	0.40		
		452	30.65	1.85	0.40		
		453	30.63	1.83	0.39		
		454	30.64	1.84	0.39		
		455	30.63	1.83	0.39		
		456	30.63	1.83	0.39		
		457	30.63	1.83	0.39		
		458	30.62	1.82	0.39		
		459	30.64	1.84	0.39		
		460	30.63	1.83	0.39		
		461	30.61	1.81	0.39		
		462	30.63	1.83	0.39		
		463	30.57	1.77	0.38		
		464	30.62	1.82	0.39		
		465	30.62	1.82	0.39		
		466	30.61	1.81	0.39		
		467	30.60	1.80	0.39		

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Annexure 3

Pump Test Data
Aquifer Testing
Bore GW104765

(Total No. of pages including blank pages = 40)

Note: This Annexure is only available on the digital version of this document

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DRAWDOWN ANALYSIS DATA

CONSTANT RATE PUMPING TEST

Test Date : 23.6.15
Start Time : 0900
Pump Off : 0900 (25.6.15)
Hole ID : 150 mm
Pump Type : Grundfos
Pump Intake : 68.0 m
Tested by : LLC & LJ
Reference Point : Top of Collar (or Air Line) = 0.67 m AGL

PROJECT : Aquifer Testing
CLIENT : Sutton Forest Quarry
JOB NO : 14068
BORE ID : GW104765
SWL at Start of Test : 42.10 m TOC (41.43 m BGL)
Average Discharge Rate: 3.0 L/s

Real Time	Elapsed Time		Water Level (m BGL)	Drawdown (m)	Discharge		Comments
	Hours	Minutes			Time to Fill 20 L (sec)	Rate (L/s) Q	
0900		0	41.43	0.00	6.7	3.0	
23.6.15		1	45.26	3.83			
		1.5	45.93	4.50			
		2	46.33	4.90			
		2.5	46.64	5.21			
		3	46.88	5.45			
		3.5	47.03	5.60			
		4	47.16	5.73			
		4.5	47.28	5.85	7.1	2.8	
		5	47.37	5.94	6.7	3.0	
		5.5	47.44	6.01			
		6	47.51	6.08			
		6.5	47.57	6.14			
		7	47.62	6.19	6.7	3.0	
		7.5	47.68	6.25			
		8	47.71	6.28			
		8.5	47.76	6.33			
		9	47.80	6.37			
		9.5	47.83	6.40			
		12	47.95	6.52	6.7	3.0	
		17	48.17	6.74			
		22	48.42	6.99			
		27	48.53	7.10	7.1	2.8	
		32	48.63	7.20	6.7	3.0	
		37	49.15	7.72			
		42	49.39	7.96			
		47	49.56	8.13	6.7	3.0	
		52	49.63	8.20			
		57	49.71	8.28			
	1	62	49.83	8.40	6.7	3.0	
		67	49.92	8.49			
		72	49.99	8.56			
		77	50.07	8.64			
		82	50.14	8.71			
		87	50.21	8.78			
		92	50.26	8.83			
		97	50.39	8.96			
		102	50.40	8.97	6.7	3.0	
		107	50.46	9.03			
		112	50.52	9.09			
		117	50.55	9.12			
	2	122	50.58	9.15			
		127	50.63	9.20			
		132	50.67	9.24			

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Real Time	Elapsed Time		Water Level (m BGL)	Drawdown (m)	Discharge		Comments
	Hours	Minutes			Time to Fill 20 L (sec)	Rate (L/s) Q	
		137	50.73	9.30			
		142	50.74	9.31			
		147	50.78	9.35			
		152	50.80	9.37			
		157	50.80	9.37			
		162	50.84	9.41			
		167	50.86	9.43			
		172	50.88	9.45			
		177	50.90	9.47			
	3	182	50.93	9.50	6.7	3.0	
		187	50.97	9.54			
		192	50.96	9.53			
		197	50.98	9.55			
		202	51.02	9.59			
		207	51.21	9.78			
		212	51.26	9.83			
		217	51.29	9.86			
		222	51.33	9.90			
		227	51.33	9.90			
		232	51.35	9.92			
		237	51.38	9.95			
	4	242	51.38	9.95	6.7	3.0	
		247	51.40	9.97			
		252	51.42	9.99			
		257	51.41	9.98			
		262	51.45	10.02			
		267	51.44	10.01			
		272	51.45	10.02			
		277	51.48	10.05			
		282	51.50	10.07			
		287	51.49	10.06			
		292	51.53	10.10			
		297	51.55	10.12			
	5	302	51.55	10.12	6.7	3.0	
		307	51.55	10.12			
		312	51.59	10.16			
		317	51.56	10.13			
		322	51.58	10.15			
		327	51.60	10.17			
		332	51.62	10.19			
		337	51.61	10.18			
		342	51.60	10.17			
		347	51.57	10.14			
		352	51.61	10.18			
		357	51.60	10.17			
	6	362	51.63	10.20			
		367	51.64	10.21			
		372	51.65	10.22			
		377	51.65	10.22			
		382	51.66	10.23			
		387	51.68	10.25			
		392	51.68	10.25			
		397	51.69	10.26			
		402	51.69	10.26			
		407	51.69	10.26			
		412	51.70	10.27			

Real Time	Elapsed Time		Water Level (m BGL)	Drawdown (m)	Discharge		Comments
	Hours	Minutes			Time to Fill 20 L (sec)	Rate (L/s) Q	
		417	51.70	10.27			
	7	422	51.71	10.28	6.7	3.0	
		427	51.71	10.28			
		432	51.71	10.28			
		437	51.72	10.29			
		442	51.72	10.29			
		447	51.73	10.30			
		452	51.73	10.30			
		457	51.73	10.30			
		462	51.74	10.31			
		467	51.74	10.31			
		472	51.75	10.32			
		477	51.75	10.32			
	8	482	51.75	10.32			
		487	51.76	10.33			
		492	51.76	10.33			
		497	51.77	10.34			
		502	51.77	10.34			
		507	51.77	10.34			
		512	51.78	10.35			
		517	51.78	10.35			
		522	51.79	10.36			
		527	51.79	10.36			
		532	51.90	10.47			
		537	51.85	10.42			
	9	542	51.88	10.45			
		547	51.90	10.47			
		552	51.90	10.47			
		557	51.90	10.47			
		562	51.92	10.49			
		567	51.90	10.47			
		572	51.91	10.48			
		577	51.92	10.49			
		582	51.90	10.47			
		587	51.94	10.51			
		592	51.92	10.49			
		597	51.98	10.55			
	10	602	51.95	10.52			
		607	51.90	10.47			
		612	51.92	10.49			
		617	51.94	10.51			
		622	51.95	10.52			
		627	51.96	10.53			
		632	51.94	10.51			
		637	51.97	10.54			
		642	51.96	10.53			
		647	51.98	10.55			
		652	51.99	10.56			
		657	51.98	10.55			
	11	662	51.98	10.55			
		667	52.04	10.61			
		672	51.96	10.53			
		677	51.97	10.54			
		682	51.97	10.54			
		687	52.01	10.58			
		692	52.00	10.57			

Real Time	Elapsed Time		Water Level (m BGL)	Drawdown (m)	Discharge		Comments
	Hours	Minutes			Time to Fill 20 L (sec)	Rate (L/s) Q	
		697	51.98	10.55			
		702	52.00	10.57			
		707	52.02	10.59			
		712	52.01	10.58			
		717	52.08	10.65			
	12	722	52.01	10.58			
		727	52.06	10.63			
		732	52.07	10.64			
		737	52.05	10.62			
		742	52.05	10.62			
		747	52.02	10.59			
		752	52.07	10.64			
		757	52.05	10.62			
		762	52.05	10.62			
		767	52.08	10.65			
		772	52.02	10.59			
		777	52.10	10.67			
	13	782	52.08	10.65			
		787	52.07	10.64			
		792	52.11	10.68			
		797	52.10	10.67			
		802	52.08	10.65			
		807	52.10	10.67			
		812	52.10	10.67			
		817	52.10	10.67			
		822	52.11	10.68			
		827	52.12	10.69			
		832	52.11	10.68			
		837	52.10	10.67			
	14	842	52.11	10.68			
		847	52.13	10.70			
		852	52.13	10.70			
		857	52.16	10.73			
		862	52.16	10.73			
		867	52.18	10.75			
		872	52.14	10.71			
		877	52.14	10.71			
		882	52.15	10.72			
		887	52.20	10.77			
		892	52.18	10.75			
		897	52.16	10.73			
	15	902	52.20	10.77			
		907	52.17	10.74			
		912	52.15	10.72			
		917	52.18	10.75			
		922	52.18	10.75			
		927	52.22	10.79			
		932	52.20	10.77			
		937	52.21	10.78			
		942	52.21	10.78			
		947	52.20	10.77			
		952	52.19	10.76			
		957	52.23	10.80			
	16	962	52.26	10.83			
		967	52.22	10.79			
		972	52.19	10.76			

Real Time	Elapsed Time		Water Level (m BGL)	Drawdown (m)	Discharge		Comments
	Hours	Minutes			Time to Fill 20 L (sec)	Rate (L/s) Q	
		977	52.24	10.81			
		982	52.19	10.76			
		987	52.19	10.76			
		992	52.22	10.79			
		997	52.23	10.80			
		1002	52.23	10.80			
		1007	52.24	10.81			
		1012	52.24	10.81			
		1017	52.23	10.80			
	17	1022	52.24	10.81			
		1027	52.23	10.80			
		1032	52.25	10.82			
		1037	52.28	10.85			
		1042	52.28	10.85			
		1047	52.26	10.83			
		1052	52.28	10.85			
		1057	52.35	10.92			
		1062	52.26	10.83			
		1067	52.33	10.90			
		1072	52.26	10.83			
		1077	52.31	10.88			
	18	1082	52.30	10.87			
		1087	52.28	10.85			
		1092	52.26	10.83			
		1097	52.27	10.84			
		1102	52.29	10.86			
		1107	52.30	10.87			
		1112	52.32	10.89			
		1117	52.31	10.88			
		1122	52.32	10.89			
		1127	52.32	10.89			
		1132	52.33	10.90			
		1137	52.32	10.89			
	19	1142	52.30	10.87			
		1147	52.32	10.89			
		1152	52.31	10.88			
		1157	52.32	10.89			
		1162	52.36	10.93			
		1167	52.35	10.92			
		1172	52.32	10.89			
		1177	52.32	10.89			
		1182	52.32	10.89			
		1187	52.34	10.91			
		1192	52.33	10.90			
		1197	52.36	10.93			
	20	1202	52.38	10.95			
		1207	52.35	10.92			
		1212	52.36	10.93			
		1217	52.33	10.90			
		1222	52.39	10.96			
		1227	52.38	10.95			
		1232	52.37	10.94			
		1237	52.36	10.93			
		1242	52.37	10.94			
		1247	52.35	10.92			
		1252	52.36	10.93			

Real Time	Elapsed Time		Water Level (m BGL)	Drawdown (m)	Discharge		Comments
	Hours	Minutes			Time to Fill 20 L (sec)	Rate (L/s) Q	
		1257	52.39	10.96			
	21	1262	52.39	10.96			
		1267	52.38	10.95			
		1272	52.36	10.93			
		1277	52.38	10.95			
		1282	52.40	10.97			
		1287	52.42	10.99			
		1292	52.38	10.95			
		1297	52.40	10.97			
		1302	52.40	10.97			
		1307	52.45	11.02			
		1312	52.41	10.98			
		1317	52.41	10.98			
	22	1322	52.43	11.00			
		1327	52.42	10.99			
		1332	52.47	11.04			
		1337	52.45	11.02			
		1342	52.46	11.03			
		1347	52.48	11.05			
		1352	52.49	11.06			
		1357	52.46	11.03			
		1362	52.46	11.03			
		1367	52.45	11.02			
		1372	52.48	11.05			
		1377	52.49	11.06			
	23	1382	52.46	11.03	6.7	3.0	
		1387	52.48	11.05			
		1392	52.49	11.06			
		1397	52.50	11.07			
		1402	52.44	11.01			
		1407	52.50	11.07			
		1412	52.52	11.09			
		1417	52.50	11.07			
		1422	52.48	11.05			
		1427	52.53	11.10			
		1432	52.50	11.07			
		1437	52.50	11.07			
	24	1442	52.51	11.08			
		1447	52.49	11.06			
		1452	52.48	11.05			
		1457	52.50	11.07			
		1462	52.54	11.11			
		1467	52.49	11.06			
		1472	52.54	11.11			
		1477	52.54	11.11			
		1482	52.50	11.07			
		1487	52.54	11.11			
		1492	52.52	11.09			
		1497	52.54	11.11			
	25	1502	52.52	11.09			
		1507	52.52	11.09			
		1512	52.50	11.07			
		1517	52.58	11.15			
		1522	52.57	11.14			
		1527	52.55	11.12			
		1532	52.56	11.13			

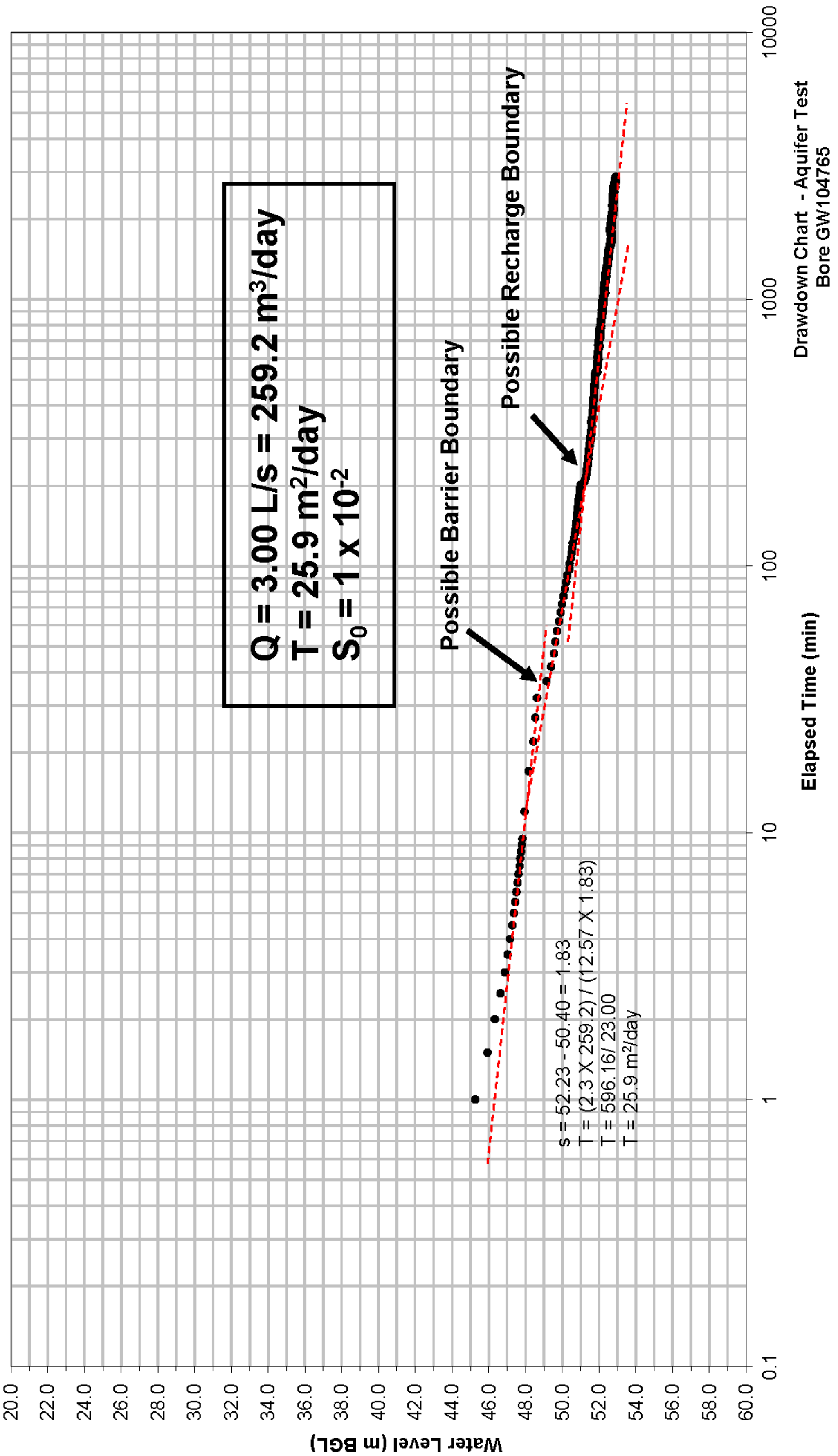
Real Time	Elapsed Time		Water Level (m BGL)	Drawdown (m)	Discharge		Comments
	Hours	Minutes			Time to Fill 20 L (sec)	Rate (L/s) Q	
		1537	52.56	11.13			
		1542	52.52	11.09			
		1547	52.56	11.13			
		1552	52.57	11.14			
		1557	52.57	11.14			
	26	1562	52.58	11.15			
		1567	52.57	11.14			
		1572	52.57	11.14			
		1577	52.57	11.14			
		1582	52.58	11.15			
		1587	52.63	11.20			
		1592	52.63	11.20			
		1597	52.62	11.19			
		1602	52.61	11.18			
		1607	52.60	11.17			
		1612	52.62	11.19			
		1617	52.62	11.19			
	27	1622	52.67	11.24			
		1627	52.63	11.20			
		1632	52.61	11.18			
		1637	52.64	11.21			
		1642	52.63	11.20			
		1647	52.61	11.18			
		1652	52.66	11.23			
		1657	52.68	11.25			
		1662	52.63	11.20			
		1667	52.67	11.24			
		1672	52.63	11.20			
		1677	52.65	11.22			
	28	1682	52.68	11.25			
		1687	52.69	11.26			
		1692	52.65	11.22			
		1697	52.67	11.24			
		1702	52.65	11.22			
		1707	52.65	11.22			
		1712	52.65	11.22			
		1717	52.69	11.26			
		1722	52.68	11.25			
		1727	52.69	11.26			
		1732	52.68	11.25			
		1737	52.65	11.22			
	29	1742	52.69	11.26			
		1747	52.63	11.20			
		1752	52.66	11.23			
		1757	52.68	11.25			
		1762	52.62	11.19			
		1767	52.67	11.24			
		1772	52.63	11.20			
		1777	52.63	11.20			
		1782	52.68	11.25			
		1787	52.66	11.23			
		1792	52.63	11.20			
		1797	52.59	11.16			
	30	1802	52.65	11.22	6.7	3.0	
		1807	52.62	11.19			
		1812	52.63	11.20			

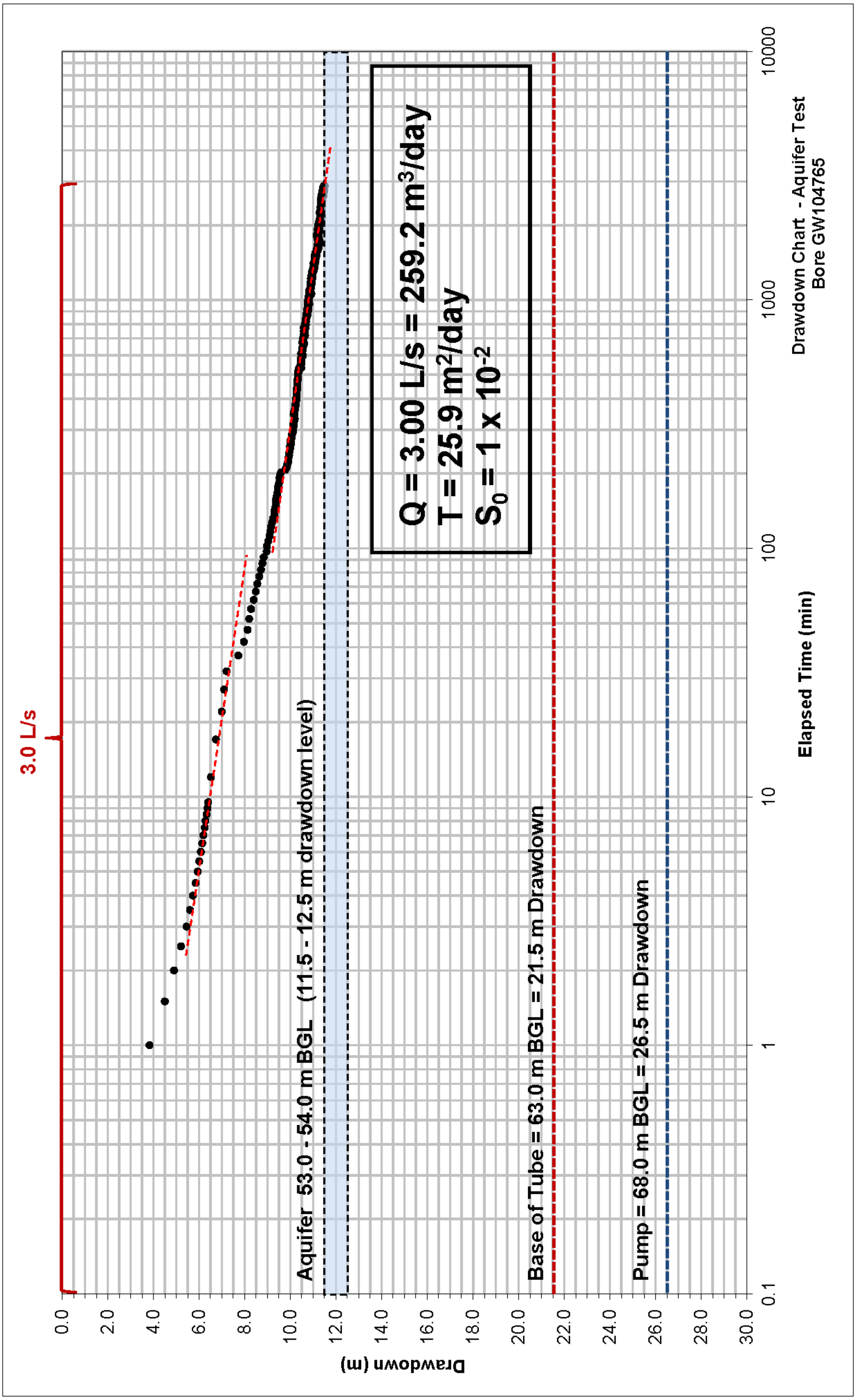
Real Time	Elapsed Time		Water Level (m BGL)	Drawdown (m)	Discharge		Comments
	Hours	Minutes			Time to Fill 20 L (sec)	Rate (L/s) Q	
		1817	52.63	11.20			
		1822	52.64	11.21			
		1827	52.64	11.21			
		1832	52.61	11.18			
		1837	52.60	11.17			
		1842	52.64	11.21			
		1847	52.65	11.22			
		1852	52.64	11.21			
		1857	52.68	11.25			
	31	1862	52.66	11.23			
		1867	52.68	11.25			
		1872	52.66	11.23			
		1877	52.67	11.24			
		1882	52.69	11.26			
		1887	52.69	11.26			
		1892	52.65	11.22			
		1897	52.67	11.24			
		1902	52.68	11.25			
		1907	52.70	11.27			
		1912	52.67	11.24			
		1917	52.63	11.20			
	32	1922	52.67	11.24			
		1927	52.69	11.26			
		1932	52.67	11.24			
		1937	52.66	11.23			
		1942	52.69	11.26			
		1947	52.66	11.23			
		1952	52.66	11.23			
		1957	52.69	11.26			
		1962	52.69	11.26			
		1967	52.67	11.24			
		1972	52.71	11.28			
		1977	52.70	11.27			
	33	1982	52.65	11.22			
		1987	52.70	11.27			
		1992	52.70	11.27			
		1997	52.67	11.24			
		2002	52.65	11.22			
		2007	52.69	11.26			
		2012	52.69	11.26			
		2017	52.70	11.27			
		2022	52.69	11.26			
		2027	52.73	11.30			
		2032	52.70	11.27			
		2037	52.72	11.29			
	34	2042	52.71	11.28			
		2047	52.72	11.29			
		2052	52.69	11.26			
		2057	52.68	11.25			
		2062	52.71	11.28			
		2067	52.72	11.29			
		2072	52.74	11.31			
		2077	52.71	11.28			
		2082	52.74	11.31			
		2087	52.77	11.34			
		2092	52.75	11.32			

Real Time	Elapsed Time		Water Level (m BGL)	Drawdown (m)	Discharge		Comments
	Hours	Minutes			Time to Fill 20 L (sec)	Rate (L/s) Q	
		2097	52.76	11.33			
	35	2102	52.76	11.33			
		2107	52.74	11.31			
		2112	52.75	11.32			
		2117	52.72	11.29			
		2122	52.74	11.31			
		2127	52.77	11.34			
		2132	52.75	11.32			
		2137	52.76	11.33			
		2142	52.73	11.30			
		2147	52.75	11.32			
		2152	52.75	11.32			
		2157	52.74	11.31			
	36	2162	52.76	11.33			
		2167	52.77	11.34			
		2172	52.81	11.38			
		2177	52.77	11.34			
		2182	52.74	11.31			
		2187	52.75	11.32			
		2192	52.73	11.30			
		2197	52.75	11.32			
		2202	52.76	11.33			
		2207	52.76	11.33			
		2212	52.73	11.30			
		2217	52.76	11.33			
	37	2222	52.72	11.29			
		2227	52.76	11.33			
		2232	52.75	11.32			
		2237	52.77	11.34			
		2242	52.75	11.32			
		2247	52.72	11.29			
		2252	52.78	11.35			
		2257	52.73	11.30			
		2262	52.75	11.32			
		2267	52.75	11.32			
		2272	52.77	11.34			
		2277	52.77	11.34			
	38	2282	52.74	11.31			
		2287	52.79	11.36			
		2292	52.75	11.32			
		2297	52.78	11.35			
		2302	52.79	11.36			
		2307	52.75	11.32			
		2312	52.77	11.34			
		2317	52.77	11.34			
		2322	52.78	11.35			
		2327	52.79	11.36			
		2332	52.79	11.36			
		2337	52.77	11.34			
	39	2342	52.77	11.34			
		2347	52.76	11.33			
		2352	52.77	11.34			
		2357	52.75	11.32			
		2362	52.80	11.37			
		2367	52.80	11.37			
		2372	52.77	11.34			

Real Time	Elapsed Time		Water Level (m BGL)	Drawdown (m)	Discharge		Comments
	Hours	Minutes			Time to Fill 20 L (sec)	Rate (L/s) Q	
		2377	52.79	11.36			
		2382	52.80	11.37			
		2387	52.78	11.35			
		2392	52.78	11.35			
		2397	52.82	11.39			
	40	2402	52.77	11.34			
		2407	52.77	11.34			
		2412	52.80	11.37			
		2417	52.76	11.33			
		2422	52.76	11.33			
		2427	52.81	11.38			
		2432	52.79	11.36			
		2437	52.78	11.35			
		2442	52.81	11.38			
		2447	52.76	11.33			
		2452	52.76	11.33			
		2457	52.78	11.35			
	41	2462	52.77	11.34			
		2467	52.76	11.33			
		2472	52.76	11.33			
		2477	52.81	11.38			
		2482	52.78	11.35			
		2487	52.81	11.38			
		2492	52.82	11.39			
		2497	52.82	11.39			
		2502	52.82	11.39			
		2507	52.79	11.36			
		2512	52.78	11.35			
		2517	52.78	11.35			
	42	2522	52.83	11.40			
		2527	52.79	11.36			
		2532	52.79	11.36			
		2537	52.79	11.36			
		2542	52.79	11.36			
		2547	52.81	11.38			
		2552	52.82	11.39			
		2557	52.79	11.36			
		2562	52.79	11.36			
		2567	52.82	11.39			
		2572	52.78	11.35			
		2577	52.81	11.38			
	43	2582	52.79	11.36			
		2587	52.83	11.40			
		2592	52.81	11.38			
		2597	52.81	11.38			
		2602	52.83	11.40			
		2607	52.85	11.42			
		2612	52.81	11.38			
		2617	52.78	11.35			
		2622	52.82	11.39			
		2627	52.88	11.45			
		2632	52.81	11.38			
		2637	52.84	11.41			
	44	2642	52.81	11.38			
		2647	52.86	11.43			
		2652	52.80	11.37			

Real Time	Elapsed Time		Water Level (m BGL)	Drawdown (m)	Discharge		Comments
	Hours	Minutes			Time to Fill 20 L (sec)	Rate (L/s) Q	
		2657	52.84	11.41			
		2662	52.82	11.39			
		2667	52.86	11.43			
		2672	52.84	11.41			
		2677	52.85	11.42			
		2682	52.83	11.40			
		2687	52.84	11.41			
		2692	52.87	11.44			
		2697	52.84	11.41			
	45	2702	52.84	11.41			
		2707	52.85	11.42			
		2712	52.84	11.41			
		2717	52.85	11.42			
		2722	52.86	11.43			
		2727	52.88	11.45			
		2732	52.83	11.40			
		2737	52.86	11.43			
		2742	52.86	11.43			
		2747	52.92	11.49			
		2752	52.86	11.43			
		2757	52.89	11.46			
	46	2762	52.85	11.42			
		2767	52.87	11.44			
		2772	52.87	11.44			
		2777	52.87	11.44			
		2782	52.92	11.49			
		2787	52.86	11.43			
		2792	52.87	11.44			
		2797	52.89	11.46			
		2802	52.88	11.45			
		2807	52.90	11.47			
		2812	52.88	11.45			
		2817	52.91	11.48			
	47	2822	52.85	11.42	6.7	3.0	
		2827	52.87	11.44			
		2832	52.89	11.46			
		2837	52.91	11.48			
		2842	52.87	11.44			
		2847	52.91	11.48			
		2852	52.91	11.48			
		2857	52.92	11.49			
		2862	52.90	11.47			
		2867	52.93	11.50			
		2872	52.91	11.48			
	48	2877	52.93	11.50			


Q = 3.00 L/s = 259.2 m³/day
T = 25.9 m²/day
S0 = 1 x 10-2
Possible Barrier Boundary
Possible Recharge Boundary
s = 52.23 - 50.40 = 1.83
T = (2.3 X 259.2) / (12.57 X 1.83)
T = 596.16/ 23.00
T = 25.9 m²/day
Water Level (m BGL)
Elapsed Time (min)
Drawdown Chart - Aquifer Test
Bore GW104765
20.0
22.0
24.0
26.0
28.0
30.0
32.0
34.0
36.0
38.0
40.0
42.0
44.0
46.0
48.0
50.0
52.0
54.0
56.0
58.0
60.0
0.1
1
10
100
1000
10000


Drawdown Chart - Aquifer Test
Bore GW104765
3.0 L/s
Q = 3.00 L/s = 259.2 m³/day
T = 25.9 m²/day
S₀ = 1 x 10⁻²
Aquifer 53.0 - 54.0 m BGL (11.5 - 12.5 m drawdown level)
Base of Tube = 63.0 m BGL = 21.5 m Drawdown
Pump = 68.0 m BGL = 26.5 m Drawdown
Drawdown (m)
Elapsed Time (min)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
30.0
0.1
1
10
100
1000
10000

RECOVERY ANALYSIS DATA

CONSTANT RATE PUMPING TEST

Test Date : 23.6.15
Start Time : 0900
Pump Off : 0900 (25.6.15)
Hole ID : 150 mm
Pump Type : Grundfos
Pump Intake : 68.0 m
Tested by : LLC & LJ
Reference Point : Top of Collar (or Air Line) = 0.67 m AGL

PROJECT : Aquifer Testing
CLIENT : Sutton Forest Quarry
JOB NO : 14068
BORE ID : GW104765
SWL at Start of Test : 42.10 m TOC (41.43 m BGL)
Average Discharge Rate: 3.0 L/s

Real Time	Elapsed Time (minutes)	Time since pump stopped		Water Level (m)	Ratio t/t'	Residual Drawdown S' (m)	Comments
		Hours	Min.				
0900	2877		0.1	52.93	28800.00	11.50	← Depth to water at
25.6.15	2882		2	46.09	1441.00	4.66	instant pump stopped
	2887		5	44.55	577.40	3.12	52.93 m
	2892		10	44.14	289.20	2.71	
	2897		15	43.92	193.13	2.49	
	2902		20	43.71	145.10	2.28	
	2907		25	43.61	116.28	2.18	
	2912		30	43.48	97.07	2.05	
	2917		35	43.39	83.34	1.96	
	2922		40	43.34	73.05	1.91	
	2927		45	43.25	65.04	1.82	
	2932		50	43.19	58.64	1.76	
	2937		55	43.13	53.40	1.70	
	2942	1	60	43.08	49.03	1.65	
	2947.0		65	43.07	45.34	1.64	
	2952.0		70	43.01	42.17	1.58	
	2957.0		75	43.00	39.43	1.57	
	2962.0		80	42.96	37.03	1.53	
	2967.0		85	42.93	34.91	1.50	
	2972.0		90	42.89	33.02	1.46	
	2977.0		95	42.87	31.34	1.44	
	2982.0		100	42.85	29.82	1.42	
	2987.0		105	42.82	28.45	1.39	
	2992.0		110	42.80	27.20	1.37	
	2997.0		115	42.79	26.06	1.36	
	3002.0	2	120	42.77	25.02	1.34	
	3007.0		125	42.74	24.06	1.31	
	3012.0		130	42.73	23.17	1.30	
	3017.0		135	42.72	22.35	1.29	
	3022.0		140	42.69	21.59	1.26	
	3027.0		145	42.68	20.88	1.25	
	3032.0		150	42.69	20.21	1.26	
	3037.0		155	42.69	19.59	1.26	
	3042.0		160	42.65	19.01	1.22	
	3047.0		165	42.64	18.47	1.21	
	3052		170	42.61	17.95	1.18	
	3057		175	42.64	17.47	1.21	
	3062	3	180	42.62	17.01	1.19	
	3067		185	42.62	16.58	1.19	
	3072		190	42.60	16.17	1.17	
	3077		195	42.59	15.78	1.16	
	3082		200	42.56	15.41	1.13	

	3087		205	42.56	15.06	1.13	
	3092		210	42.55	14.72	1.12	
	3097		215	42.53	14.40	1.10	
	3102		220	42.53	14.10	1.10	
	3107		225	42.53	13.81	1.10	
	3112		230	42.53	13.53	1.10	
	3117		235	42.53	13.26	1.10	
	3122	4	240	42.51	13.01	1.08	
	3127		245	42.51	12.76	1.08	
	3132		250	42.50	12.53	1.07	
	3137		255	42.49	12.30	1.06	
	3142		260	42.48	12.08	1.05	
	3147		265	42.48	11.88	1.05	
	3152		270	42.48	11.67	1.05	
	3157		275	42.49	11.48	1.06	
	3162		280	42.46	11.29	1.03	
	3167		285	42.47	11.11	1.04	
	3172		290	42.44	10.94	1.01	
	3177		295	42.45	10.77	1.02	
	3182	5	300	42.45	10.61	1.02	
	3187		305	42.44	10.45	1.01	
	3192		310	42.43	10.30	1.00	
	3197		315	42.43	10.15	1.00	
	3202		320	42.42	10.01	0.99	
	3207		325	42.42	9.87	0.99	
	3212		330	42.44	9.73	1.01	
	3217		335	42.41	9.60	0.98	
	3222		340	42.41	9.48	0.98	
	3227		345	42.42	9.35	0.99	
	3232		350	42.39	9.23	0.96	
	3237		355	42.43	9.12	1.00	
	3242	6	360	42.40	9.01	0.97	
	3247		365	42.41	8.90	0.98	
	3252		370	42.40	8.79	0.97	
	3257		375	42.38	8.69	0.95	
	3262		380	42.38	8.58	0.95	
	3267		385	42.37	8.49	0.94	
	3272		390	42.39	8.39	0.96	
	3277		395	42.39	8.30	0.96	
	3282		400	42.36	8.21	0.93	
	3287		405	42.39	8.12	0.96	
	3292		410	42.36	8.03	0.93	
	3297		415	42.35	7.94	0.92	
	3302	7	420	42.35	7.86	0.92	
	3307		425	42.35	7.78	0.92	
	3312		430	42.34	7.70	0.91	
	3317		435	42.34	7.63	0.91	
	3322		440	42.36	7.55	0.93	
	3327		445	42.34	7.48	0.91	
	3332		450	42.33	7.40	0.90	
	3337		455	42.35	7.33	0.92	
	3342		460	42.32	7.27	0.89	
	3347		465	42.34	7.20	0.91	
	3352		470	42.34	7.13	0.91	
	3357		475	42.32	7.07	0.89	
	3362	8	480	42.34	7.00	0.91	
	3367		485	42.32	6.94	0.89	
	3372		490	42.33	6.88	0.90	
	3377		495	42.32	6.82	0.89	

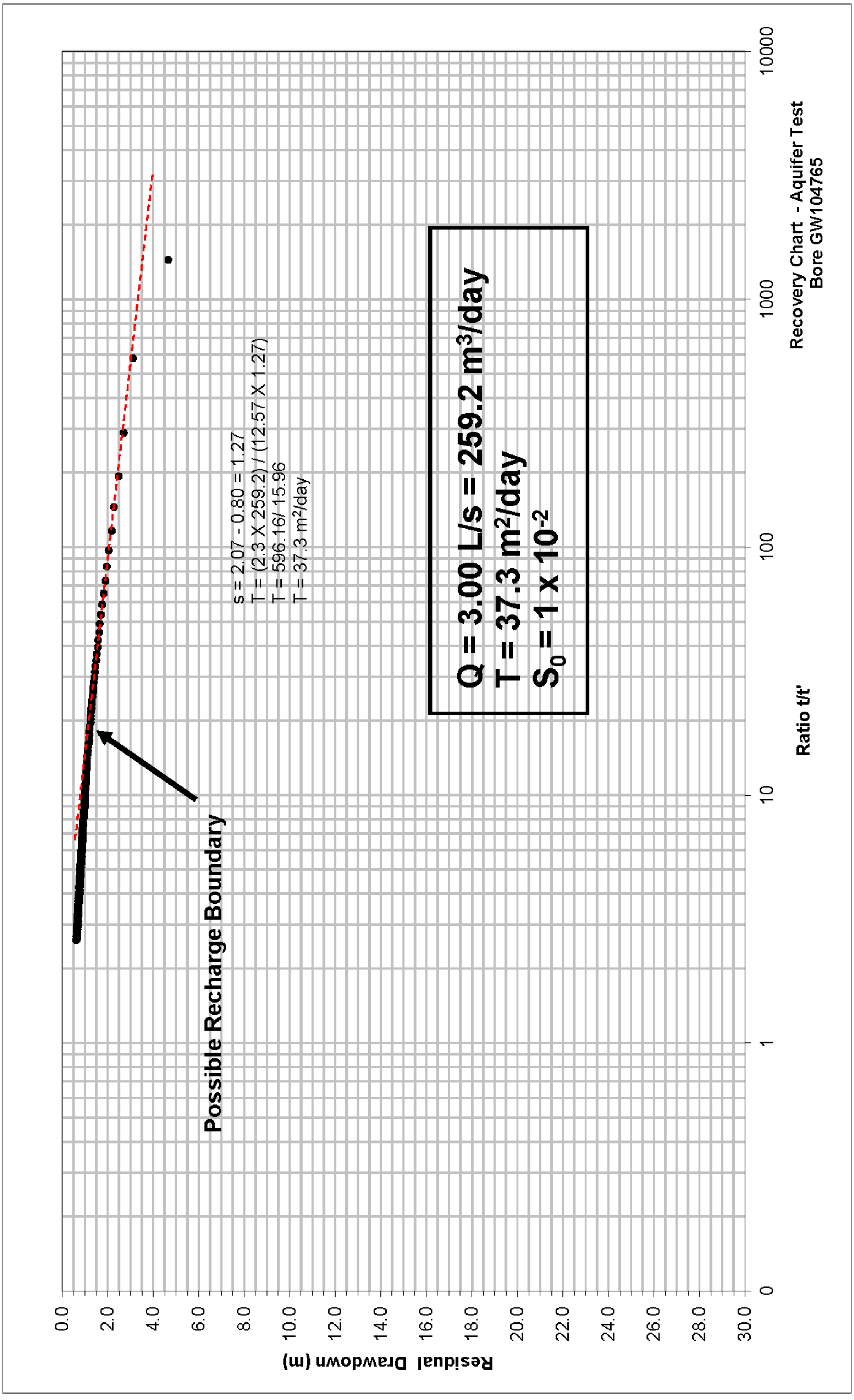
	3382		500	42.33	6.76	0.90	
	3387		505	42.29	6.71	0.86	
	3392		510	42.31	6.65	0.88	
	3397		515	42.31	6.60	0.88	
	3402		520	42.34	6.54	0.91	
	3407		525	42.29	6.49	0.86	
	3412		530	42.29	6.44	0.86	
	3417		535	42.30	6.39	0.87	
	3422	9	540	42.31	6.34	0.88	
	3427		545	42.30	6.29	0.87	
	3432		550	42.31	6.24	0.88	
	3437		555	42.28	6.19	0.85	
	3442		560	42.30	6.15	0.87	
	3447		565	42.29	6.10	0.86	
	3452		570	42.29	6.06	0.86	
	3457		575	42.28	6.01	0.85	
	3462		580	42.26	5.97	0.83	
	3467		585	42.31	5.93	0.88	
	3472		590	42.28	5.88	0.85	
	3477		595	42.27	5.84	0.84	
	3482	10	600	42.26	5.80	0.83	
	3487		605	42.28	5.76	0.85	
	3492		610	42.25	5.72	0.82	
	3497		615	42.25	5.69	0.82	
	3502		620	42.29	5.65	0.86	
	3507		625	42.27	5.61	0.84	
	3512		630	42.27	5.57	0.84	
	3517		635	42.28	5.54	0.85	
	3522		640	42.25	5.50	0.82	
	3527		645	42.24	5.47	0.81	
	3532		650	42.26	5.43	0.83	
	3537		655	42.26	5.40	0.83	
	3542	11	660	42.26	5.37	0.83	
	3547		665	42.25	5.33	0.82	
	3552		670	42.25	5.30	0.82	
	3557		675	42.27	5.27	0.84	
	3562		680	42.25	5.24	0.82	
	3567		685	42.23	5.21	0.80	
	3572		690	42.22	5.18	0.79	
	3577		695	42.24	5.15	0.81	
	3582		700	42.24	5.12	0.81	
	3587		705	42.26	5.09	0.83	
	3592		710	42.26	5.06	0.83	
	3597		715	42.24	5.03	0.81	
	3602	12	720	42.23	5.00	0.80	
	3607		725	42.24	4.98	0.81	
	3612		730	42.24	4.95	0.81	
	3617		735	42.22	4.92	0.79	
	3622		740	42.22	4.89	0.79	
	3627		745	42.22	4.87	0.79	
	3632		750	42.24	4.84	0.81	
	3637		755	42.22	4.82	0.79	
	3642		760	42.22	4.79	0.79	
	3647		765	42.22	4.77	0.79	
	3652		770	42.21	4.74	0.78	
	3657		775	42.25	4.72	0.82	
	3662	13	780	42.20	4.69	0.77	
	3667		785	42.22	4.67	0.79	
	3672		790	42.22	4.65	0.79	

	3677		795	42.22	4.63	0.79	
	3682		800	42.20	4.60	0.77	
	3687		805	42.22	4.58	0.79	
	3692		810	42.22	4.56	0.79	
	3697		815	42.22	4.54	0.79	
	3702		820	42.19	4.51	0.76	
	3707		825	42.21	4.49	0.78	
	3712		830	42.19	4.47	0.76	
	3717		835	42.21	4.45	0.78	
	3722	14	840	42.18	4.43	0.75	
	3727		845	42.21	4.41	0.78	
	3732		850	42.20	4.39	0.77	
	3737		855	42.19	4.37	0.76	
	3742		860	42.21	4.35	0.78	
	3747		865	42.20	4.33	0.77	
	3752		870	42.20	4.31	0.77	
	3757		875	42.19	4.29	0.76	
	3762		880	42.21	4.28	0.78	
	3767		885	42.17	4.26	0.74	
	3772		890	42.20	4.24	0.77	
	3777		895	42.17	4.22	0.74	
	3782	15	900	42.18	4.20	0.75	
	3787		905	42.19	4.18	0.76	
	3792		910	42.18	4.17	0.75	
	3797		915	42.18	4.15	0.75	
	3802		920	42.20	4.13	0.77	
	3807		925	42.19	4.12	0.76	
	3812		930	42.18	4.10	0.75	
	3817		935	42.18	4.08	0.75	
	3822		940	42.17	4.07	0.74	
	3827		945	42.18	4.05	0.75	
	3832		950	42.16	4.03	0.73	
	3837		955	42.17	4.02	0.74	
	3842	16	960	42.20	4.00	0.77	
	3847		965	42.15	3.99	0.72	
	3852		970	42.17	3.97	0.74	
	3857		975	42.18	3.96	0.75	
	3862		980	42.17	3.94	0.74	
	3867		985	42.19	3.93	0.76	
	3872		990	42.17	3.91	0.74	
	3877		995	42.16	3.90	0.73	
	3882		1000	42.18	3.88	0.75	
	3887		1005	42.18	3.87	0.75	
	3892		1010	42.18	3.85	0.75	
	3897		1015	42.15	3.84	0.72	
	3902	17	1020	42.16	3.83	0.73	
	3907		1025	42.17	3.81	0.74	
	3912		1030	42.16	3.80	0.73	
	3917		1035	42.17	3.78	0.74	
	3922		1040	42.17	3.77	0.74	
	3927		1045	42.17	3.76	0.74	
	3932		1050	42.15	3.74	0.72	
	3937		1055	42.15	3.73	0.72	
	3942		1060	42.16	3.72	0.73	
	3947		1065	42.15	3.71	0.72	
	3952		1070	42.18	3.69	0.75	
	3957		1075	42.17	3.68	0.74	
	3962	18	1080	42.16	3.67	0.73	
	3967		1085	42.15	3.66	0.72	

	3972		1090	42.15	3.64	0.72	
	3977		1095	42.16	3.63	0.73	
	3982		1100	42.14	3.62	0.71	
	3987		1105	42.15	3.61	0.72	
	3992		1110	42.14	3.60	0.71	
	3997		1115	42.15	3.58	0.72	
	4002		1120	42.16	3.57	0.73	
	4007		1125	42.16	3.56	0.73	
	4012		1130	42.14	3.55	0.71	
	4017		1135	42.15	3.54	0.72	
	4022	19	1140	42.14	3.53	0.71	
	4027		1145	42.13	3.52	0.70	
	4032		1150	42.14	3.51	0.71	
	4037		1155	42.15	3.50	0.72	
	4042		1160	42.15	3.48	0.72	
	4047		1165	42.15	3.47	0.72	
	4052		1170	42.15	3.46	0.72	
	4057		1175	42.16	3.45	0.73	
	4062		1180	42.13	3.44	0.70	
	4067		1185	42.13	3.43	0.70	
	4072		1190	42.12	3.42	0.69	
	4077		1195	42.12	3.41	0.69	
	4082	20	1200	42.15	3.40	0.72	
	4087		1205	42.12	3.39	0.69	
	4092		1210	42.13	3.38	0.70	
	4097		1215	42.12	3.37	0.69	
	4102		1220	42.14	3.36	0.71	
	4107		1225	42.12	3.35	0.69	
	4112		1230	42.13	3.34	0.70	
	4117		1235	42.15	3.33	0.72	
	4122		1240	42.13	3.32	0.70	
	4127		1245	42.14	3.31	0.71	
	4132		1250	42.12	3.31	0.69	
	4137		1255	42.13	3.30	0.70	
	4142	21	1260	42.13	3.29	0.70	
	4147		1265	42.15	3.28	0.72	
	4152		1270	42.12	3.27	0.69	
	4157		1275	42.13	3.26	0.70	
	4162		1280	42.12	3.25	0.69	
	4167		1285	42.14	3.24	0.71	
	4172		1290	42.12	3.23	0.69	
	4177		1295	42.10	3.23	0.67	
	4182		1300	42.12	3.22	0.69	
	4187		1305	42.12	3.21	0.69	
	4192		1310	42.13	3.20	0.70	
	4197		1315	42.13	3.19	0.70	
	4202	22	1320	42.13	3.18	0.70	
	4207		1325	42.11	3.18	0.68	
	4212		1330	42.11	3.17	0.68	
	4217		1335	42.13	3.16	0.70	
	4222		1340	42.12	3.15	0.69	
	4227		1345	42.13	3.14	0.70	
	4232		1350	42.12	3.13	0.69	
	4237		1355	42.11	3.13	0.68	
	4242		1360	42.12	3.12	0.69	
	4247		1365	42.12	3.11	0.69	
	4252		1370	42.11	3.10	0.68	
	4257		1375	42.14	3.10	0.71	
	4262	23	1380	42.11	3.09	0.68	

	4267		1385	42.12	3.08	0.69	
	4272		1390	42.11	3.07	0.68	
	4277		1395	42.12	3.07	0.69	
	4282		1400	42.12	3.06	0.69	
	4287		1405	42.10	3.05	0.67	
	4292		1410	42.12	3.04	0.69	
	4297		1415	42.12	3.04	0.69	
	4302		1420	42.10	3.03	0.67	
	4307		1425	42.09	3.02	0.66	
	4312		1430	42.10	3.02	0.67	
	4317		1435	42.10	3.01	0.67	
	4322	24	1440	42.11	3.00	0.68	
	4327		1445	42.08	2.99	0.65	
	4332		1450	42.11	2.99	0.68	
	4337		1455	42.09	2.98	0.66	
	4342		1460	42.10	2.97	0.67	
	4347		1465	42.08	2.97	0.65	
	4352		1470	42.11	2.96	0.68	
	4357		1475	42.11	2.95	0.68	
	4362		1480	42.12	2.95	0.69	
	4367		1485	42.10	2.94	0.67	
	4372		1490	42.09	2.93	0.66	
	4377		1495	42.07	2.93	0.64	
	4382	25	1500	42.09	2.92	0.66	
	4387		1505	42.09	2.91	0.66	
	4392		1510	42.09	2.91	0.66	
	4397		1515	42.10	2.90	0.67	
	4402		1520	42.09	2.90	0.66	
	4407		1525	42.10	2.89	0.67	
	4412		1530	42.07	2.88	0.64	
	4417		1535	42.10	2.88	0.67	
	4422		1540	42.09	2.87	0.66	
	4427		1545	42.11	2.87	0.68	
	4432		1550	42.09	2.86	0.66	
	4437		1555	42.09	2.85	0.66	
	4442	26	1560	42.09	2.85	0.66	
	4447		1565	42.09	2.84	0.66	
	4452		1570	42.08	2.84	0.65	
	4457		1575	42.07	2.83	0.64	
	4462		1580	42.10	2.82	0.67	
	4467		1585	42.08	2.82	0.65	
	4472		1590	42.10	2.81	0.67	
	4477		1595	42.09	2.81	0.66	
	4482		1600	42.08	2.80	0.65	
	4487		1605	42.09	2.80	0.66	
	4492		1610	42.08	2.79	0.65	
	4497		1615	42.06	2.78	0.63	
	4502	27	1620	42.09	2.78	0.66	
	4507		1625	42.08	2.77	0.65	
	4512		1630	42.09	2.77	0.66	
	4517		1635	42.09	2.76	0.66	
	4522		1640	42.08	2.76	0.65	
	4527		1645	42.08	2.75	0.65	
	4532		1650	42.10	2.75	0.67	
	4537		1655	42.06	2.74	0.63	
	4542		1660	42.08	2.74	0.65	
	4547		1665	42.08	2.73	0.65	
	4552		1670	42.07	2.73	0.64	
	4557		1675	42.09	2.72	0.66	

	4562	28	1680	42.09	2.72	0.66	
	4567		1685	42.07	2.71	0.64	
	4572		1690	42.08	2.71	0.65	
	4577		1695	42.09	2.70	0.66	
	4582		1700	42.06	2.70	0.63	
	4587		1705	42.07	2.69	0.64	
	4592		1710	42.07	2.69	0.64	
	4597		1715	42.06	2.68	0.63	
	4602		1720	42.08	2.68	0.65	
	4607		1725	42.06	2.67	0.63	
	4612		1730	42.07	2.67	0.64	
	4617		1735	42.06	2.66	0.63	
	4622	29	1740	42.07	2.66	0.64	
	4627		1745	42.08	2.65	0.65	
	4632		1750	42.07	2.65	0.64	
	4637		1755	42.07	2.64	0.64	
	4642		1760	42.07	2.64	0.64	
	4647		1765	42.08	2.63	0.65	
	4652		1770	42.08	2.63	0.65	
	4657		1775	42.07	2.62	0.64	
	4662		1780	42.06	2.62	0.63	
	4667		1785	42.08	2.61	0.65	
	4672		1790	42.05	2.61	0.62	
	4677		1795	42.06	2.61	0.63	
	4682	30	1800	42.05	2.60	0.62	
	4687		1805	42.05	2.60	0.62	


Recovery Chart - Aquifer Test
Bore GW104765
Ratio t/t'
Residual Drawdown (m)
0
1
10
100
1000
10000
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
30.0
Possible Recharge Boundary
s = 2.07 - 0.80 = 1.27
T = (2.3 X 259.2) / (12.57 X 1.27)
T = 596.16/ 15.96
T = 37.3 m2/day
Q = 3.00 L/s = 259.2 m3/day
T = 37.3 m2/day
S0 = 1 x 10-2

MONITORING DATA
CONSTANT RATE PUMPING TEST

Test Date : 23.6.15
Start Time : 0900
Pump Off : 0900 (25.6.15)
Hole ID : 200 mm

PROJECT : Aquifer Testing
CLIENT : Sutton Forest Quarry
JOB NO. : 14068
MONITORING BORE ID. : GW101872
PUMPED BORE ID: GW104765

Tested by : LJ
SWL at Start of Test : 62.51 m TOC
Reference Point : Top of Air Line = 0.17 m AGL

Real Time	Elapsed Time		Water Level	Drawdown	Comments
	Hours	Minutes	(m BGL)	(m)	
0900		0	62.34	0.00	
23.6.15		5	62.34	0.00	
		10	62.34	0.00	
		15	62.34	0.00	
		20	62.34	0.00	
		25	62.34	0.00	
		30	62.34	0.00	
		35	62.34	0.00	
		40	62.34	0.00	
		45	62.34	0.00	
		50	62.34	0.00	
		55	62.34	0.00	
	1	60	62.34	0.00	
		65	62.34	0.00	
		70	62.34	0.00	
		75	62.34	0.00	
		80	62.34	0.00	
		85	62.34	0.00	
		90	62.34	0.00	
		95	62.34	0.00	
		100	62.34	0.00	
		105	62.34	0.00	
		110	62.34	0.00	
		115	62.34	0.00	
	2	120	62.35	0.01	
		125	62.34	0.00	
		130	62.34	0.00	
		135	62.35	0.01	
		140	62.35	0.01	
		145	62.35	0.01	
		150	62.35	0.01	
		155	62.35	0.01	
		160	62.35	0.01	
		165	62.35	0.01	
		170	62.35	0.01	
		175	62.35	0.01	
	3	180	62.35	0.01	
		185	62.35	0.01	
		190	62.35	0.01	
		195	62.35	0.01	
		200	62.35	0.01	
		205	62.35	0.01	
		210	62.35	0.01	

		215	62.36	0.02	
		220	62.36	0.02	
		225	62.36	0.02	
		230	62.36	0.02	
		235	62.36	0.02	
	4	240	62.36	0.02	
		245	62.36	0.02	
		250	62.36	0.02	
		255	62.36	0.02	
		260	62.36	0.02	
		265	62.36	0.02	
		270	62.36	0.02	
		275	62.36	0.02	
		280	62.36	0.02	
		285	62.36	0.02	
		290	62.36	0.02	
		295	62.36	0.02	
	5	300	62.36	0.02	
		305	62.36	0.02	
		310	62.36	0.02	
		315	62.36	0.02	
		320	62.36	0.02	
		325	62.36	0.02	
		330	62.36	0.02	
		335	62.36	0.02	
		340	62.36	0.02	
		345	62.36	0.02	
		350	62.36	0.02	
		355	62.36	0.02	
	6	360	62.36	0.02	
		365	62.36	0.02	
		370	62.36	0.02	
		375	62.36	0.02	
		380	62.36	0.02	
		385	62.36	0.02	
		390	62.36	0.02	
		395	62.36	0.02	
		400	62.36	0.02	
		405	62.36	0.02	
		410	62.36	0.02	
		415	62.36	0.02	
	7	420	62.36	0.02	
		425	62.36	0.02	
		430	62.36	0.02	
		435	62.36	0.02	
		440	62.36	0.02	
		445	62.36	0.02	
		450	62.36	0.02	
		455	62.36	0.02	
		460	62.36	0.02	
		465	62.36	0.02	
		470	62.36	0.02	
		475	62.36	0.02	
	8	480	62.36	0.02	
		485	62.36	0.02	
		490	62.36	0.02	

		495	62.36	0.02	
		500	62.36	0.02	
		505	62.36	0.02	
		510	62.36	0.02	
		515	62.36	0.02	
		520	62.36	0.02	
		525	62.36	0.02	
		530	62.36	0.02	
		535	62.35	0.01	
	9	540	62.35	0.01	
		545	62.35	0.01	
		550	62.35	0.01	
		555	62.35	0.01	
		560	62.35	0.01	
		565	62.35	0.01	
		570	62.35	0.01	
		575	62.35	0.01	
		580	62.35	0.01	
		585	62.35	0.01	
		590	62.35	0.01	
		595	62.35	0.01	
	10	600	62.35	0.01	
		605	62.35	0.01	
		610	62.35	0.01	
		615	62.35	0.01	
		620	62.35	0.01	
		625	62.35	0.01	
		630	62.35	0.01	
		635	62.35	0.01	
		640	62.35	0.01	
		645	62.35	0.01	
		650	62.35	0.01	
		655	62.35	0.01	
	11	660	62.35	0.01	
		665	62.35	0.01	
		670	62.35	0.01	
		675	62.35	0.01	
		680	62.35	0.01	
		685	62.35	0.01	
		690	62.35	0.01	
		695	62.36	0.02	
		700	62.35	0.01	
		705	62.35	0.01	
		710	62.36	0.02	
		715	62.36	0.02	
	12	720	62.35	0.01	
		725	62.36	0.02	
		730	62.36	0.02	
		735	62.35	0.01	
		740	62.36	0.02	
		745	62.36	0.02	
		750	62.36	0.02	
		755	62.36	0.02	
		760	62.36	0.02	
		765	62.36	0.02	
		770	62.35	0.01	

		775	62.35	0.01	
	13	780	62.36	0.02	
		785	62.35	0.01	
		790	62.36	0.02	
		795	62.35	0.01	
		800	62.36	0.02	
		805	62.35	0.01	
		810	62.35	0.01	
		815	62.35	0.01	
		820	62.35	0.01	
		825	62.35	0.01	
		830	62.35	0.01	
		835	62.35	0.01	
	14	840	62.35	0.01	
		845	62.35	0.01	
		850	62.35	0.01	
		855	62.35	0.01	
		860	62.35	0.01	
		865	62.36	0.02	
		870	62.35	0.01	
		875	62.35	0.01	
		880	62.35	0.01	
		885	62.35	0.01	
		890	62.35	0.01	
		895	62.35	0.01	
	15	900	62.36	0.02	
		905	62.36	0.02	
		910	62.36	0.02	
		915	62.36	0.02	
		920	62.36	0.02	
		925	62.35	0.01	
		930	62.36	0.02	
		935	62.36	0.02	
		940	62.36	0.02	
		945	62.36	0.02	
		950	62.36	0.02	
		955	62.36	0.02	
	16	960	62.36	0.02	
		965	62.36	0.02	
		970	62.36	0.02	
		975	62.36	0.02	
		980	62.36	0.02	
		985	62.36	0.02	
		990	62.36	0.02	
		995	62.36	0.02	
		1000	62.36	0.02	
		1005	62.36	0.02	
		1010	62.36	0.02	
		1015	62.36	0.02	
	17	1020	62.36	0.02	
		1025	62.36	0.02	
		1030	62.36	0.02	
		1035	62.36	0.02	
		1040	62.36	0.02	
		1045	62.36	0.02	
		1050	62.36	0.02	

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		1075	62.37	0.03	
	18	1080	62.37	0.03	
		1085	62.37	0.03	
		1090	62.37	0.03	
		1095	62.37	0.03	
		1100	62.37	0.03	
		1105	62.37	0.03	
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		1180	62.37	0.03	
		1185	62.37	0.03	
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		1330	62.36	0.02	

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		1545	62.36	0.02	
		1550	62.37	0.03	
		1555	62.36	0.02	
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		1570	62.37	0.03	
		1575	62.37	0.03	
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		1595	62.37	0.03	
		1600	62.37	0.03	
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		1610	62.38	0.03	

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		1690	62.38	0.04	
		1695	62.38	0.04	
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		1750	62.39	0.05	
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		1890	62.38	0.04	

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		2055	62.37	0.03	
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		2065	62.37	0.03	
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		2080	62.37	0.03	
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		2110	62.37	0.03	
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		2165	62.37	0.03	
		2170	62.36	0.02	

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		2590	62.38	0.04	
		2595	62.38	0.04	
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		2605	62.38	0.04	
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		2845	62.35	0.01	
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		3355	62.34	0.00	
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		3365	62.33	-0.01	
		3370	62.33	-0.01	
		3375	62.33	-0.01	
		3380	62.33	-0.01	
		3385	62.33	-0.01	
		3390	62.33	-0.01	
		3395	62.33	-0.01	
		3400	62.33	-0.01	
		3405	62.33	-0.01	
		3410	62.33	-0.01	
		3415	62.33	-0.01	
	57	3420	62.33	-0.01	
		3425	62.33	-0.01	
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		3435	62.32	-0.02	
		3440	62.32	-0.02	
		3445	62.32	-0.02	
		3450	62.32	-0.02	
		3455	62.32	-0.02	
		3460	62.32	-0.02	
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		3470	62.32	-0.02	
		3475	62.32	-0.02	
	58	3480	62.32	-0.02	
		3485	62.32	-0.02	
		3490	62.31	-0.03	
		3495	62.32	-0.02	
		3500	62.31	-0.03	
		3505	62.31	-0.03	
		3510	62.32	-0.02	
		3515	62.31	-0.03	
		3520	62.31	-0.03	
		3525	62.32	-0.02	
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		3545	62.31	-0.03	
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		3565	62.31	-0.03	
		3570	62.31	-0.03	

		3575	62.31	-0.03	
		3580	62.31	-0.03	
		3585	62.31	-0.03	
		3590	62.31	-0.03	
		3595	62.31	-0.03	
	60	3600	62.31	-0.03	
		3605	62.31	-0.03	
		3610	62.31	-0.03	
		3615	62.31	-0.03	
		3620	62.31	-0.03	
		3625	62.31	-0.03	
		3630	62.31	-0.03	
		3635	62.31	-0.03	
		3640	62.31	-0.03	
		3645	62.31	-0.03	
		3650	62.31	-0.03	
		3655	62.31	-0.03	
	61	3660	62.31	-0.03	
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		3675	62.30	-0.04	
		3680	62.30	-0.04	
		3685	62.30	-0.04	
		3690	62.30	-0.04	
		3695	62.30	-0.04	
		3700	62.30	-0.04	
		3705	62.30	-0.04	
		3710	62.30	-0.04	
		3715	62.30	-0.04	
	62	3720	62.30	-0.04	
		3725	62.30	-0.04	
		3730	62.30	-0.04	
		3735	62.30	-0.04	
		3740	62.30	-0.04	
		3745	62.30	-0.04	
		3750	62.30	-0.04	
		3755	62.30	-0.04	
		3760	62.30	-0.04	
		3765	62.30	-0.04	
		3770	62.30	-0.04	
		3775	62.30	-0.04	
	63	3780	62.30	-0.04	
		3785	62.30	-0.04	
		3790	62.30	-0.04	
		3795	62.30	-0.04	
		3800	62.30	-0.04	
		3805	62.30	-0.04	
		3810	62.30	-0.04	
		3815	62.30	-0.04	
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		3845	62.30	-0.04	
		3850	62.30	-0.04	

		3855	62.30	-0.04	
		3860	62.30	-0.04	
		3865	62.30	-0.04	
		3870	62.30	-0.04	
		3875	62.30	-0.04	
		3880	62.30	-0.04	
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		3895	62.30	-0.04	
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		3915	62.30	-0.04	
		3920	62.30	-0.04	
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		3930	62.30	-0.04	
		3935	62.30	-0.04	
		3940	62.30	-0.04	
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		4395	62.26	-0.08	
		4400	62.26	-0.08	
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		4410	62.27	-0.07	

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		4465	62.27	-0.07	
		4470	62.27	-0.07	
		4475	62.28	-0.06	
		4480	62.27	-0.07	
		4485	62.28	-0.06	
		4490	62.28	-0.06	
		4495	62.28	-0.06	
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		4515	62.28	-0.06	
		4520	62.28	-0.06	
		4525	62.28	-0.06	
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		4535	62.28	-0.06	
		4540	62.28	-0.06	
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		4550	62.28	-0.06	
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		4575	62.29	-0.05	
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		4670	62.29	-0.05	
		4675	62.29	-0.05	
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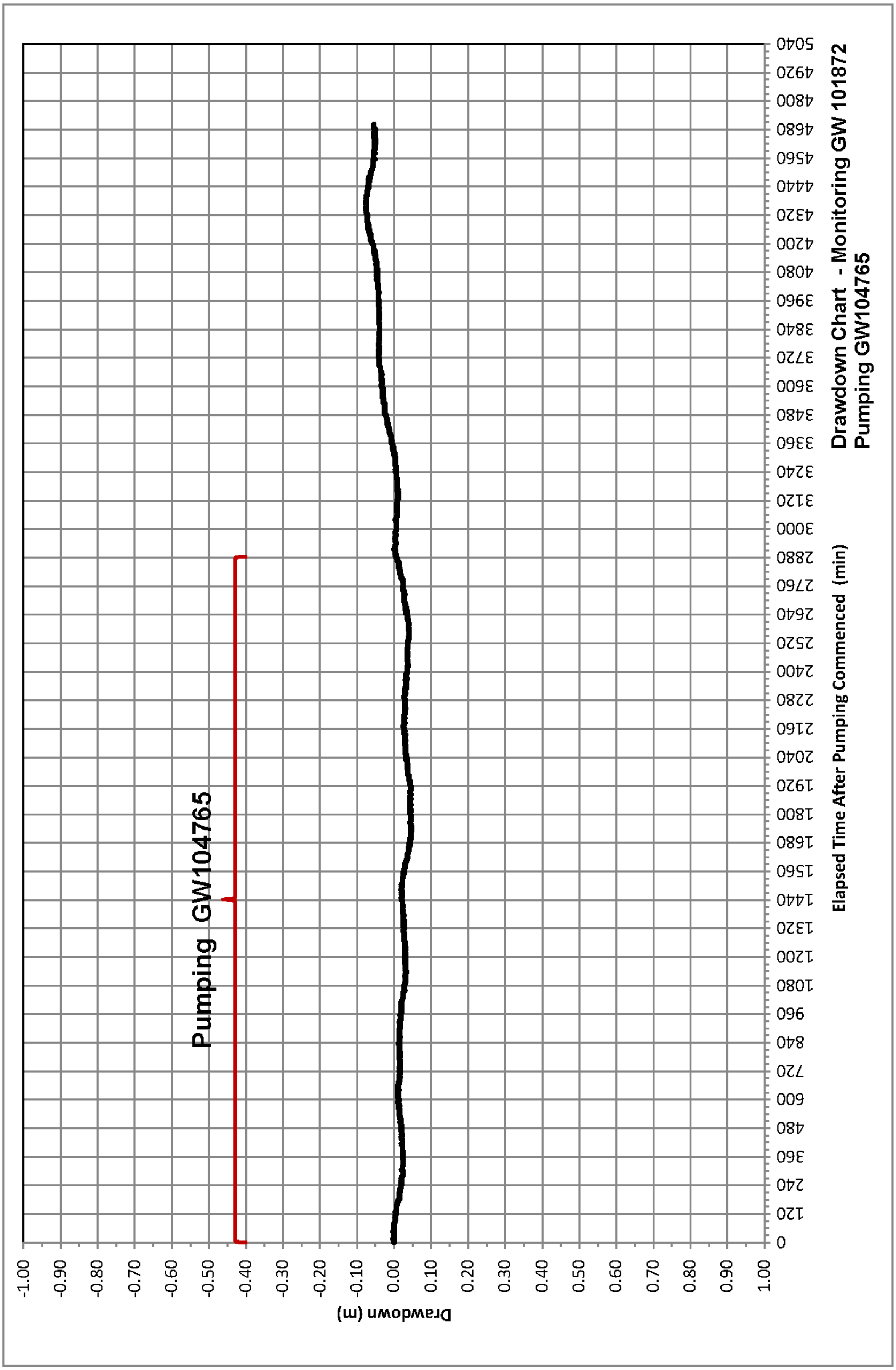
		4685	62.29	-0.05	
		4690	62.29	-0.05	

		4695	62.29	-0.05	
		4700	62.29	-0.05	


Drawdown Chart - Monitoring GW 101872
Pumping GW104765
Pumping GW104765
Elapsed Time After Pumping Commenced (min)
Drawdown (m)
0
120
240
360
480
600
720
840
960
1080
1200
1320
1440
1560
1680
1800
1920
2040
2160
2280
2400
2520
2640
2760
2880
3000
3120
3240
3360
3480
3600
3720
3840
3960
4080
4200
4320
4440
4560
4680
4800
4920
5040
-1.00
-0.90
-0.80
-0.70
-0.60
-0.50
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

Annexure 4

Laboratory Certificate Permeability Testing

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coffey information
SPECIALISTS IN SCIENTIFIC TESTING SOLUTIONS

REPORT ON

ROCK TESTING

For

Larry Cook Consulting Pty Ltd

Permeability Testing

28th February 2013

126 Trenerry Crescent | Abbotsford, VIC 3067 | Australia
T: +61 03 9473 1300 | F: +61 03 9473 1450

coffey information
SPECIALISTS IN SCIENTIFIC TESTING AND SOLUTIONS

Project: Larry Cook Consulting Pty Ltd - Permeability Testing

Falling Head Conductivity Test based on AS 1289.6.7.2

Identification	SFQ DDH 1 / 35.88 - 36.10	SFQ DDH 3 / 25.75-26.03	SFQ DDH 3 / 34.82-35.04
Sample ID	SFQ DDH 1_1	SFQ DDH 3_2	SFQ DDH 3_3
Sample Depth From (m)	35.88	25.75	34.82
Sample Depth To (m)	36.10	26.03	35.04
Diameter [mm]	61.00	61.30	60.80
Length [mm]	148.00	156.30	147.20
Conductivity at testing temperature [m/s]	0.00	0.00	0.00
Conductivity at testing temperature [mm/h]	1.73	36.34	2.77
k Standardized at 20 deg C	0.00	0.00	0.00
k at testing temperature [m/s]	1.64	34.59	2.64
Testing temperature [deg C]	22.00	22.00	22.00

Report Prepared by: Juan Jofre (Senior Testing Engineer - Laboratory Manager)

Annexure 5

Laboratory Certificate Water Quality Testing

(Total No. of pages including blank pages = 12)

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12 Ashley Street, Chatswood, NSW 2067
tel: +61 2 9910 6200
email: sydney@envirolab.com.au
envirolab.com.au
Envirolab Services Pty Ltd - Sydney | ABN 37 112 535 645

CERTIFICATE OF ANALYSIS **143210**

Client:
Larry Cook & Associates
PO Box 8146
TUMBI UMBI
NSW 2261

Attention: Larry Cook

Sample log in details:

Your Reference:	**Larry Cook - Sutton Forest**	
No. of samples:	8 Waters	
Date samples received / completed instructions received	11/03/16	/ 11/03/16

Analysis Details:
Please refer to the following pages for results, methodology summary and quality control data.
Samples were analysed as received from the client. Results relate specifically to the samples as received.
Results are reported on a dry weight basis for solids and on an as received basis for other matrices.
Please refer to the last page of this report for any comments relating to the results.

Report Details:

Date results requested by: / Issue Date:	18/03/16	/ 19/04/16
Date of Preliminary Report:	Not issued	

NATA accreditation number 2901. This document shall not be reproduced except in full.
Accredited for compliance with ISO/IEC 17025. **Tests not covered by NATA are denoted with *.**

Results Approved By:

Jacinta Hurst
Laboratory Manager

Envirolab Reference: 143210
Revision No: R 00

ACCREDITED FOR TECHNICAL COMPETENCE

Client Reference: Larry Cook - Sutton Forest

HM in water - total						
Our Reference:	UNITS	143210-1	143210-2	143210-3	143210-4	143210-5
Your Reference	--------------	SFQDDH1	SFQDDH2D	SFQOH2S	OH4	SFQDDH3S
Date Sampled	------------	10/03/2016	10/03/2016	10/03/2016	10/03/2016	10/03/2016
Type of sample		Water	Water	Water	Water	Water
Date prepared	-	14/03/2016	14/03/2016	14/03/2016	14/03/2016	14/03/2016
Date analysed	-	14/03/2016	14/03/2016	14/03/2016	14/03/2016	14/03/2016
Arsenic-Total	µg/L	<1	<1	<1	<1	<1
Cadmium-Total	µg/L	<0.1	<0.1	<0.1	<0.1	<0.1
Chromium-Total	µg/L	<1	<1	1	1	<1
Copper-Total	µg/L	1	<1	<1	1	1
Lead-Total	µg/L	<1	<1	<1	<1	1
Nickel-Total	µg/L	3	9	<1	2	<1
Zinc-Total	µg/L	19	14	10	21	13

HM in water - total				
Our Reference:	UNITS	143210-6	143210-7	143210-8
Your Reference	--------------	SFQDDH4D	SFQDDH5D	SFQDDH5S
Date Sampled	------------	10/03/2016	10/03/2016	10/03/2016
Type of sample		Water	Water	Water
Date prepared	-	14/03/2016	14/03/2016	14/03/2016
Date analysed	-	14/03/2016	14/03/2016	14/03/2016
Arsenic-Total	µg/L	2	<1	<1
Cadmium-Total	µg/L	<0.1	<0.1	<0.1
Chromium-Total	µg/L	1	1	2
Copper-Total	µg/L	1	1	<1
Lead-Total	µg/L	<1	<1	1
Nickel-Total	µg/L	<1	2	1
Zinc-Total	µg/L	<1	73	36

Client Reference: Larry Cook - Sutton Forest

Ion Balance Our Reference: Your Reference Date Sampled Type of sample	UNITS ------------- ------------	143210-1 SFQDDH1 10/03/2016 Water	143210-2 SFQDDH2D 10/03/2016 Water	143210-3 SFQOH2S 10/03/2016 Water	143210-4 OH4 10/03/2016 Water	143210-5 SFQDDH3S 10/03/2016 Water
Date prepared	-	14/03/2016	14/03/2016	14/03/2016	14/03/2016	14/03/2016
Date analysed	-	14/03/2016	14/03/2016	14/03/2016	14/03/2016	14/03/2016
Calcium - Dissolved	mg/L	<0.5	37	0.7	<0.5	<0.5
Potassium - Dissolved	mg/L	<0.5	1.6	<0.5	<0.5	<0.5
Sodium - Dissolved	mg/L	11	17	9.7	7.1	4.5
Magnesium - Dissolved	mg/L	1.0	6.4	1.3	<0.5	<0.5
Hydroxide Alkalinity (OH^-) as $CaCO_3$	mg/L	<5	<5	<5	<5	<5
Bicarbonate Alkalinity as $CaCO_3$	mg/L	7	130	5	5	5
Carbonate Alkalinity as $CaCO_3$	mg/L	<5	<5	<5	<5	<5
Total Alkalinity as $CaCO_3$	mg/L	7	130	5	5	5
Sulphate, SO4	mg/L	1	10	<1	1	2
Chloride, Cl	mg/L	18	15	16	10	4
Ionic Balance	%	-7.3	-1.3	0.46	-12	-14

Ion Balance Our Reference: Your Reference Date Sampled Type of sample	UNITS ------------- ------------	143210-6 SFQDDH4D 10/03/2016 Water	143210-7 SFQDDH5D 10/03/2016 Water	143210-8 SFQDDH5S 10/03/2016 Water
Date prepared	-	14/03/2016	14/03/2016	14/03/2016
Date analysed	-	14/03/2016	14/03/2016	14/03/2016
Calcium - Dissolved	mg/L	52	1.0	0.5
Potassium - Dissolved	mg/L	2.1	2.4	<0.5
Sodium - Dissolved	mg/L	9.8	11	8.6
Magnesium - Dissolved	mg/L	0.6	0.9	0.8
Hydroxide Alkalinity (OH^-) as $CaCO_3$	mg/L	<5	<5	<5
Bicarbonate Alkalinity as $CaCO_3$	mg/L	95	7	6
Carbonate Alkalinity as $CaCO_3$	mg/L	<5	<5	<5
Total Alkalinity as $CaCO_3$	mg/L	95	7	6
Sulphate, SO4	mg/L	40	3	3
Chloride, Cl	mg/L	13	17	18
Ionic Balance	%	0.52	0.17	-20

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Revision No: R 00

Client Reference: Larry Cook - Sutton Forest

Miscellaneous Inorganics						
Our Reference:	UNITS	143210-1	143210-2	143210-3	143210-4	143210-5
Your Reference	--------------	SFQDDH1	SFQDDH2D	SFQOH2S	OH4	SFQDDH3S
Date Sampled	------------	10/03/2016	10/03/2016	10/03/2016	10/03/2016	10/03/2016
Type of sample		Water	Water	Water	Water	Water
Date prepared	-	14/03/2016	14/03/2016	14/03/2016	14/03/2016	14/03/2016
Date analysed	-	14/03/2016	14/03/2016	14/03/2016	14/03/2016	14/03/2016
pH	pH Units	5.1	7.3	5.3	5.2	5.3
Electrical Conductivity	µS/cm	61	280	64	43	26
Total Dissolved Solids (grav)	mg/L	37	180	38	25	16

Miscellaneous Inorganics				
Our Reference:	UNITS	143210-6	143210-7	143210-8
Your Reference	--------------	SFQDDH4D	SFQDDH5D	SFQDDH5S
Date Sampled	------------	10/03/2016	10/03/2016	10/03/2016
Type of sample		Water	Water	Water
Date prepared	-	14/03/2016	14/03/2016	14/03/2016
Date analysed	-	14/03/2016	14/03/2016	14/03/2016
pH	pH Units	7.9	5.5	5.3
Electrical Conductivity	µS/cm	280	76	53
Total Dissolved Solids (grav)	mg/L	220	67	63

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Revision No: R 00

Client Reference: Larry Cook - Sutton Forest

Method ID	Methodology Summary
Metals-022 ICP-MS	Determination of various metals by ICP-MS.
Metals-020 ICP-AES	Determination of various metals by ICP-AES.
Inorg-006	Alkalinity - determined titrimetrically in accordance with APHA latest edition, 2320-B.
Inorg-081	Anions - a range of Anions are determined by Ion Chromatography, in accordance with APHA latest edition, 4110-B. Alternatively determined by colourimetry/turbidity using Discrete Analyer.
Inorg-040	The concentrations of the major ions (mg/L) are converted to milliequivalents and summed. The ionic balance should be within +/- 10% ie total anions = total cations +/-10%.
Inorg-001	pH - Measured using pH meter and electrode in accordance with APHA latest edition, 4500-H+. Please note that the results for water analyses are indicative only, as analysis outside of the APHA storage times.
Inorg-002	Conductivity and Salinity - measured using a conductivity cell at 25oC in accordance with APHA latest edition 2510 and Rayment & Lyons.
Inorg-018	Total Dissolved Solids - determined gravimetrically. The solids are dried at 180+/-5oC.

Envirolab Reference: 143210
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Client Reference: Larry Cook - Sutton Forest

QUALITY CONTROL HM in water - total	UNITS	PQL	METHOD	Blank	Duplicate Sm#	Duplicate results Base II Duplicate II %RPD	Spike Sm#	Spike % Recovery
Date prepared	-			14/03/2016	143210-1	14/03/2016 || 14/03/2016	LCS-W1	14/03/2016
Date analysed	-			14/03/2016	143210-1	14/03/2016 || 14/03/2016	LCS-W1	14/03/2016
Arsenic-Total	µg/L	1	Metals-022 ICP-MS	<1	143210-1	<1 || <1	LCS-W1	97%
Cadmium-Total	µg/L	0.1	Metals-022 ICP-MS	<0.1	143210-1	<0.1 || <0.1	LCS-W1	102%
Chromium-Total	µg/L	1	Metals-022 ICP-MS	<1	143210-1	<1 || <1	LCS-W1	94%
Copper-Total	µg/L	1	Metals-022 ICP-MS	<1	143210-1	1 || 1 || RPD: 0	LCS-W1	97%
Lead-Total	µg/L	1	Metals-022 ICP-MS	<1	143210-1	<1 || <1	LCS-W1	102%
Nickel-Total	µg/L	1	Metals-022 ICP-MS	<1	143210-1	3 || 3 || RPD: 0	LCS-W1	96%
Zinc-Total	µg/L	1	Metals-022 ICP-MS	<1	143210-1	19 || 20 || RPD: 5	LCS-W1	100%

QUALITY CONTROL Ion Balance	UNITS	PQL	METHOD	Blank	Duplicate Sm#	Duplicate results Base II Duplicate II %RPD	Spike Sm#	Spike % Recovery
Date prepared	-			14/03/2016	143210-1	14/03/2016 || 14/03/2016	LCS-2	14/03/2016
Date analysed	-			14/03/2016	143210-1	14/03/2016 || 14/03/2016	LCS-2	14/03/2016
Calcium - Dissolved	mg/L	0.5	Metals-020 ICP-AES	<0.5	143210-1	<0.5 || [N/T]	LCS-2	106%
Potassium - Dissolved	mg/L	0.5	Metals-020 ICP-AES	<0.5	143210-1	<0.5 || [N/T]	LCS-2	107%
Sodium - Dissolved	mg/L	0.5	Metals-020 ICP-AES	<0.5	143210-1	11 || [N/T]	LCS-2	107%
Magnesium - Dissolved	mg/L	0.5	Metals-020 ICP-AES	<0.5	143210-1	1.0 || [N/T]	LCS-2	105%
Hydroxide Alkalinity (OH^-) as $CaCO_3$	mg/L	5	Inorg-006	<5	143210-1	<5 || <5	[NR]	[NR]
Bicarbonate Alkalinity as $CaCO_3$	mg/L	5	Inorg-006	<5	143210-1	7 || 5 || RPD: 33	[NR]	[NR]
Carbonate Alkalinity as $CaCO_3$	mg/L	5	Inorg-006	<5	143210-1	<5 || <5	[NR]	[NR]
Total Alkalinity as $CaCO_3$	mg/L	5	Inorg-006	<5	143210-1	7 || 5 || RPD: 33	LCS-2	105%
Sulphate, SO4	mg/L	1	Inorg-081	<1	143210-1	1 || 1 || RPD: 0	LCS-2	120%
Chloride, Cl	mg/L	1	Inorg-081	<1	143210-1	18 || 17 || RPD: 6	LCS-2	111%
Ionic Balance	%		Inorg-040	[NT]	143210-1	-7.3 || [N/T]	[NR]	[NR]

Envirolab Reference: 143210
Revision No: R 00

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Client Reference: Larry Cook - Sutton Forest

QUALITY CONTROL Miscellaneous Inorganics	UNITS	PQL	METHOD	Blank	Duplicate Sm#	Duplicate results Base II Duplicate II %RPD	Spike Sm#	Spike % Recovery
Date prepared	-			14/03/2016	143210-1	14/03/2016 || 14/03/2016	LCS-W1	14/03/2016
Date analysed	-			14/03/2016	143210-1	14/03/2016 || 14/03/2016	LCS-W1	14/03/2016
pH	pH Units		Inorg-001	[NT]	143210-1	5.1 || 5.1 || RPD: 0	LCS-W1	101%
Electrical Conductivity	µS/cm	1	Inorg-002	<1	143210-1	61 || 72 || RPD: 17	LCS-W1	100%
Total Dissolved Solids (grav)	mg/L	5	Inorg-018	<5	143210-1	37 || [N/T]	LCS-W1	106%

QUALITY CONTROL HM in water - total	UNITS	Dup. Sm#	Duplicate Base + Duplicate + %RPD	Spike Sm#	Spike % Recovery
Date prepared	-	[NT]	[NT]	143210-2	14/03/2016
Date analysed	-	[NT]	[NT]	143210-2	14/03/2016
Arsenic-Total	µg/L	[NT]	[NT]	143210-2	97%
Cadmium-Total	µg/L	[NT]	[NT]	143210-2	102%
Chromium-Total	µg/L	[NT]	[NT]	143210-2	94%
Copper-Total	µg/L	[NT]	[NT]	143210-2	89%
Lead-Total	µg/L	[NT]	[NT]	143210-2	99%
Nickel-Total	µg/L	[NT]	[NT]	143210-2	91%
Zinc-Total	µg/L	[NT]	[NT]	143210-2	94%

QUALITY CONTROL Ion Balance	UNITS	Dup. Sm#	Duplicate Base + Duplicate + %RPD
Date prepared	-	143210-5	14/03/2016 || 14/03/2016
Date analysed	-	143210-5	14/03/2016 || 14/03/2016
Calcium - Dissolved	mg/L	143210-5	<0.5 || <0.5
Potassium - Dissolved	mg/L	143210-5	<0.5 || <0.5
Sodium - Dissolved	mg/L	143210-5	4.5 || 4.5 || RPD: 0
Magnesium - Dissolved	mg/L	143210-5	<0.5 || <0.5

Client Reference: **Larry Cook - Sutton Forest**

Report Comments:
TDS done by calculation for sample #1,#3,#4 and #5 due to high sediment present in the sample.

Asbestos ID was analysed by Approved Identifier:	Not applicable for this job
Asbestos ID was authorised by Approved Signatory:	Not applicable for this job

INS: Insufficient sample for this test	PQL: Practical Quantitation Limit	NT: Not tested
NR: Test not required	RPD: Relative Percent Difference	NA: Test not required
<: Less than	>: Greater than	LCS: Laboratory Control Sample

Client Reference: **Larry Cook - Sutton Forest**

Quality Control Definitions

Blank: This is the component of the analytical signal which is not derived from the sample but from reagents, glassware etc, can be determined by processing solvents and reagents in exactly the same manner as for samples.

Duplicate: This is the complete duplicate analysis of a sample from the process batch. If possible, the sample selected should be one where the analyte concentration is easily measurable.

Matrix Spike : A portion of the sample is spiked with a known concentration of target analyte. The purpose of the matrix spike is to monitor the performance of the analytical method used and to determine whether matrix interferences exist.

LCS (Laboratory Control Sample) : This comprises either a standard reference material or a control matrix (such as a blank sand or water) fortified with analytes representative of the analyte class. It is simply a check sample.

Surrogate Spike: Surrogates are known additions to each sample, blank, matrix spike and LCS in a batch, of compounds which are similar to the analyte of interest, however are not expected to be found in real samples.

Laboratory Acceptance Criteria

Duplicate sample and matrix spike recoveries may not be reported on smaller jobs, however, were analysed at a frequency to meet or exceed NEPM requirements. All samples are tested in batches of 20. The duplicate sample RPD and matrix spike recoveries for the batch were within the laboratory acceptance criteria.

Filters, swabs, wipes, tubes and badges will not have duplicate data as the whole sample is generally extracted during sample extraction.

Spikes for Physical and Aggregate Tests are not applicable.

For VOCs in water samples, three vials are required for duplicate or spike analysis.

Duplicates: <5xPQL - any RPD is acceptable; >5xPQL - 0-50% RPD is acceptable.

Matrix Spikes, LCS and Surrogate recoveries: Generally 70-130% for inorganics/metals; 60-140% for organics (+/-50% surrogates) and 10-140% for labile SVOCs (including labile surrogates), ultra trace organics and speciated phenols is acceptable.

In circumstances where no duplicate and/or sample spike has been reported at 1 in 10 and/or 1 in 20 samples respectively, the sample volume submitted was insufficient in order to satisfy laboratory QA/QC protocols.

When samples are received where certain analytes are outside of recommended technical holding times (THTs), the analysis has proceeded. Where analytes are on the verge of breaching THTs, every effort will be made to analyse within the THT or as soon as practicable.

Where sampling dates are not provided, Envirolab are not in a position to comment on the validity of the analysis where recommended technical holding times may have been breached.

To: Envirolab Services Pty Ltd
12 Ashley Street
Chatswood NSW 2147

CHAIN OF CUSTODY

Date: 11.3.16 Page: 1 of 1

REPORT TO: Larry Cook
COMPANY: Larry Cook Consulting
ADDRESS: PO Box 8146
TUMBI UMBI NSW 2261

INVOICE TO: Larry Cook
COMPANY: Larry Cook Consulting
ADDRESS: PO Box 8146
TUMBI UMBI NSW 2261

Telephone: 0428 884645
Email: larrycookconsulting@gmail.com

ANALYSIS REQUIRED

	Client Sample ID	Sample Date	Matrix	IONIC BALANCE	PH, EC, TDS	7 METALS
1	SFQ DDH1	10.3.16	WATER	✓	✓	✓
2	SFQ DDH2D	↓	↓	✓	✓	✓
3	SFQ OH2S	↓	↓	✓	✓	✓
4	SFQ OH4	↓	↓	✓	✓	✓
5	SFQ DDH3S	↓	↓	✓	✓	✓
6	SFQ DDH4D	↓	↓	✓	✓	✓
7	SFQ DDH5D	↓	↓	✓	✓	✓
8.	SFQ DDH5S	↓	↓	✓	✓	✓

Stamp: ENVIROLAB Envirolab Services 12 Ashley St Chatswood NSW 2067 Ph: (02) 9910 6200
Job No:
Date Received: 11032016
Time Received: 1845.
Received by: CB
Temp: Cool/Ambient
Cooling: Ice/Icepack
Security: Intact/Broken/None

Stamp: ENVIROLAB Envirolab Services 12 Ashley St Chatswood NSW 2067 Ph: (02) 9910 6200
Job No: 143210
Date Received: 11032016.
Time Received: 1845.
Received by: CB.
Temp: Cool/Ambient
Cooling: Ice/Icepack
Security: Intact/Broken/None

Project ID	Relinquished By:	Date/Time	Received By:	Date/Time
SUTTON FOREST	L.COOK [signature]	11.3.16	Calum BONSER	
	Relinquished By:	Date/Time	Received By:	Date/Time
	Relinquished By:	Date/Time	Received By:	Date/Time

Comments:

Annexure 6

Groundwater Modelling Report

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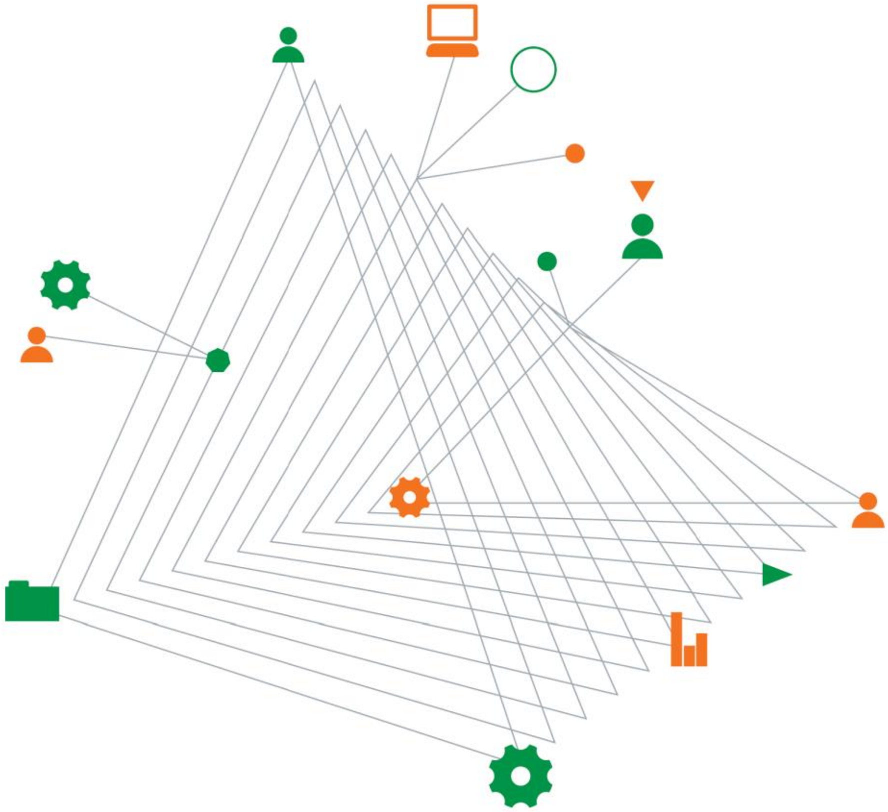
Sutton Forest Quarries Pty Ltd

Sutton Forest Sand Quarry

Groundwater Modelling Assessment

29 August 2016



Experience
comes to life
when it is
powered by
expertise

Coffey Geotechnics Pty Ltd

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Sutton Forest Sand Quarry

Prepared for
Sutton Forest Quarries Pty Ltd

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29 August 2016

Document authorisation

Our ref: GEOTWOLL03661AB-AH

For and on behalf of Coffey

Paul Tammetta
Associate Subsurface Hydrologist

Quality Information

Revision History

Revision	Description	Date	Author	Reviewer	Signatory
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Rev 1	Final Draft AC	9/02/2016	Ben Rotter	Corinna De Castro	Corinna De Castro
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Rev 4	Final Draft AG	24/05/2016	Ben Rotter	Corinna De Castro	Corinna De Castro
Rev 5	Final AH	29/08/2016	Paul Tammetta	Ben Rotter	Paul Tammetta

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AE Final Draft_rev 3	1	PDF	R.W. Corkery & Co Pty Limited	22/04/2016
AG Final Draft_rev 4	1	PDF	R.W. Corkery & Co Pty Limited	24/05/2016
AH Final_rev 5	1	PDF	R.W. Corkery & Co Pty Limited	29/08/2016

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Executive Summary

Coffey Geotechnics Pty Ltd (Coffey) has undertaken a groundwater modelling assessment for the Sutton Forest Sand Quarry Project located at Sutton Forest, NSW, for Sutton Forest Quarries Pty Ltd. The purpose of the assessment was to estimate the impact of proposed extraction operations on the groundwater system and changes in baseflow to the nearby Long Swamp Creek.

The Site is located near the Hume Highway, about 12 km west of Bundanoon in the Southern Highlands of NSW. Landforms are typical of incised Hawkesbury Sandstone terrain in the Southern Highlands. The area hosts several temperate highland peat swamps. Long Swamp is located approximately 200 m to the northwest of the extraction area, and Hanging Rock Swamp is located approximately 1.8 km to the south.

The hydrogeological conceptual model comprises a layered vertically anisotropic fractured medium with relatively large vertical hydraulic head gradients. Groundwater is sourced mainly from rainfall recharge. Discharge occurs at springs and at watercourses such as Long Swamp Creek and Paddys River.

The conceptual model was used to develop a numerical groundwater flow model to assess the potential drawdown in private bores in the area, and the effect on baseflow to Long Swamp and its associated creek, due to the proposed quarry. Predictive modelling results are as follows:

- The modelled intercepted baseflow to Long Swamp, Long Swamp Creek and its tributaries due to extraction is a maximum of about 2.6% compared to the calculated long-term average baseflow.
- The modelled contour of 0.2 m drawdown of the water table (due to Site extraction operations) extends a maximum of about 1 km from the extraction area at the end of Stage 5 (Year 28), and about 1.2 km at the end of Stage 7 (end of extraction operations, Year 45). The maximum modelled drawdown of the water table at the end of extraction operations (Year 45) at each private bore is less than 0.5 m.
- The maximum modelled drawdown of the water table (due to Site extraction operations) at Year 45 (end of extraction operations) in the vicinity of the four closest private bores to the extraction area is as follows:
  - GW035166: < 0.3 m.
  - GW037967: < 0.3 m.
  - GW068897: < 0.5 m.
  - GW101872: < 0.3 m.

  Given the depth of the four closest bores to the extraction area, and their recorded water levels, this is unlikely to cause significant loss of available groundwater at these locations and is within drawdown limits set in the Aquifer Interference Policy. Other private bores are unlikely to be influenced by the proposed extraction regime, including the Coca Cola mineral water bores located approximately 2 km southwest of the extraction area.
- The long-term average groundwater discharge from the backfill in the extraction area is calculated as 0.002 ML/day. This is likely to be consumed by evaporation before being able to form free water drainage features. Where increased discharge occurs (during higher rainfall periods), the discharge (where not consumed by surface evaporation) will exit the area as streamflow.

1. Introduction

This report presents the results of a groundwater modelling assessment for the proposed Sutton Forest Sand Quarry, located near Sutton Forest, NSW (Drawing 1). The assessment was undertaken by Coffey Geotechnics Pty Ltd (Coffey) for Sutton Forest Quarries Pty Ltd (the Applicant). The purpose of the assessment was to estimate the extent of groundwater drawdown, and changes in baseflow to Long Swamp Creek, due to the proposed extraction operations.

The assessment comprised compilation and analysis of a groundwater database, development of a hydrogeological conceptual model, and development of a groundwater flow numerical model to simulate drawdown on the groundwater system and changes in baseflow to streams.

For the purposes of this report, the proposed quarry is located within an area referred to as the Site (see Drawing1).

2. Site characteristics

2.1. Location and topography

The regional location of the proposed quarry is shown in Drawing 1. The extraction area within the quarry is located about 12 km west of Bundanoon and about 1 km northwest of the Hume Highway in the Southern Highlands of NSW. The Site boundary and numerical model boundary are illustrated in Drawing 1.

Ground elevations in the model study area range between 750 m AHD to less than 600 m AHD. The typical landform comprises Hawkesbury Sandstone incised (deeply in parts) by drainage channels, typical for the Southern Highlands.

Peat swamps occur along major creeks in lower elevations, where the gradient of the drainage channel decreases significantly. The swamps are predominately located on Permian and Narrabeen Group sedimentary strata outcrop (Coffey, 2007).

2.2. Rainfall and evaporation

Average annual rainfall for the Site is about 902 mm (SEEC 2016), based on long-term rainfall data from surrounding weather stations. Rainfall is measured by the Applicant at a site weather station (see Drawing 2). For the full months of January to July 2015 inclusive, the weather station recorded 631 mm of rainfall. Despite the limited site data, a correlation of these months of rainfall with monthly rainfall over the same period from the two closest BOM rainfall stations with long-term records, was considered useful. Results are listed in Table 1.

Average annual Class A pan evaporation obtained from the Australian Bureau of Meteorology (ABM) Gridded Dataset is 1497 mm for the Site. This dataset is based on stations with at least ten years of records between 1975 and 2005, with at least 80% complete data over the recorded period. Gridded data were generated using the Barnes 2-D meteorological analysis.

The average annual potential evapotranspiration (PET) is estimated to be about 1167 mm (SEEC 2016). SEEC (2016) estimated evaporation from pond surfaces as approximately 1.5 times the PET, for the purpose of surface water budget calculations.

Table 1. Comparison of site monthly rainfall (January to July 2015 inclusive) with other stations.

Correlated station	Site Weather Station	68008 (Bundanoon)	68045 (Moss Vale)
Observed long-term annual average (mm)	N/A	1158	962
Distance from site	N/A	11 km west-southwest	19 km west-northwest
Elevation (m AHD)	705	688	675
Total rainfall January to July 2015 inclusive	631	877	674
Site rainfall as a proportion of station rainfall	N/A	0.72	0.94
Monthly rainfall correlation			
Fitted line slope (site rainfall as a proportion of station rainfall)		0.64	0.84
Regression coefficient (-)		0.90	0.81
Residuals normality		Reasonable	Poor

Recharge to the groundwater system is mainly from rainfall recharge. In natural land areas, rainfall infiltration to the Hawkesbury Sandstone groundwater system may reach up to around 5% of rainfall. Where the sandstone underlies the Wianamatta Group, recharge to the sandstone groundwater system is lower. Rainfall recharge to basalt can be in excess of 10% of annual rainfall.

2.3. Surface drainage

The main watercourse in the area is Long Swamp Creek, a fourth-order watercourse located to the north and west of the extraction area (Drawing 1). It drains in a westerly direction and has a catchment area of approximately 12.1 km^2 at point WSL2 (a water sampling location, shown on Drawing 2, referred to as WQL3 in SEEC (2016)).

An un-named second-order tributary of Long Swamp Creek is located southwest of the extraction area (see Drawing 2). The proposed extraction area is not located in the surface catchment of the un-named watercourse.

No flow measurements are known to be available for Long Swamp Creek. It was observed to be flowing in August 2013 and March/April 2014, however much of the flow west of the proposed extraction area was through thick reed beds (SEEC 2016). A surface water depth of about 0.5 m was observed at location WSL3 in 2014 (pers. comm. SEEC 2016).

Long Swamp was viewed at the Old Crossing (see Drawing 2) by Coffey staff on 23 July 2014. At that time the swamp was approximately 100 m wide with water-filled voids in the peat on both sides of the crossing. The voids were connected by a drainage channel approximately 1 m wide (estimated visually) running under the crossing. The flow velocity in the channel was estimated as 2 m per minute. The flow in the channel was calculated as about 4.3 ML/day using the velocity estimate and a channel depth of about 1.5 m (estimated visually). 23 July 2014 had been preceded by 4 months of below average rainfall (162 mm), with no daily rainfall above 2.4 mm in the preceding 20 days. The flow estimated for 23 July is therefore considered to have a large component of baseflow. Actual baseflow was likely to have been larger as other voids in the peat were observed.

The catchment of Long Swamp Creek for the point where it exits the model domain (see Drawing 1) is 24.8 km^2, of which 93.7% occurs in the model domain (24.1 km^2). Surface lithology in the catchment is composed of 51% Hawkesbury Sandstone, 42% Wianamatta Group, 4% Permian strata, and 3% basalt. Numerous baseflow analyses for other watercourses in the Southern Highlands indicate that baseflow would comprise about 2.5% to 3.5% of incident rainfall for a relatively undisturbed catchment with outcrop lithology proportions, and general landform, similar to the Long Swamp Creek catchment in the model domain. It is estimated that for long-term average rainfall conditions (902 mm/year), baseflow in Long Swamp Creek, where it exits the model domain, would be between about 1.4 and 1.7 ML/day. The proportion of baseflow (with respect to incident rainfall) is not constant but increases as rainfall increases, so that for higher rainfall conditions (such as during the calibration period, discussed below), the baseflow proportion will be higher.

Springs at high elevations are reported to occur in the local area (LCC 2016). A large expanse of basaltic extrusions north of the extraction area and north of Long Swamp Creek are likely to have associated springs emanating from near the contact with the underlying Wianamatta Group, which may provide baseflow to Long Swamp Creek (Coffey 2007).

Based on site observations, desktop assessments, and the presence of areas of deep incision of the Hawkesbury Sandstone by watercourses, it was estimated that lower lying watercourses (generally below 630 m AHD, depending on landform) are perennial and watercourses at higher elevation are ephemeral.

2.4. Groundwater dependent ecosystems

On 29 April 2005, the Commonwealth Government included a number of temperate highland peat swamps on sandstone as threatened ecological communities under section 181 of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The list included various swamps in the Southern Highlands, including the Paddys River Swamps (also known as Hanging Rock, Long, Mundego and Stingray Swamps), Wildes Meadow Swamp, and Wingecarribee Swamp.

The commencement of Long Swamp within Long Swamp Creek is located approximately 200 m to the northwest of the extraction area, and Hanging Rock Swamp along Paddys River is located approximately 1.8 km south of the proposed quarry. Swamp locations are shown on Drawing 1 and have been digitised from the internet map provided by the Australian Department of Environment and Heritage on temperate peat swamps on sandstone. It is recognised that baseflow to the watercourses in which these swamps occur are a component for their survival.

Studies undertaken for Wingecarribee Swamp, to the north east (Coffey, 2007) indicate that spring seeps from basaltic terrain were also significant components of the water balance for the swamp. Basaltic extrusions to the north of the Site may play a similar part for Long Swamp.

2.4.1. Hydrological environment for peat swamp growth

The peat swamps require the following essential conditions for growth and survival:

- Impeded drainage at the floor of the peat substrate (a floor of low permeability clay or localised low-permeability rock). Vertical drainage of water from the peat must be minimal.
- Waterlogged conditions (limiting the amount of oxygen) and low temperatures. Both these conditions reduce the rate of decomposition of the vegetation in the peat substrate.
- Accumulation of organic matter faster than the rate of decomposition. Acidic conditions are an advantage.

To maintain waterlogged conditions, a swamp requires a location with high net soil water retention (rainfall recharge minus evaporation remains relatively high). The peat requires a quasi-continual, uninterrupted supply of water to avoid drying out. Much of the water supply comes from runoff or spring/baseflow but also rainfall. Groundwater accession (inflow) from surrounding rock strata also occurs as a secondary recharge process. For a continual water supply to be available, the runoff behaviour must be dominant for peat swamp development. Runoff patterns are dependent on regional topography and sedimentation. Sediment chokes can trap low-flow runoff. In the Southern Highlands, swamps tend to occur at elevations of between 600 m AHD and 700 m AHD.

2.5. Geology

The Site is located on the southwest margin of the Sydney Basin. The geological sequence in this area is as follows (in stratigraphic order of increasing age):

- Robertson Basalt (Tertiary basalt, dolerite and volcanic breccia).
- Wianamatta Group (Bringelly Shale, Minchinbury Sandstone, and Ashfield Shale) and Mittagong Formation (Triassic).
- Hawkesbury Sandstone (Triassic).
- Narrabeen Group (present only in parts) (Triassic).
- Illawarra Coal Measures (Permian).
- Shoalhaven Group (Permian).

Three published interpretations of geology were found for the model study area (Figure 1). The area hosts outcrops of Wianamatta Group, Hawkesbury Sandstone, and underlying Narrabeen Group and/or Permian coal measures. Since 1966, the geological interpretation has been modified with significant areas previously mapped as Permian now designated as Triassic Hawkesbury Sandstone (Figure 1c). The geology as used in the current work is shown in Drawing 1, based on the two most recent published interpretations.

Geological Survey of NSW Bulletin 26 (1980) provides detailed geological descriptions of the fractured media lithologies. The Triassic Wianamatta Group (WG) comprises black shale interbedded with lithic sandstones. The shale consists mainly of sulphide-rich claystones and siltstones containing abundant plant debris and some lenses of coal. The Minchinbury Sandstone is a persistent sandstone horizon which separates the Ashfield and Bringelly Shales of the WG.

The Triassic Hawkesbury Sandstone (HS) is a quartz arenite, containing grains of sub-angular quartz with a smaller proportion of feldspar, clay, and iron compounds such as siderite. It ranges in thickness from less than 100 m on the southwest edge of the Sydney Basin to around 250 m in the Sydney metropolitan area. In the Berrima area it is around 120 m thick where fully developed. It is composed of the following three facies:

- Sheet facies (cross-bedded strata bounded by planar sub-horizontal surfaces).
- Massive facies (nearly, but not wholly, structureless poorly sorted sandstone, containing higher proportions of clay and less chemical cement and quartz overgrowth than the sheet facies).
- Claystone facies (thin dark grey to black mudstone units with a characteristic thickness of between 0.3 m and 3 m).

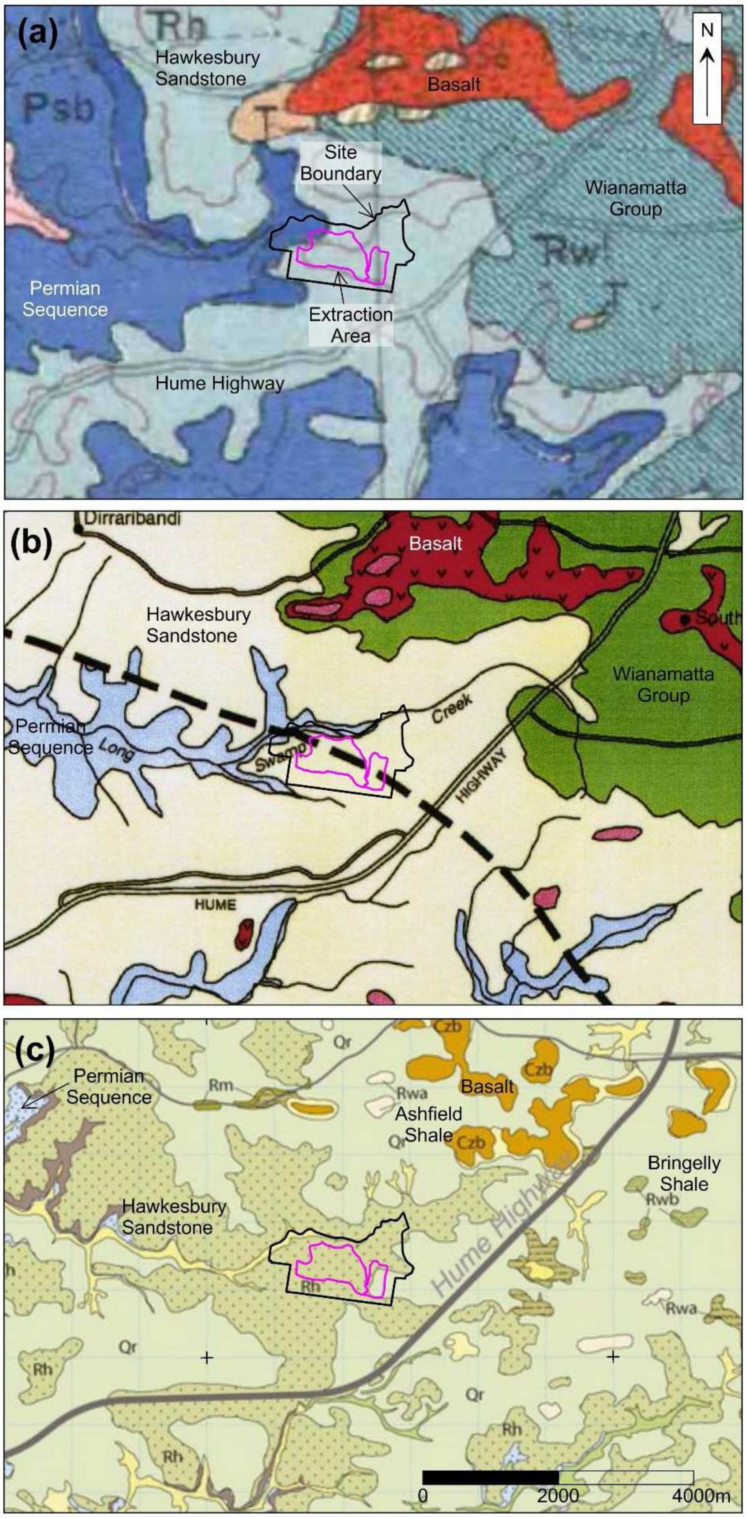

Figure 2.1. Evolution of published geological interpretations of the model study area: (a) GSNSW (1966), (b) Mason (1995), and (c) GSNSW (2010). Window limits and scales are identical.

The thickness of the HS is reported as being about 80 m thick to the north of the site to about 50 m near Wingello (Mason, 1995). Structure contours for the base of the HAW, and its thickness, in the model domain were assessed from the following information:

- Analysis of thickness at varying positions from the centre of the Sydney Basin (169 m at Tahmoor Colliery, 123 m in the vicinity of Kangaloon, with continued thinning towards the edges of the basin, to eventual termination of the HS to the southwest).
- Geological structure contours of the base of the Hawkesbury Sandstone in the vicinity of the proposed quarry interpreted by Crouch (1980).
- Borehole logs from private bores in the vicinity of the site (GW042926 and GW105308, with an average thickness of 81 m).
- Detailed analysis of elevations of the HS / Narrabeen Group contact at ground surface, using a 30 m digital elevation model (DEM).

The overall sandstone thickness beneath the extraction area is about 80 m. This accords with topographic patterns in cross section (see Figure 2.8). Interpreted structure contours for the base of the HS are shown in Drawing 1. The average elevation of the base of the Hawkesbury Sandstone beneath the proposed extraction area is about 617 m AHD.

The Narrabeen Group has been almost completely eroded in the south western marginal zone of the Sydney Basin. It is absent over a large part of the study area, reaching a maximum thickness of around 6 m at Berrima. Where it is not present, the Hawkesbury Sandstone unconformably overlies the Illawarra Coal Measures (ICM).

The ICM are a freshwater sequence comprising alternating layers of conglomerate, quartz-lithic sandstone, grey shale, carbonaceous shale and coal seams. These rock types occur in a cyclic pattern up the profile, with each cycle consisting of a basal sandstone layer overlain by shale or mudstone (seat soil), then by a coal seam. The ICM thickness ranges from about 50 m in the Southern Highlands to more than 250 m near Wollongong.

The ICM are underlain by the Shoalhaven Group, which comprises sandstones deposited under marine conditions interbedded with latite flows (intermediate potassic volcanic extrusives). In the project area the Group unconformably overlies the strongly folded Palaeozoic basement.

2.6. Subsurface hydraulic properties

2.6.1. Hydraulic conductivity

A large database has been compiled of hydraulic conductivity (K) measurements from insitu hydraulic testing at the site and in the wider area. Assessment of hydraulic properties has focussed on the HAW, as this unit is where extraction is proposed. The K of the HS in the area has been assessed from the following sources:

- Site specific data:
  - A long-term pumping test undertaken at private bore GW051450 (see Drawing 2) located 1.5 km south-southwest of the extraction area. The pumped bore and two observation bores were monitored.
  - A long-term pumping test undertaken at private bore GW104765 within the Site (see Drawing 2). The pumped bore and one observation bore were monitored.
  - Three slug tests undertaken in two bores.
  - Laboratory tests on three cores of friable HAW, retrieved from two boreholes.
- Regional data:

- Packer test results from the southern part of the Sydney Basin in Tammetta and Hawkes (2009).
- 105 estimates of hydraulic conductivity from specific capacity data in government records for private water bores. Appendix A shows the method used to obtain K from specific capacity.
- Six long-term pumping tests from private bores in the area.
- Previous studies in the Southern Highlands (Coffey, 2006, 2008, 2012a, and 2012b).

Figure 2.2 shows the K database developed from these measurements. Results indicate decreasing K with depth, but elevated magnitudes in comparison to other areas in the Southern Coalfield. This is believed to be the result of significant regional tectonic disturbance and associated intrusive activity southwest of the Mount Murray Monocline located about 30 km northeast of the Site (the monocline strikes northwest-southeast). For a volume of media comparable to the cell sizes used in the model, K varies from about 1 m/day at the surface to about 0.1 m/day at 100 m depth. The ratio of vertical K to horizontal K (Kv/Kh) is estimated to be about 0.01 to 0.02.

Sutton Forest Sand Quarry
Groundwater Modelling Assessment

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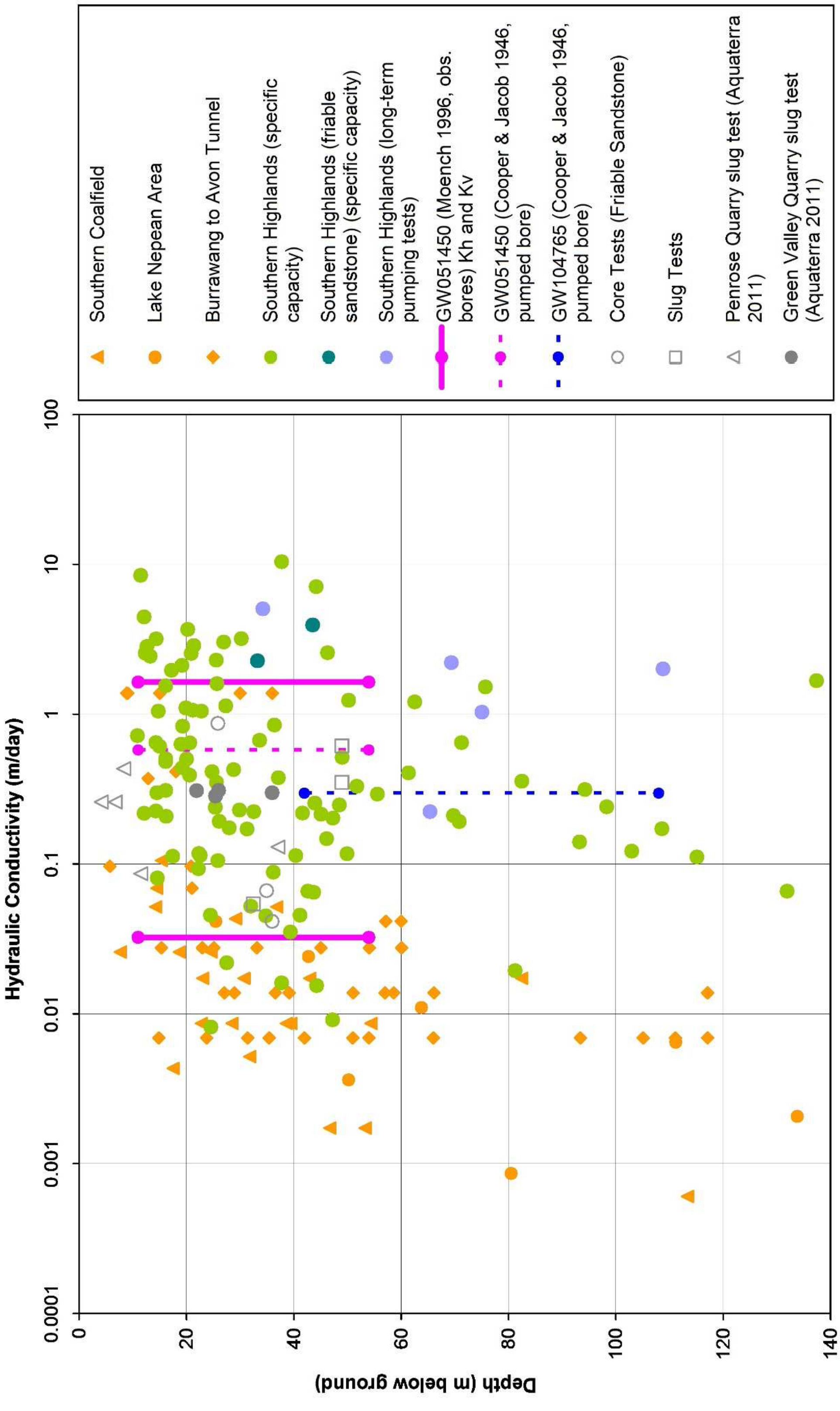

Figure 2.2. K database for the Sutton Forest Quarry area.

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Pumping tests

Two long-term, single-rate pumping tests were carried out during part of the studies for the Proposal, at private bores GW051450 (duration 1 day) and GW104765 (duration 2 days), with monitoring at observation piezometers for each test. Pumping bore locations are shown in Drawing 1.

Drawdown at observation piezometers for the GW051450 test were of comparable magnitude despite being located at distances of 93 m and 378 m from the pumped bore. In addition, drawdown in the pumped bore remained stable (decreasing slightly) during the 2nd day of the test. Drawdowns at monitoring bores continued to rise following cessation of pumping, suggesting the influence of earth tides and barometric pressure, or continued drainage following emptying of a subsurface void at a faster rate than it can be naturally recharged by enclosing media. These aspects do not accord with any of the more common conceptual models used in pump test analysis. Initial analysis indicated observed drawdowns could not be simultaneously matched using a laterally isotropic and homogenous radial flow system with vertical anisotropy. The drawdown response suggests preferential drawdown in a direction just east of magnetic north, sub-parallel to the direction of the principle horizontal stress field in the area, and the principal lateral conductivity direction at Kangaloon (Coffey, 2006, 2008). Nevertheless, it was considered useful to analyse drawdown from each observation bore separately, using automatic parameter estimation with WTAQ (Barlow and Moench, 1999) as the analytical model. WTAQ allows simulation of partial pumping bore and piezometer penetration, and a vertically anisotropic medium. Simulated and observed drawdowns are shown in Figure 2.3. The geometric means of the optimised values are shown in Figure 2.2. Kv/Kh was an average of 0.02. Drawdown at the pumped bore for the GW051450 test was analysed using the Cooper Jacob (1946) method, reasonably applicable for the pumped bore at longer times; results were similar to those form WTAQ.

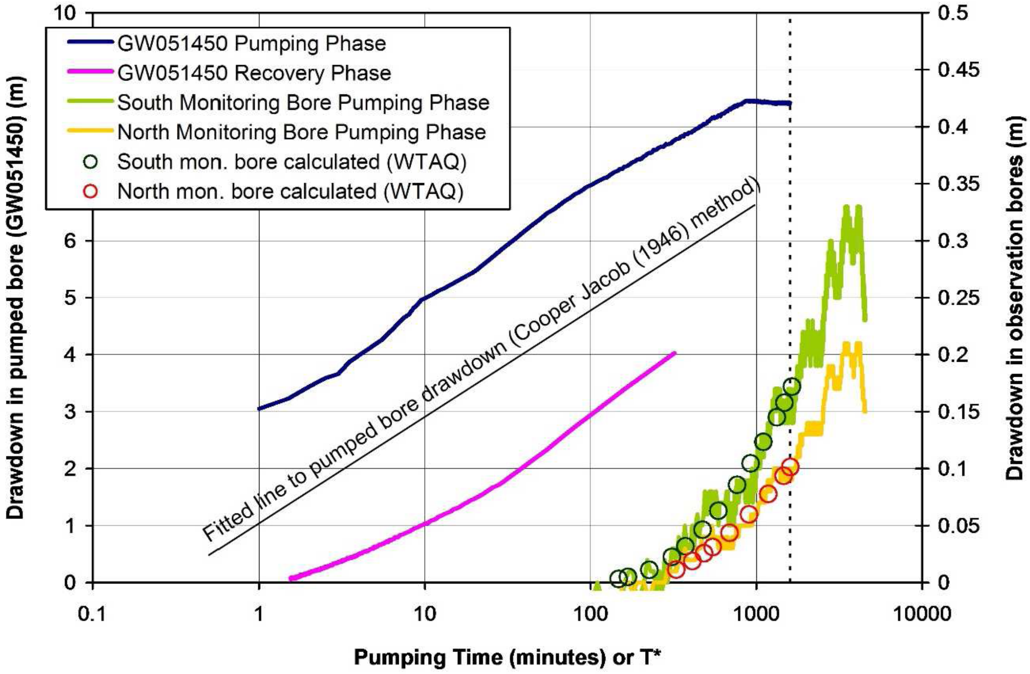

Figure 2.3. Analysis of drawdown at observation piezometers (Moench (1996) method) and at the pumped bore (Cooper and Jacob (1946) method) for the pumping test at GW051450.

T* denotes the ratio of [time since pump started] / [time since pump stopped].

Drawdown at the observation piezometer for the GW104765 test indicates a gradual but small rise. Comparison to high-frequency monitoring at distant bores indicated the drawdown was most likely due to earth tides and/or barometric pressure fluctuations. Drawdown from the pumped bore was analysed using the Cooper Jacob (1946) method. The interpretation is shown in Figure 2.4.

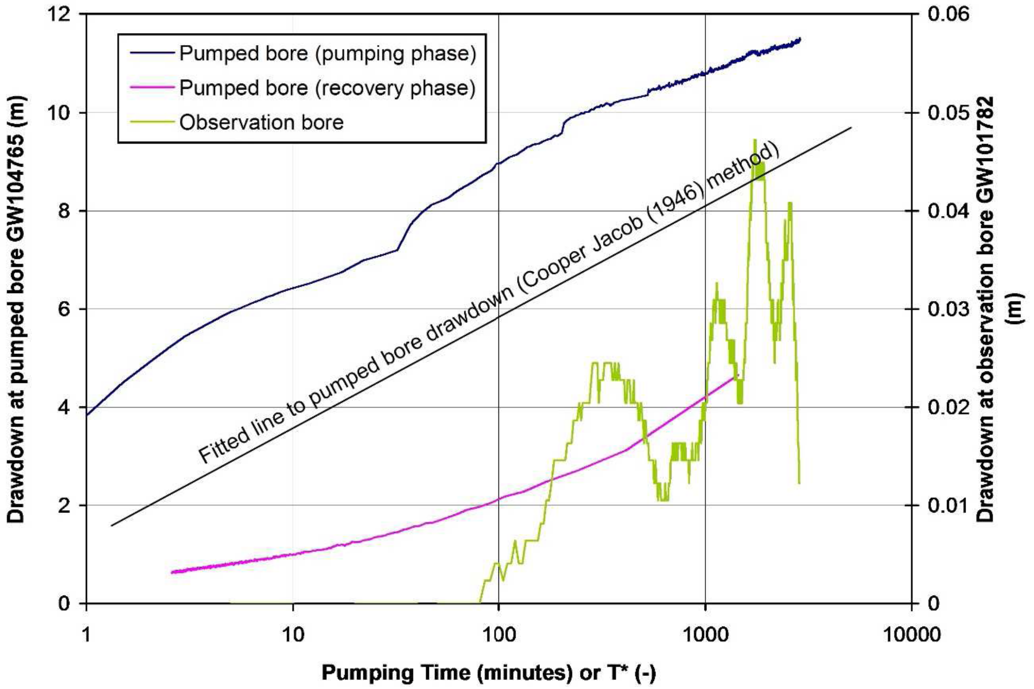

Figure 2.4. Analysis of drawdown at the pumped bore for the GW104765 test using the method of Cooper and Jacob (1946).
T* denotes the ratio of [time since pump started] / [time since pump stopped].

2.6.2. Storativity

Specific yield

Typical coal measures media have a void distribution composed of pores and defects. The pore distribution is created during sedimentation and diagenesis, and individual entities are closely spaced and very small. Defects (existing fractures, joints, and partings, and those introduced by caving) are created during failure of the rock mass (from a changing stress field) and their geometry is completely different to pores. Drainage occurs quickly from defects and slowly from pores. The majority of the total void space is contained in the pores (typically 10% to 20% of the medium) however observations demonstrate that this void space contributes negligibly to specific yield (Sy) in the medium term. This is due to the moisture retention characteristics of the matrix. It can withstand much higher suction (compared to defects) prior to pore drainage. This is amplified by the absence of solar radiation in underground voids.

If the time rate of water table change in defects is rapid compared to matrix K then overall Sy may approach defect Sy. Conversely, where the time rate of water table change is slow compared to matrix K, overall Sy may have a non-negligible matrix drainage component.

Specific yield, void space, and specific storage usually decrease with depth. Sy for coal measures rocks is rarely more than a few percent, ranging from less than 0.01 for claystones to around 0.02 to 0.03 for highly fractured sandstone. Typical published estimates are 0.013 for Devonian siltstone (Risser et al. 2005) and 0.012 for laminated shale (Woods and Wright 2003). Unpublished results from Australia are an Sy of between 0.005 and 0.007 (over 5 years) for Permian coal measures (claystone, sandstone, and interbedded coal) in the Western Coalfield, and an Sy of between 0.004 and 0.008 (over 3 years) for Permian coal measures in the Hunter Coalfield. Studies conducted in the Sydney metropolitan area and elsewhere indicate a specific yield of between 0.01 and 0.02 is reasonable for typical, undeformed Hawkesbury Sandstone (Tammetta and Hewitt 2004). The transient aspect of Sy is important.

Specific storage

The dominant component of specific storage is media compression, mostly via contraction of defect apertures. The specific storage of Hawkesbury Sandstone in the Blue Mountains west of Sydney has been estimated to be about 1×10^{-6} m^{-1} (Kelly et al. 2005) in the upper zones where fracture flow is dominant. Results of long duration pump testing in Hawkesbury Sandstone in western Sydney (Tammetta and Hawkes 2009) indicated an average specific storage of 1.5×10^{-6} m^{-1} for depths between ground surface and 300 m.

Assuming that the total primary and secondary porosity that allows fluid flow ranges between 10% at the surface and 5% at depth, and assuming that the medium is incompressible, then the specific storage ranges between 4.5×10^{-7} m^{-1} at the surface to 2.3×10^{-7} m^{-1} at depth (field measurements of specific storage show its depth variability; see for example Heywood, 1997). Greater media compression is possible at shallower depths, where flow through defects predominates, than at deeper depths.

2.6.3. Peat

The hydraulic properties of peat are as follows:

- Hydraulic conductivity:
  - Quinton et al (2008): Kh of 10 m/day to 1000 m/day above 0.1 m depth, decreasing to between 0.5 m/day and 5 m/day below 0.2 m (more decomposed).
  - Wong et al (2009): Kv between 1 m/day and 0.001 m/day (lower in amorphous peat, higher in fibrous peat).
  - US DoE (2008): 4.5 m/day from 2 month peat bed test.
- Storage capacity: Variable; peat expands and contracts with increases and decreases in water content.

2.7. Groundwater levels

Groundwater levels at the Site are monitored by Larry Cook Consulting (LCC) on behalf of the Applicant using a network of monitoring piezometers and private bores. The network comprises 14 piezometers at nine locations and two private bores, giving 16 subsurface measurement points at 11 locations. Monitoring commenced in July 2014. Table 2 lists monitoring piezometer and private bore completion details. Locations are shown in Drawing 2. Drawing 2 also shows the three surface water monitoring locations on Long Swamp Creek (WSL1 to WSL3) established by SEEC (2016). Four piezometers (SFQ DDH4D, DDH5D, DDH5S and OH2D) are outfitted with automatic water level recorders; high frequency monitoring for the period 5 May 2015 to early August 2015 is available for these.

Water levels from 1975, obtained from government records for private bore GW043719, were found useful for interpretation of hydraulic head cross sections.

Table 2. Piezometer completion details.

Piezometer or bore	Easting (MGA)	Northing (MGA)	Ground Elevation (mAHD)	Depth (mbgl)*	Collar Elevation (m AHD)	Screen Interval (mbgl)		Gravel Pack Interval (mbgl)	
						From	To	From	To
SFQ DDH1	243185	6166154	692.7	51.1	693.2	48	51	47	51
SFQ DDH2	242705	6166295	682	40.5	682.6	37	40	36	41
SFQ DDH3	243009	6166460	688	38.9	688.7	36	39	35	39
SFQ DDH3S	243009	6166460	688	23.0	688.9	17	23		
SFQ DDH4D	242745	6166385	671	51.1	671.8	35	41		
SFQ DDH4S	242745	6166385	671	11.0	672.0	5	11		
SFQ DDH5D	243168	6166263	689	65.5	689.8	51	57		
SFQ DDH5S	243168	6166263	689	28.0	689.7	22	28		
SFQ OH1	243507	6166192	690	33.0	690.5	27	33	26	33
SFQ OH2D	242932	6166254	685.2	36.0	658.7	30	36	29	36
SFQ OH2S	242932	6166254	670.2	15.0	670.8	9	15		
SFQ OH3	243207	6166329	684.5	39.0	685.2	33	39	32	39
SFQ OH4	242758	6166545	686	40.7	686.7	35	41	34	41
SFQ OH5	243724	6165912	687	42.0	687.6	39	42	38	42
GW104765	244057	6166221	686	108		42^	108^		
GW101872	243873	6165776	771	204		63^	90^		

* Denotes metres below ground level.
^ Open bores. Values in the screen interval columns refer to the recorded water level in the bore (qualifying as the top of the hydraulic interval for these bore completions) and the base of the bore (the bottom of the hydraulic interval). GW101872 appears to have been backfilled; its depth is uncertain.

2.7.1. Hydrographs

Piezometers SFQ DDH2, OH1, and OH3 have been dry throughout the time of monitoring. Hydrographs for piezometers fitted with automatic water level recorders are shown in Figure 2.5, compared to rainfall measured at the site weather station. Hydrographs for remaining piezometers are shown in Figure 2.6. Figure 2.5 indicates that hydraulic heads are largely unresponsive to rainfall events, except for a partial response seen at SFQ OH2D following the rainfall event of mid-June 2015 (the first part of the response is not available from records). Hydraulic heads have remained relatively stable throughout the monitoring period, mainly showing response to natural fluctuations in barometric pressure and earth tides.

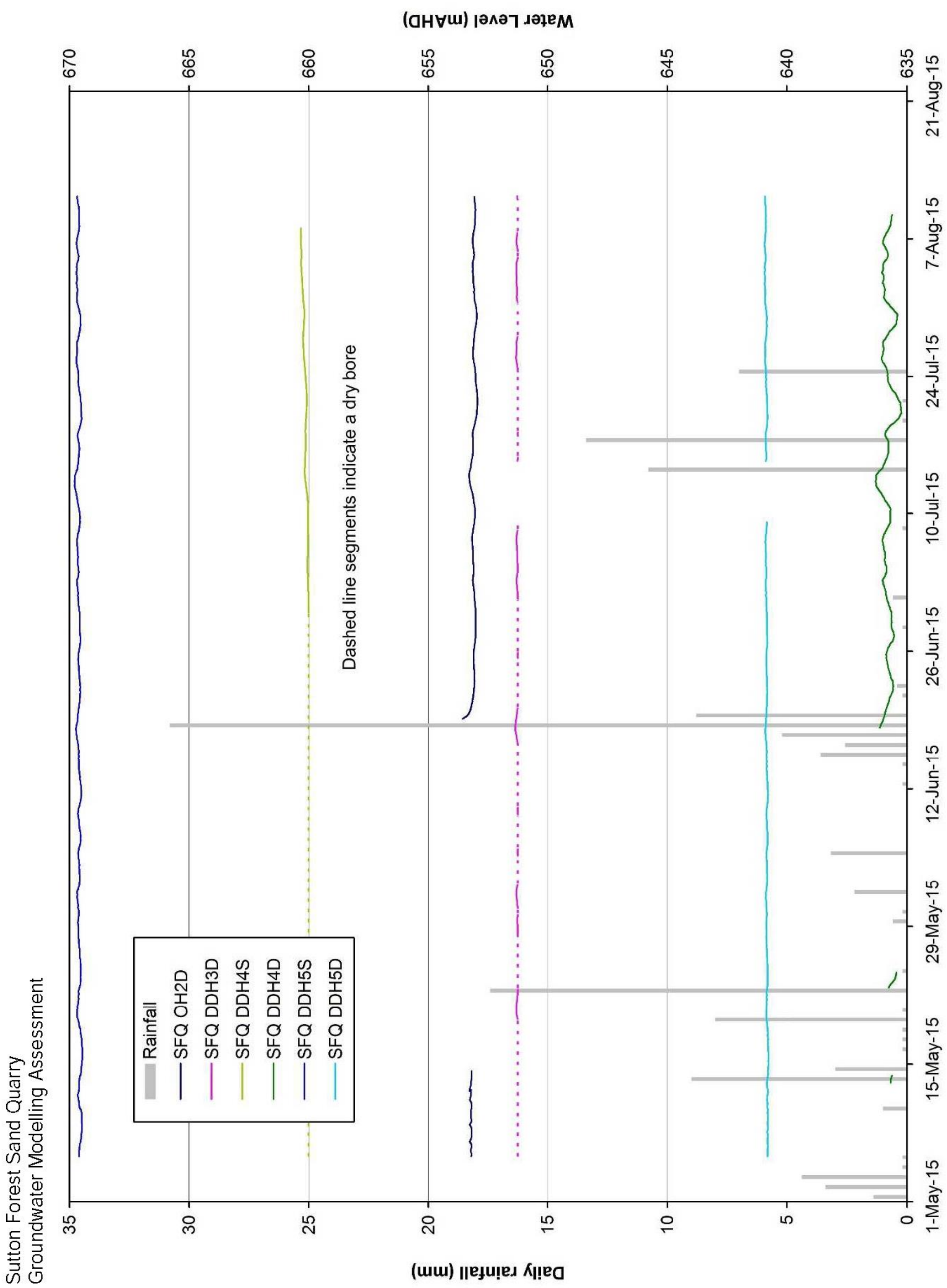

Figure 2.5. Hydrographs for piezometers fitted with automatic recorders.

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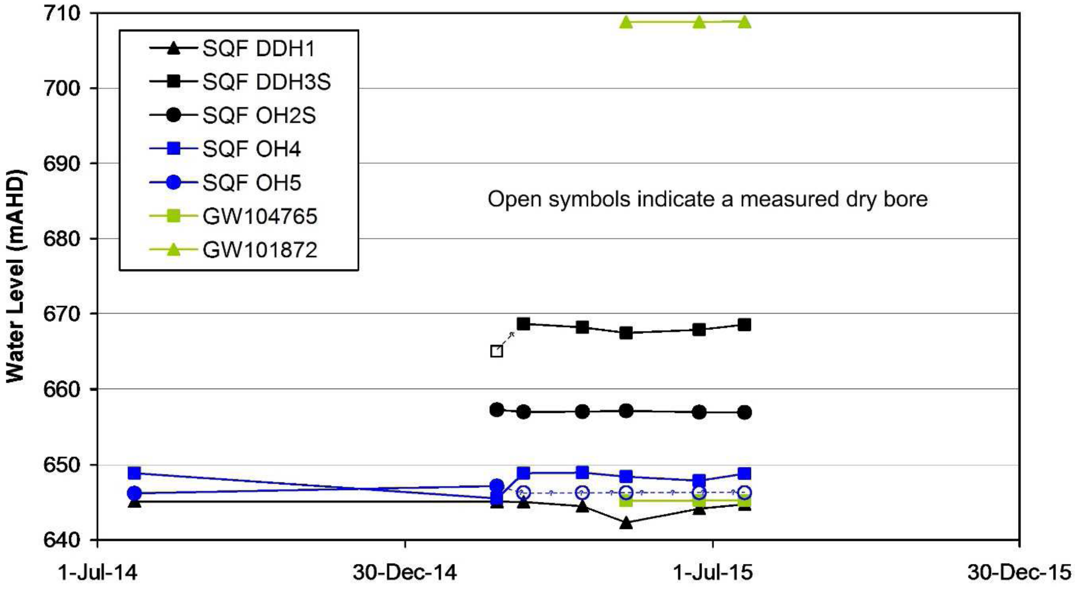

Figure 2.6. Hydrographs for piezometers monitored manually.

2.7.2. Vertical hydraulic head gradients

Vertical hydraulic head gradients were assessed by analysing the pressure head distribution of the hydraulic head measurements. Figure 2.7 shows pressure head versus depth for site piezometers and two private bores during 2015. The data are interpreted to indicate two saturated systems in the proposed extraction area. Dry and intermittently saturated piezometers indicate a high probability of an unsaturated zone between an upper perched saturated system and a deeper saturated system. The perched system is characterised by being bounded at the top and bottom by a capillary fringe.

The presence of the unsaturated zone means that depressurisation or drawdown in the deeper system has no effect on the perched system. Baseflow to Long Swamp Creek is most likely to be almost entirely provided by the deep system. For these reasons, the model was designed to replicate the deeper groundwater system only.

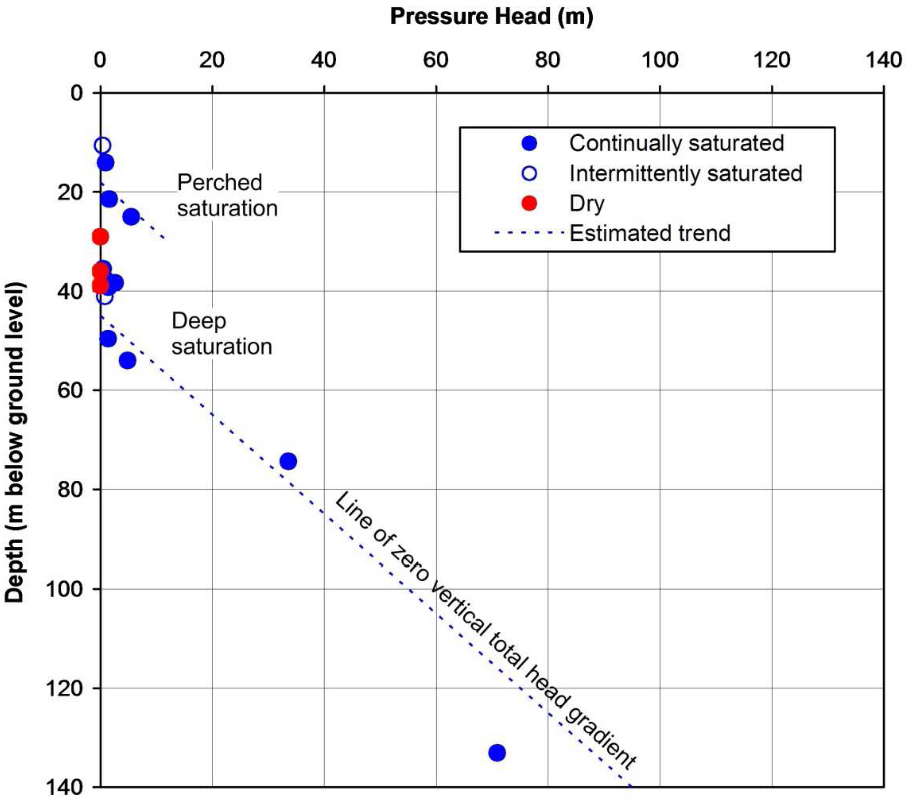

Figure 2.7. Pressure head profile for the model study area.

Total head and pressure head measurements from site piezometers (and from private bore GW043719 for March 1975) have been used to develop approximate hydraulic head cross sections along east-west and north-south transects through the proposed extraction area. These, and their locations, are shown in Figure 2.8. The locations of saturated and unsaturated zones down the profile have been interpreted using total head and pressure head. For modelling purposes, localised perched zones of saturation are ignored as these contribute minimally in the relationship between the groundwater system and Long Swamp Creek.

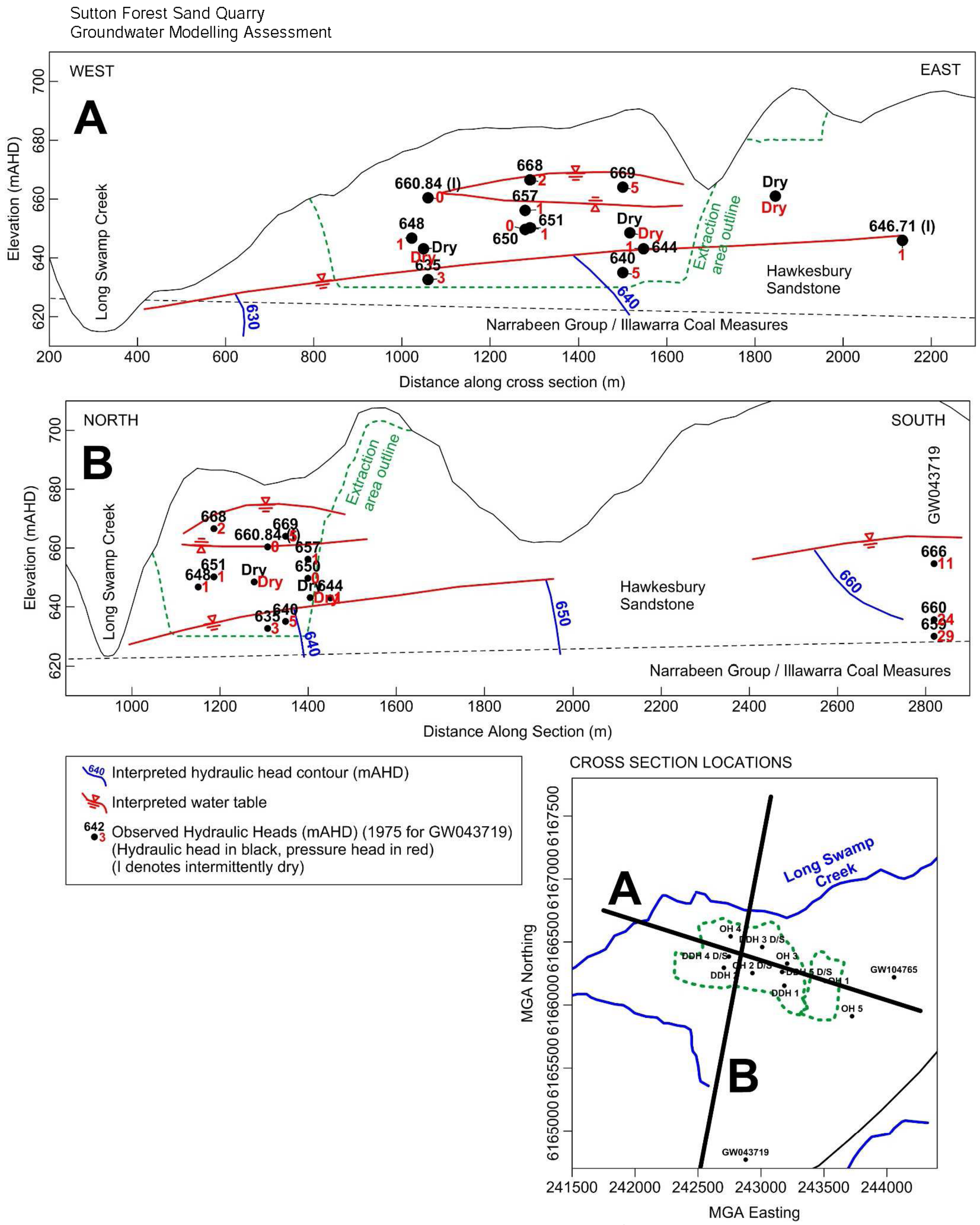

Figure 2.8. Interpreted hydraulic head contours and positions of the various water tables.

2.7.3. Hydraulic Head Surface

In an environment of relatively large vertical hydraulic head gradients, it is important to consider the vertical position of a piezometer in the profile when assessing hydraulic head or drawdown contour surfaces. A hydraulic head surface was interpolated for the deeper groundwater system using a selection of piezometer measurements considered to best represent it, based on the preceding discussion. The largest number of measurements was available for February to March 2015; averages of measurements from these monitoring rounds were used to interpolate a hydraulic head surface, shown in Figure 2.9. Hydraulic head measurements were tied using Long Swamp Creek bed elevations from a detailed DEM. The surface is relatively uniform. The vertical distance between the surface and the overlying water table decreases moving northward, and is similar to the water table elevation in the vicinity of Long Swamp Creek. Along this surface, groundwater flows in a northerly direction with a gradient of about 0.035.

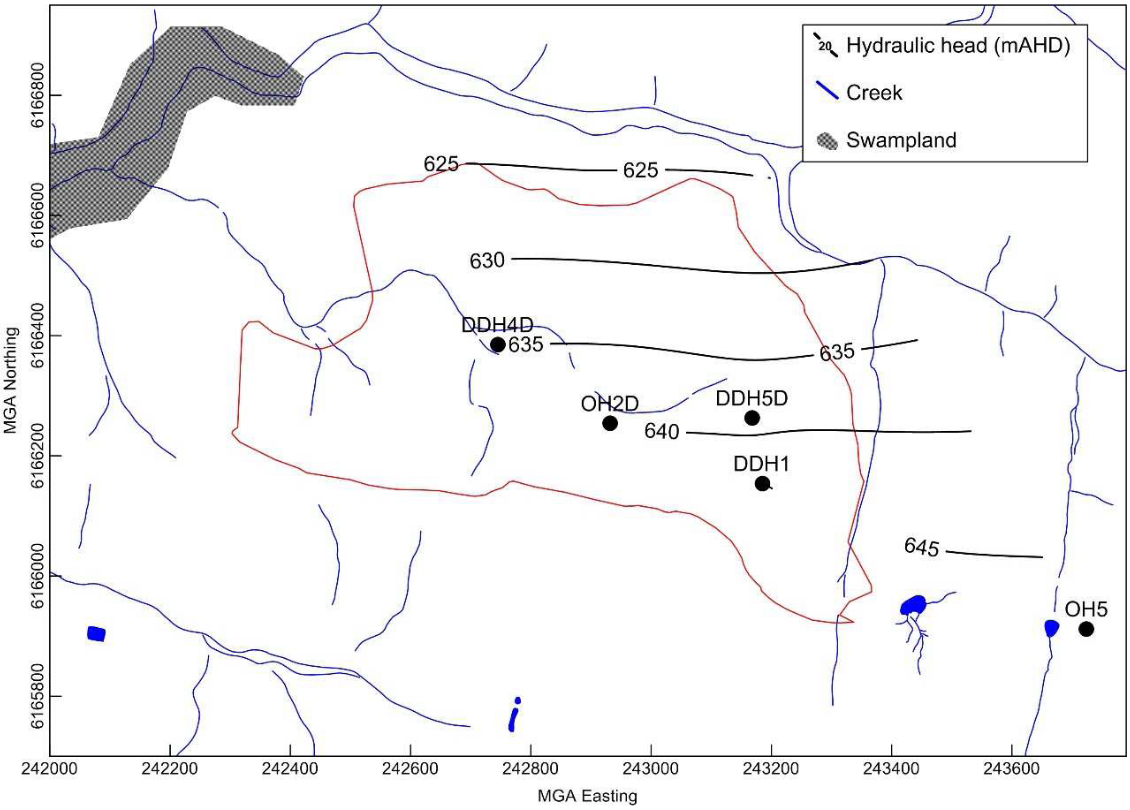

Figure 2.9. Hydraulic head surface for the deeper groundwater system for February / March 2015.

2.8. Registered groundwater bores

Approximately 42 registered groundwater bores are located within 2.5 km of the proposed extraction area. Bore depths vary between 30 m and 204 m and are used for stock, domestic, irrigation, and industrial water supplies. Ten of these bores have licensed allocations, some of which are known to pump groundwater on a regular basis. The locations of these bores are shown in Drawing 1 and their details are listed in Table 3. LCC (2016) provides a map showing the location of all registered bores within 2.5 km of the Site.

Table 3. Private pumping bores within 2.5 km of the proposed quarry with licensed allocations.

Bore Number	Easting (MGA)	Northing (MGA)	Ground Elevation* (mAHD)	Depth (mbgl)^	Allocation (ML/year)	Property	Authorised Purpose
GW037967	243900	6165599	720	84	19	Danellan	Irrigation
GW101488	241466	6164876	655	23	20	Wandoo	Industrial
GW102447	240591	6165383	645	37	60	Penrose	Irrigation, Industrial
GW103106	241725	6164795	660	37	63	Edith Vale	Industrial, Domestic
GW104765	244057	6166221	690	108	45	Henderson	Irrigation
GW106311	245608	6167299	690	91	30	Sutton Forest Estate Wines	Irrigation, Industrial
GW108683	242075	6167838	700	114	25	Robinson	Irrigation
GW108457	241133	6164839	650	32	120 (combined)	Tennyson Park (Coca Cola)	Industrial (mineral water extraction)
GW102066	241055	6164967	650	34			
GW101583	241047	6164933	650	34			

* Approximate (estimated from topographic map).
^ Denotes metres below ground level.

3. Hydrogeological conceptual model

A hydrogeological conceptual model has been developed based on the data analysis conducted in the preceding sections

3.1. Recharge

Recharge to the groundwater system occurs mainly by rainfall infiltration. Recharge may also occur from drainage channels wherever the stream stage is higher than the water table. Annual recharge to the water table is estimated to be about 2% of annual rainfall.

3.2. Key hydraulic properties

Hydraulic conductivity and storativity decrease with depth. The K field for the Site has greater magnitudes than seen elsewhere in the Southern Sydney Basin, and is believed to result from significant tectonic disturbance and associated intrusive activity.

Vertical anisotropy is also believed to decrease with depth, given the greater proportion of matrix flow at depth. Kv/Kh is estimated to be around 0.01 at the depths monitored during the pumping tests.

3.3. Discharge

Groundwater discharge or consumption occurs as follows:

- Baseflow discharge to drainage channels.
- Evapotranspiration in the unsaturated zone, in zones with shallow water tables, at escarpments, and at forested areas.
- Groundwater pumping.

3.4. Conceptual model

The elements of the conceptual model discussed above are presented pictorially in Figure 3.1., based on the hydraulic head cross section of Figure 2.8. It shows a schematic representation of the hydraulic head field that will be created by extraction operations at maximum quarry development. The subsurface comprises a layered vertically anisotropic medium with moderate downward vertical hydraulic head gradients. Unsaturated zones in the sandstone are likely to occur:

- At the top of sequences underlying reasonable expanses of Wianamatta Group and basalt.
- Localised zones of limited lateral and vertical extent which may occur underneath thicker shale lenses within the sandstone, as attested by dry conditions at piezometer SFQ-DDH2 and the presence of saturation at surrounding piezometers.

Groundwater is sourced from rainfall infiltration into the underlying rock and recharge to the water table with evapotranspiration from both the unsaturated zone, the water table at shallow depth and evaporation of inflow to the extraction area. Natural discharge would remain at springs and at watercourses such as Long Swamp Creek and Paddys River with some localised limited capture of seepage by the extraction area.

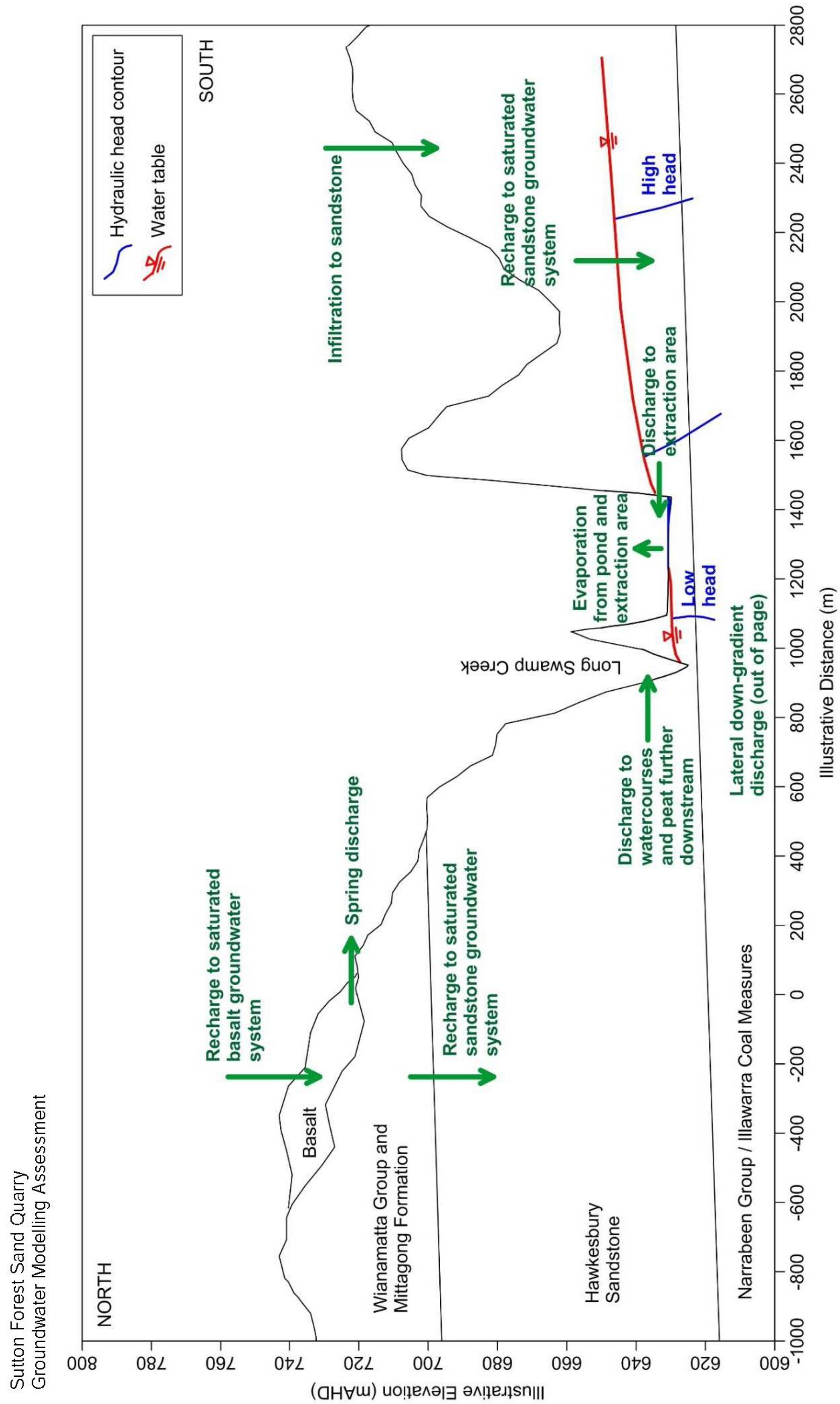

Figure 3.1. **Post-extraction hydrogeological conceptual model (horizontal to vertical exaggeration 10:1).**

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4. Proposed extraction operations

Extraction operations would comprise removal of soil and rock from the extraction area and the processing and stockpiling area as shown in Figure 4.1. Extraction is planned to occur in eight stages (Stages 0 to 7) over a period of about 45 years. Each Stage is a defined subdivision of the extraction area. The development consent currently being sought is for Stages 0 to 5 (a period of about 30 years). Development of the subsequent extraction stages (6 and 7) would be enabled by additional development consent being sought in the future. Predictive simulation is undertaken for the entirety of the proposed development so that readers may develop an understanding of the Applicant's objectives and plans for the life of the development, from site establishment and construction through to closure and rehabilitation of the Quarry.

Figure 4.1 shows the boundary of each stage, and the lowest excavated floor elevations for the extraction area and the processing and stockpiling area. Most of the extraction area will be excavated to a floor elevation of 630 m AHD. Stage 0 comprises the preparation of three pads to form the processing and stockpiling area. Stage 1 initiates when the central and southern pads (680 m AHD and 690 m AHD floors, respectively) are complete. Excavation of the northern pad in Stage 0 (floor at 660 m AHD) occurs concurrently with extraction in Stage 1, in Year 4. Excavation Stage 0 is primarily to prepare the processing area for emplacement of the necessary infrastructure, however a proportion of the excavated material will be processed for sale. Stages 1 to 7 are located in the main extraction area, and would be carried out sequentially. Extraction would not immediately occur below the water table of the deeper groundwater system.

Extraction would commence at a rate of 0.25 million tonnes / year (Mt/y) in Year 1, to 0.5 Mt/y in Year 2, to 0.82 Mt/y in Year 4. Of the 1.7 Mt extracted in Stage 0, about 0.3 Mt would be used for areas in Stage 0 that require filling, and about 0.1 Mt would be used to construct acoustic barriers. In times of high market demand, the extraction rate may increase to 1 Mt/y. Table 4 lists salient features of the proposed excavation schedule. Excavation will be by conventional ripping and some blasting.

Table 4. Details of proposed excavation.

Stage	Friable Sandstone Reserves (Mt)	Indicative Years of Operation
0	1.7	1 to 3
1	0.5	3 to 4
2	6.4	5 to 11
3	6.3	12 to 20
4	1.4	21 to 22
5	4.8	23 to 28
6	7.6	29 to 38
7	5.5	39 to 45
Total:	34.2	45

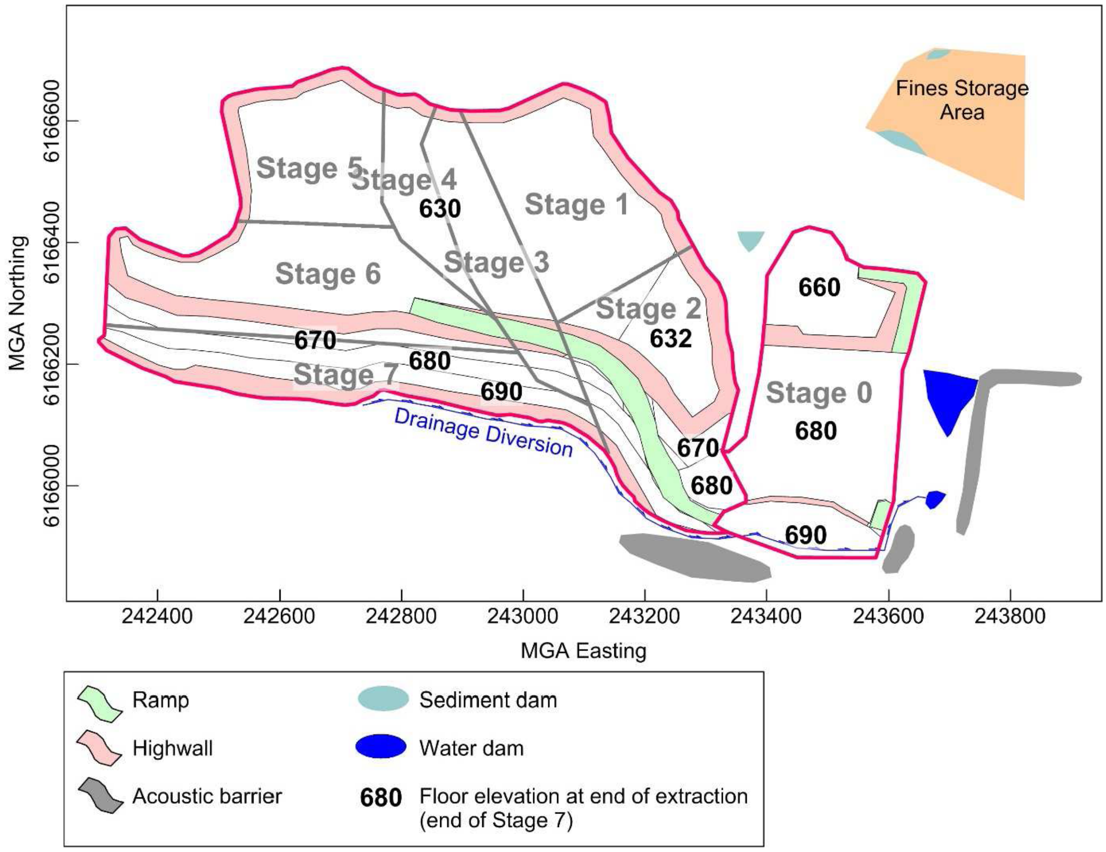

Figure 4.1. Proposed extraction area showing pit stages and lowest excavated floor elevation.

Figure 4.2 shows a long section of the elevation of the Long Swamp Creek channel (and Long Swamp), and the lowest excavated floor level in the extraction area along a line parallel to, but shifted 250 m south of, the creek. The line through the extraction area intersects the deepest parts of the excavation. The lowest level in the extraction area is a minimum of about 10 m above the channel directly opposite. The channel achieves the same elevation as the lowest level in the extraction area about 600 m upstream, along the creek reach.

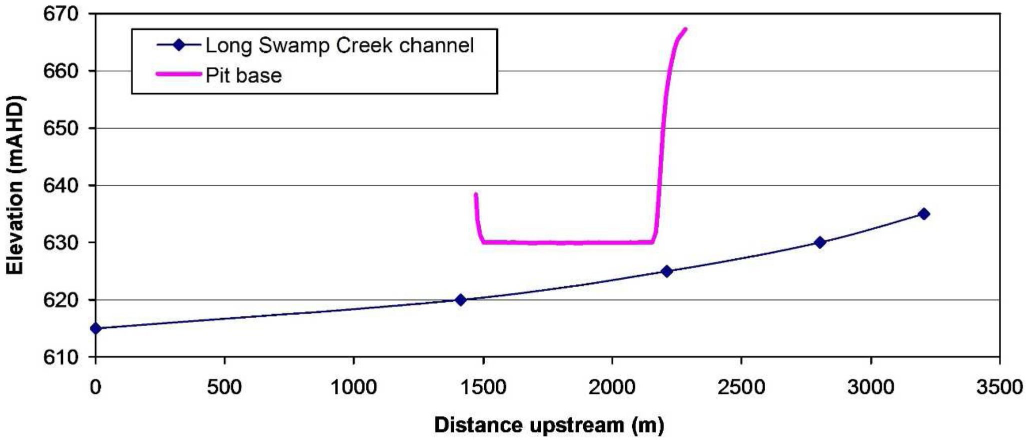

Figure 4.2. Long section of Long Swamp Creek and the proposed extraction area.

The extraction voids will be progressively backfilled with unsaleable oversize materials and processing fines, in combination with imported Virgin Excavated Natural Material (VENM) and Excavated Natural Material (ENM). Approximately 9.7×10^6 m^3 of backfill will be required to achieve the final landform. It is estimated that, for the backfill emplaced up to completion of Stage 5, 60% will be composed of materials originating on site, with the remainder composed of VENM / ENM principally sourced from the Sydney metropolitan area. Coarse backfill material is assumed to have a high hydraulic conductivity although the processing fines would generally have a lower hydraulic conductivity.

Figure 4.3 shows the proposed final landform. Topography over the previous extraction areas ranges between 650 m AHD and 700 m AHD, with the majority being 660 m AHD. The final landform has been designed with no remnant voids reaching down to the floor of the extraction area. The final topography falls from the prior southern extraction boundary to the prior northern extraction boundary, in the direction of groundwater flow. Only minor undulations may be present which may allow transient ponding.

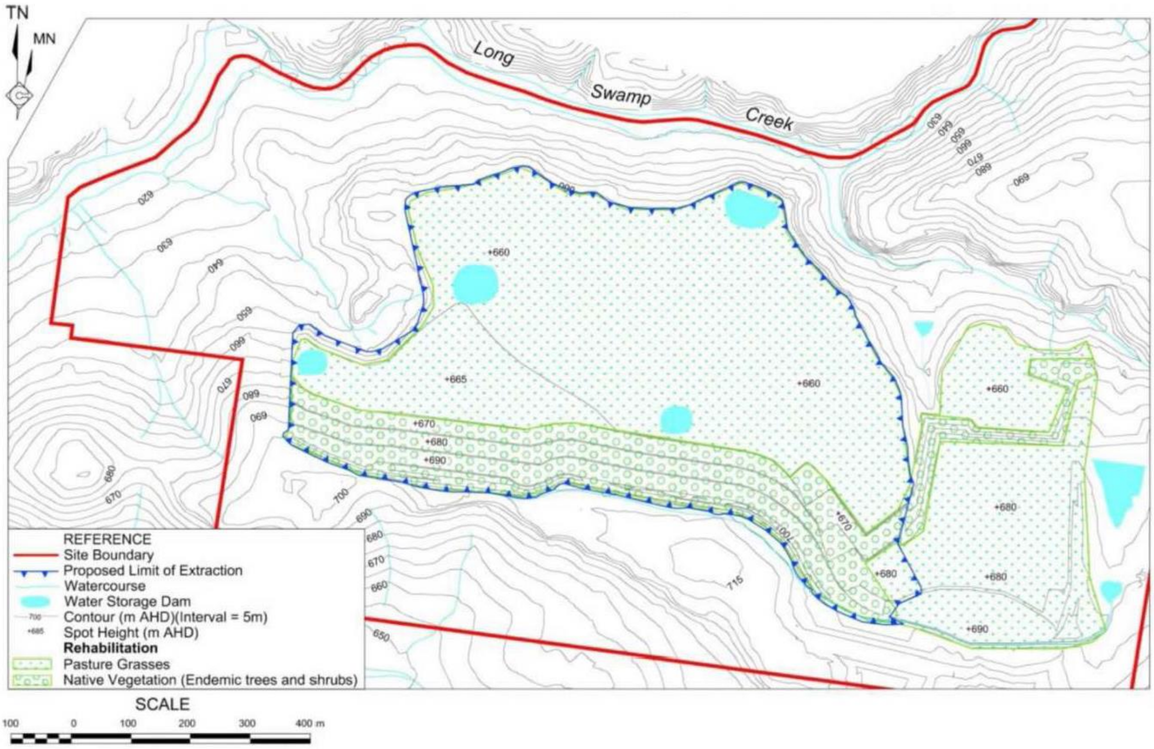

Figure 4.3. Final landform (after completion of rehabilitation following extraction).

5. Model development and calibration

5.1. Model code and structure

The model was developed using MODFLOW-SURFACT Version 3, distributed by Hydrogeologic, Inc. (Virginia, USA). It is an advanced version of the standard USGS MODFLOW finite difference algorithm and is able to simulate variably saturated flow. MODFLOW-SURFACT was run within the Visual MODFLOW (Version 2009) pre- and post-processing environment, developed by Schlumberger Water Services.

The active model area (see Drawing 1) covers 32 km^2 within an area of 9 km east-west by 7 km north-south. The model boundary follows natural features and has been selected at sufficient distances to significantly minimise the effect of quarry drawdown on them.

5.2. Layering and cell mesh

The model consists of seven layers, with a mesh composed of 102 columns and 80 rows. Cell dimensions are 50 m by 50 m over the extraction area, expanding to 100 m by 100 m over the remainder of the model area as shown in Figure 5.1. The increased resolution over the extraction area was to provide sufficient head and drawdown detail during calibration and predictive simulations.

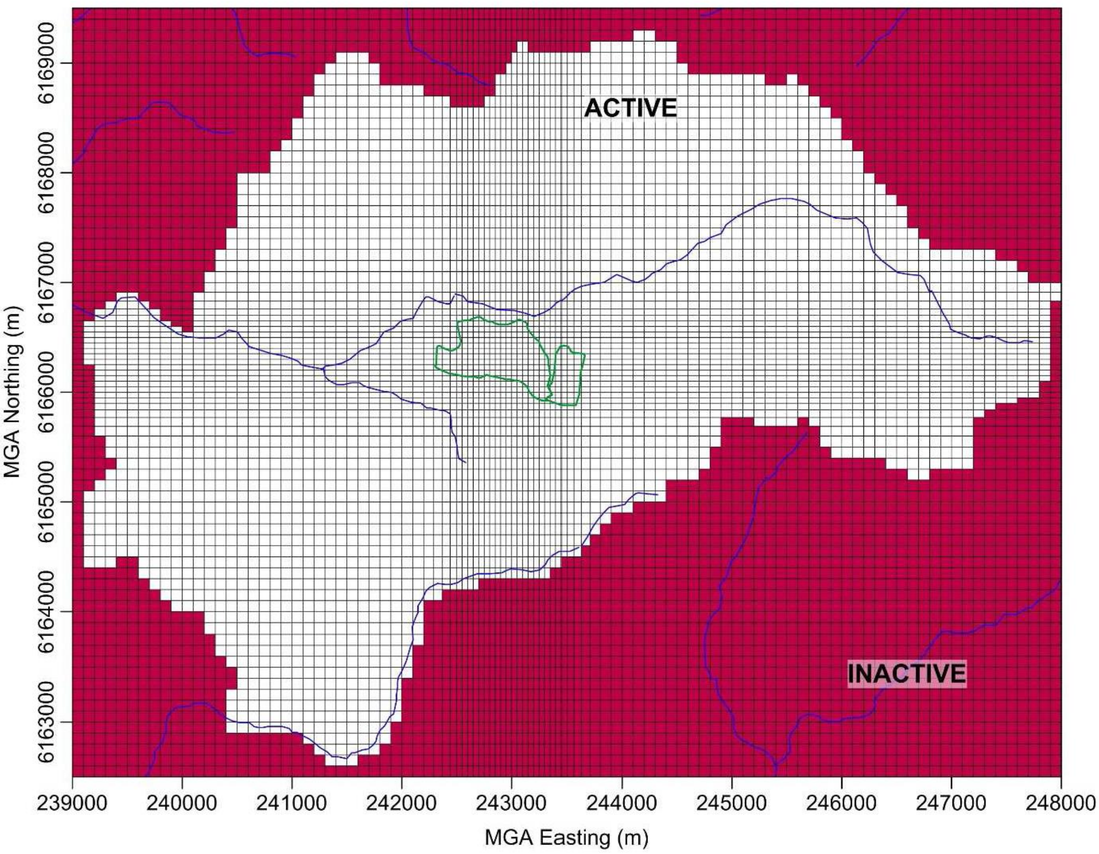

Figure 5.1. Model mesh.

Seven layers were used to allow sufficient resolution for simulating vertical head gradients, lithological contrasts, and extraction area boundary conditions. Layer elevations are listed in Table 5 and illustrated in Figure 5.2. All layers allow both unconfined and confined conditions. The pseudo-soil option was used to simulate variably saturated conditions.

Table 5. Model layers.

Layer	Top (m AHD)	Base (m AHD)	Lithology
1	705	685	Hawkesbury Sandstone
2	685	665	
3	665	645	
4	645	623	
5	623	605	Narrabeen Group / Permian Coal Measures
6	605	587	
7	587	570	

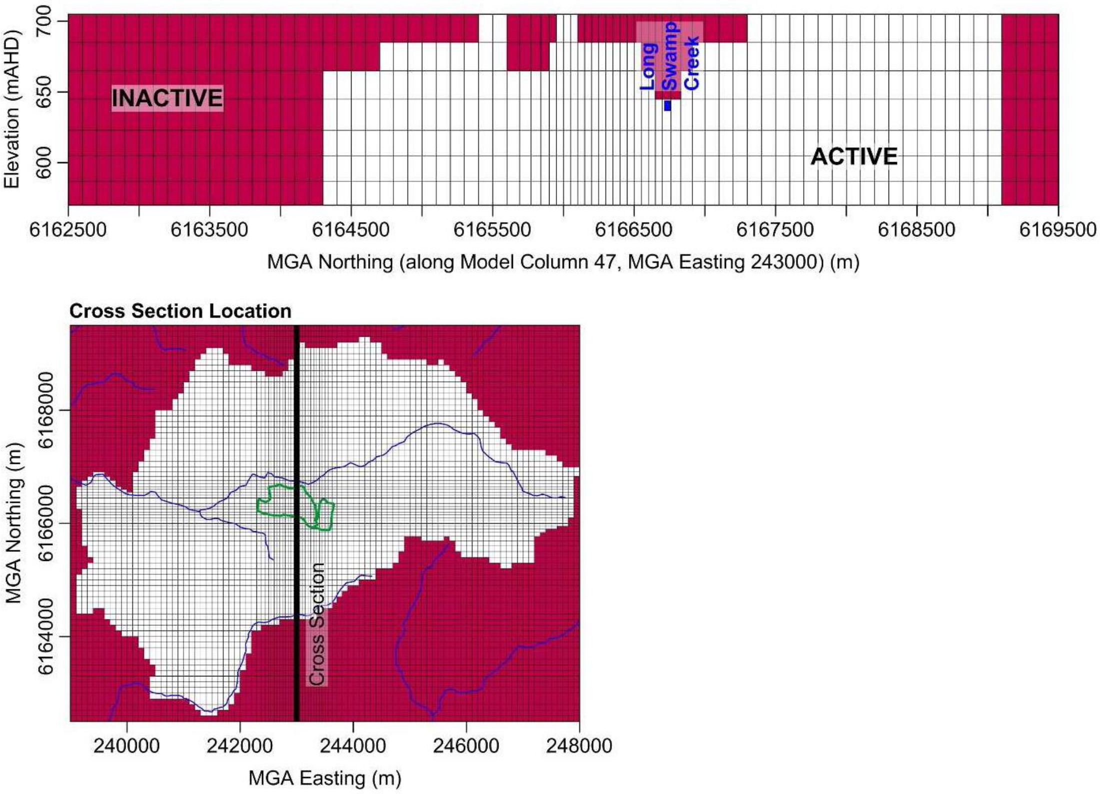

Figure 5.2. Model cross section through the extraction area showing model layers.

The Wianamatta Group, Mittagong Formation, and basalt occur in the north and east of the model area, overlying the Hawkesbury Sandstone. Lithological changes due to these units were not explicitly modelled; their presence is incorporated by applying lower rainfall recharge to the Hawkesbury Sandstone in these areas (Coffey 2006, 2008). These units are far from the extraction area and therefore would be negligibly influenced by extraction. In addition, very few of the watercourses in the model area intersect the Wianamatta Group or the Mittagong Formation.

5.2.1. Hydraulic conductivity zonation

There are nine subsurface hydraulic conductivity zones, used to represent changes in hydraulic conductivity versus depth interpreted from the database (see Figure 2.2). Figure 5.3 shows the hydraulic conductivity zone distribution for the bottom layer in the model. In the figure, Zone 1 does not appear since all parts of the layer are overlain by one or more other layers.

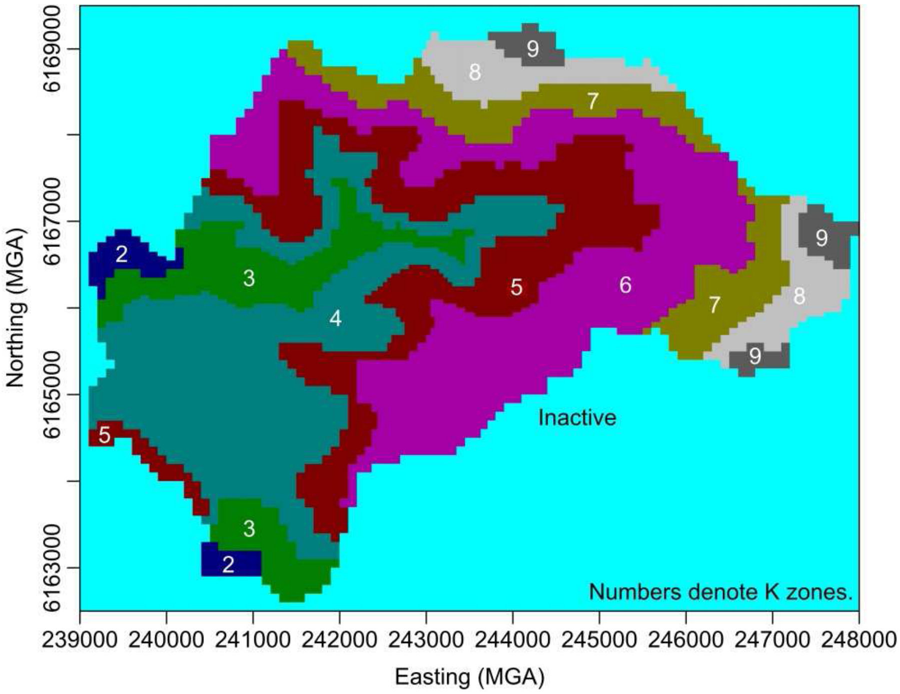

Figure 5.3. Hydraulic conductivity zonation for model layer 7 (numbers refer to the hydraulic conductivity zone).

5.3. Boundary conditions

The perimeter of the model area was selected to be sufficiently distant from the extraction area not to influence drawdown. The boundary conditions at the extremity of the model area consist of:

- No-flow at topographic divides.
- Discharge/drainage at watercourses.
- Use of the Drain mechanism to simulate seepage faces in the layers within the creek valley.
- A general head condition at the western perimeter in the active layer at that location (Layer 7) to simulate down-gradient groundwater flux out of the model domain at Long Swamp Creek and Paddys River.

- For predictive simulations, use of the drain mechanism to simulate extraction operations.

Boundary conditions applied in the model are shown in Figure 5.4.

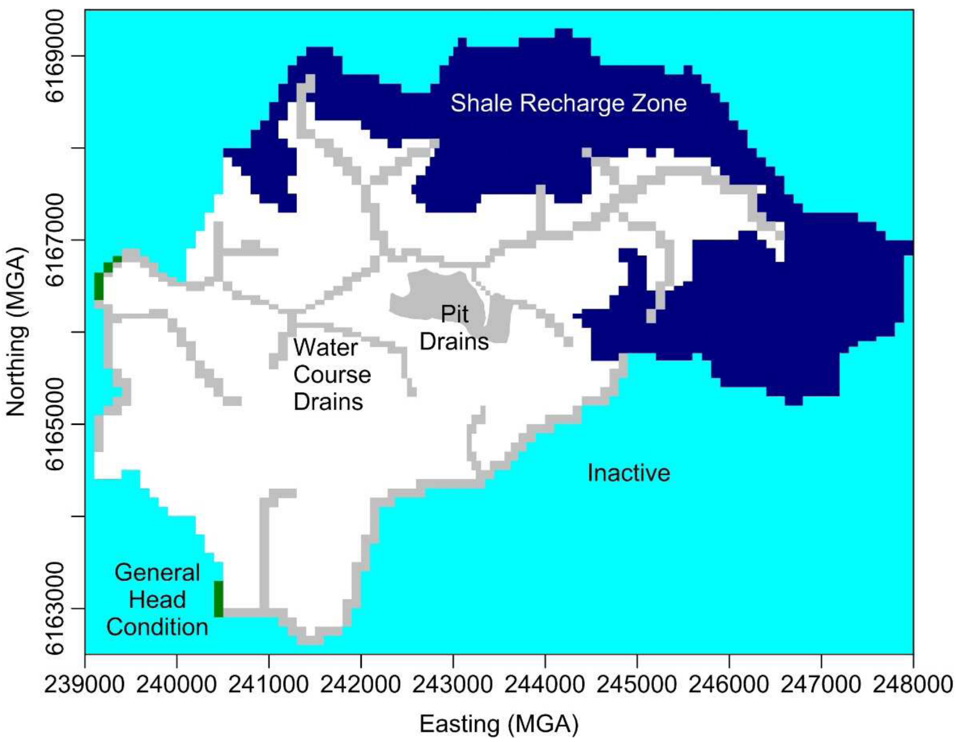

Figure 5.4. Model boundary conditions.

5.3.1. Watercourses

Based on available data, it was assumed for the model area that that lower lying watercourses (generally below 630 m AHD, depending on landform) are perennial and watercourses at higher elevation are ephemeral. The lowest excavation level for extraction operations would also be 630 m AHD. In this situation, there is a significantly small probability of direct seepage from Long Swamp Creek to the pit. Several previously-run scenarios of alternative pit designs (for viability assessments), where elevations within the extraction area reached down to 620 m AHD, incorporated the MODFLOW River package (which allows bidirectional exchange) for watercourses below 630 m AHD; no direct leakage from the watercourses to the extraction area was induced in these scenarios. For these reasons, watercourses have been modelled using the MODFLOW Drain package. Drain elevations were estimated using:

- A 30 m DEM obtained from the Geoscience Australia internet service for the wider model domain.
- A more detailed DEM for the Site developed from photogrammetry, for Long Swamp Creek and nearby watercourses.

Drain conductances were set to relatively high values (compared to media hydraulic conductivities) to allow baseflow to be controlled by the host media.

5.3.2. Rainfall recharge

Rainfall recharge used in the modelling is net recharge, representing that recharge that enters the groundwater system after consumption by evapotranspiration. Two recharge zones are used, according to outcrop lithology (Wianamatta Group / Basalt, and Hawkesbury Sandstone, as shown in Figure 5.4). Net rainfall recharge was applied as a percentage of incident rainfall, to the topmost active cell in each vertical column.

The model boundary is considered to encompass the recharge area for each of the pumping bores, assuming up to 3% recharge.

5.3.3. Evapotranspiration

Evapotranspiration is not explicitly simulated but is accounted for in the recharge rate. Evapotranspiration is generally a quasi-constant offset to the rainfall recharge in natural conditions. Use of the MODFLOW Evapotranspiration package may underestimate the effects of plant transpiration when drawdown occurs below the specified extinction depth. This is because the interception and transpiration of rainfall recharge in the unsaturated zone are not considered to be adequately simulated by the simple equations used in the package.

5.3.4. Pumping bores

The ten bores within 2.5 km of the proposed extraction area that have licensed allocations (see Table 3) have been incorporated in the model at a long-term pumping rate commencing at about 67% of the annual allocation, based on anecdotal information regarding pumping from the Coca Cola bores (compared to their allocation). The three Coca Cola bores were modelled as a single bore due to their proximity and taking into account the model cell size of 100 m by 100 m in that area.

For bores whose hydraulic interval penetrates multiple model layers, pumping is partitioned according to the transmissivity of the layer compared to the transmissivity of the total penetrated interval. This means pumping rates may decrease should one or more intersected layers dry during the course of the simulation.

5.4. Model calibration

Calibration was undertaken manually in transient mode. The calibration period comprised a seven-month period containing the available high-frequency observations from automatic recorders, and additional manually measured observations (1 February to 31 August 2015 inclusive).

5.4.1. Calibration targets

Calibration targets comprised:

- Water level observations over the period February to August 2015 for seven piezometers and one well. Continuous monitoring records were available for four of the piezometers.
- Estimates of flow in Long Swamp Creek.
- The large database of hydraulic conductivity measurements.

Piezometers DDH2, OH1, and OH3 were dry throughout the time of monitoring and could not be used for model calibration. Observations from DDH4S, DDH5S, and OH2S were interpreted to represent the localised perched groundwater system and were not used. Limited observations were available for OH5 over the calibration period. The depth of private bore GW101872 is unclear and observations could not be assigned with certainty to a position in the profile.

5.4.2. Calibration results

A significant source of uncertainty in comparing observed and modelled hydraulic heads is in relating the vertical position of a piezometer screen to the head calculated by the model for a layer. In a numerical model, a layer will have only one head value per cell (an average value, applicable to the centre of the cell). Assuming a 20 m thick layer (as adopted in this model) and a vertical hydraulic gradient of 0.5, the continuum of hydraulic heads at the top and bottom of the layer differ from the average layer value by ± half of 10 m, or ±5 m. The significance of this error increases where vertical gradients are large. Calibration differences will also include other uncertainties normally encountered for a numerical simulator.

Figure 5.5 shows modelled and observed hydraulic heads for the end of the calibration period (31 August 2015), compared to actual observations. The normalised root-mean-squared (NRMS) error is 7.0% and is considered reasonable. The average residual is -1.69 m, and residuals are reasonably normally distributed.

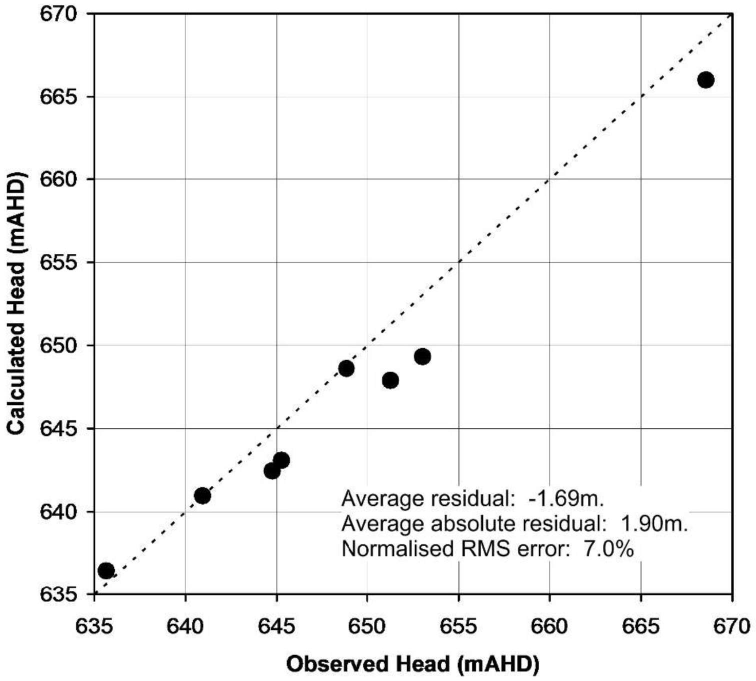

Figure 5.5. Calibrated and observed water levels for 31 August 2015.

Figure 5.6 shows modelled and observed piezometer hydrographs. The match is considered reasonable.

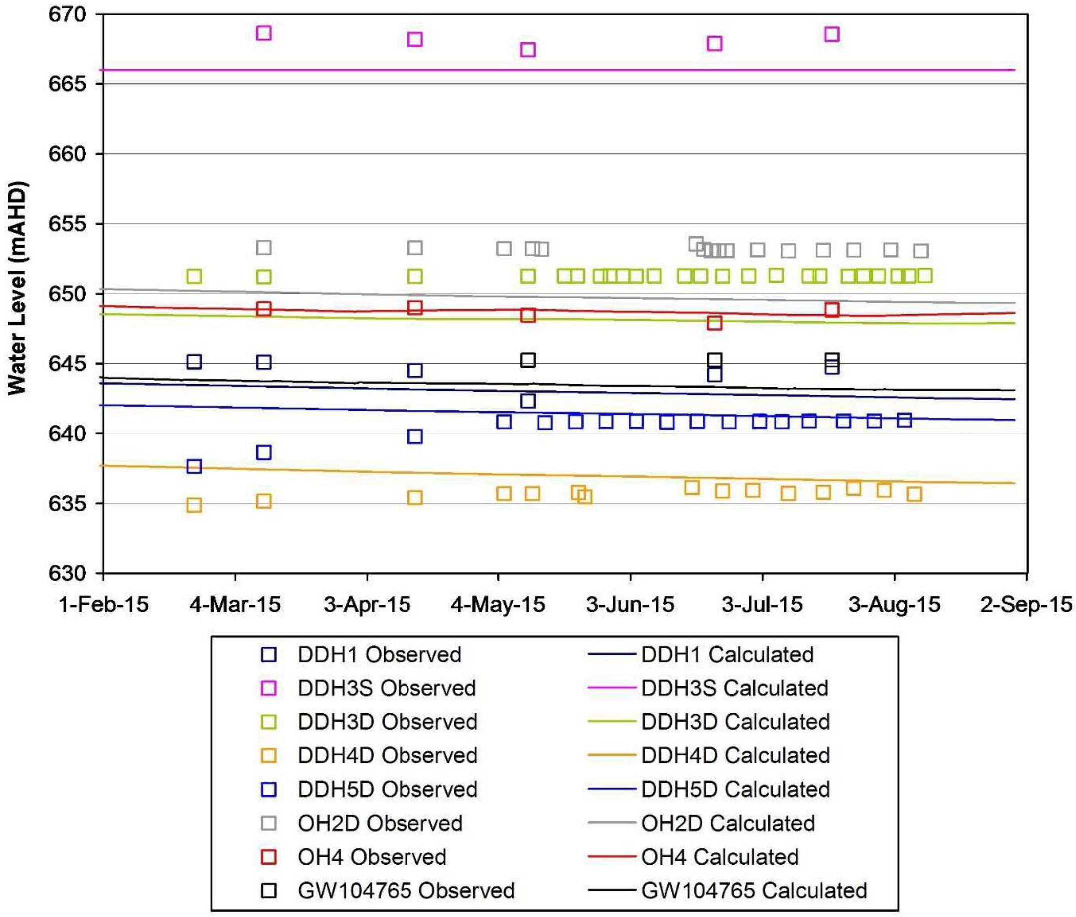

Figure 5.6. Hydrographs of modelled and observed hydraulic head.

Figure 5.7 shows the calibrated water table for the sandstone. Figure 5.8 shows modelled hydraulic heads along a cross-section through the centre of the proposed extraction area, for comparison to the interpreted hydraulic head field in Figure 2.8. The similarity between modelled hydraulic head contours and those interpreted from observations is considered reasonable, indicating that vertical hydraulic head gradients are being acceptably replicated by the model. The calibrated model is considered fit for use in estimating drawdowns and inflows caused by extraction at the Site.

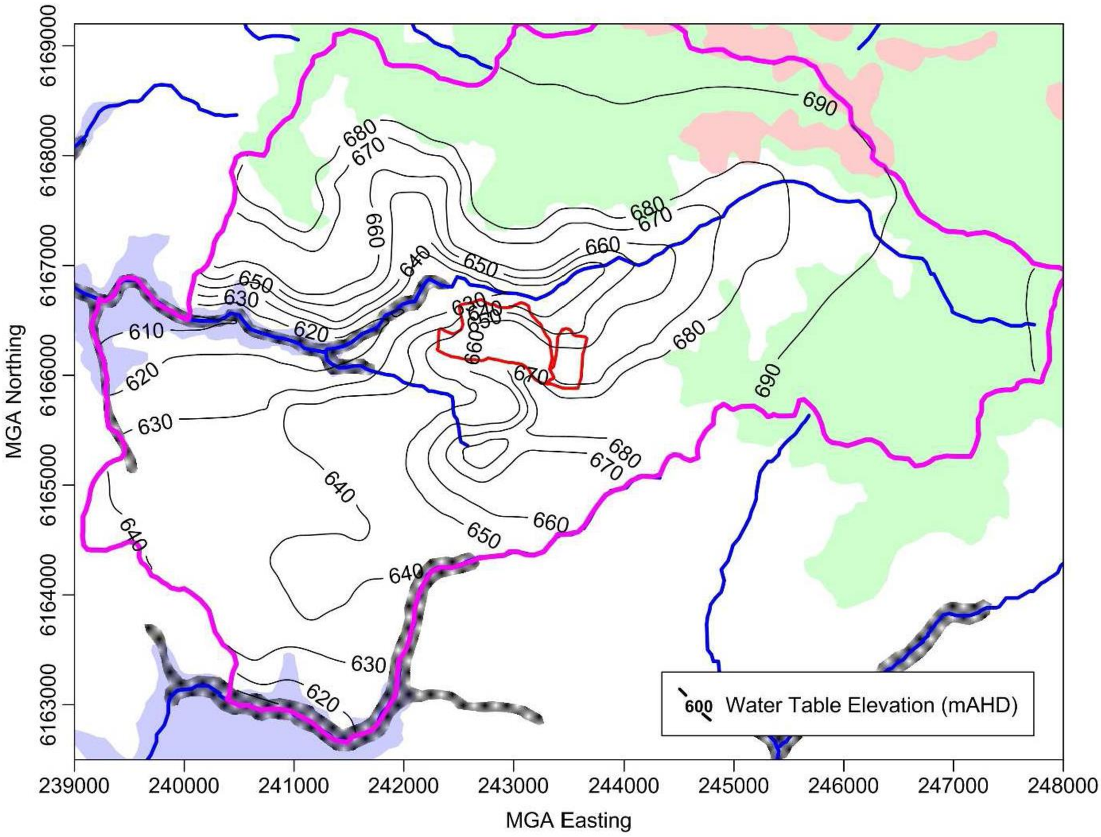

Figure 5.7. Calibrated water table for sandstone for 31 August 2015.

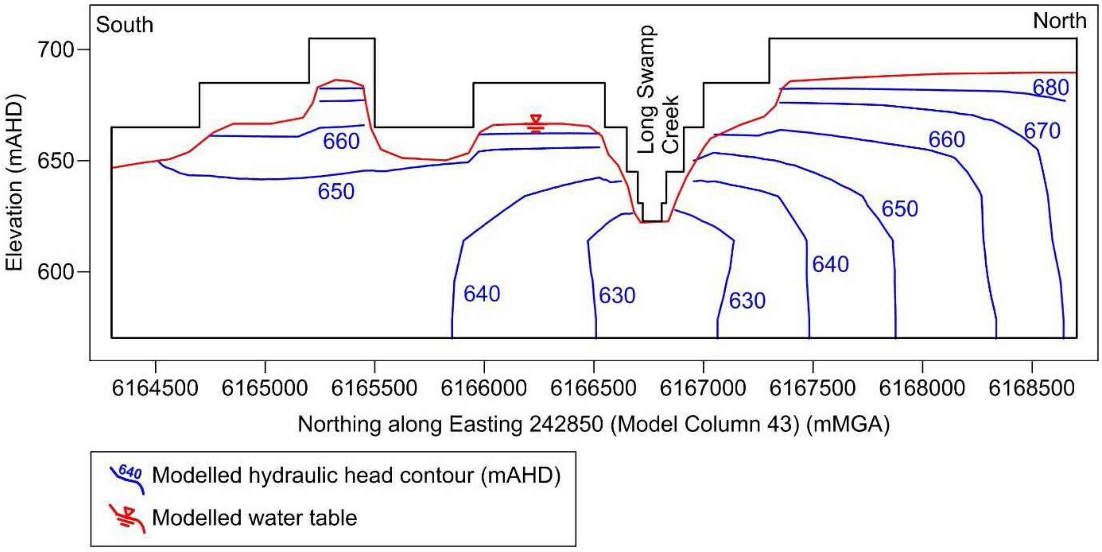

Figure 5.8. Calibrated hydraulic head field along a north-south cross section through the proposed extraction zone for 31 August 2015 (for comparison to Figure 2.8).

Calibrated media properties are listed in Table 6. Figure 5.9 compares calibrated and observed K. Large-scale measurements of K are mostly representative of the lateral component of the K tensor (except where specifically analysed for Kv, where measurements allow). The calibrated Kh distribution is considered to reasonably represent K observations. The calibrated Kv distribution is considered a reasonable replication of the large scale Kv distribution in the subsurface. It is supported by calibration to shallow groundwater discharges, and important large scale Kv estimates from one long-term pump test undertaken by LCC on the Site. These datasets are independent of each other.

Table 6. Calibrated media properties.

Hydraulic Conductivity Zone	Depth (mbgl)		Kh* (m/day)	Kv* (m/day)	Kv/Kh (-)	Specific Storage (1/m)	Specific Yield (-)
	From	To					
1	0	20	1.5	0.01	0.0067	1×10^{-6}	0.02
2	20	40	1	0.001	0.001		
3	40	60	0.2	0.001	0.005		
4	60	82	0.05	0.003	0.06		
5	82	100	0.05	0.003	0.06		
6	100	118	0.03	0.005	0.17		
7	118	135	0.01	0.005	0.5		
8	135	153	0.005	0.001	0.2		
9	153	171	0.005	0.001	0.2		

*Lateral hydraulic conductivity.

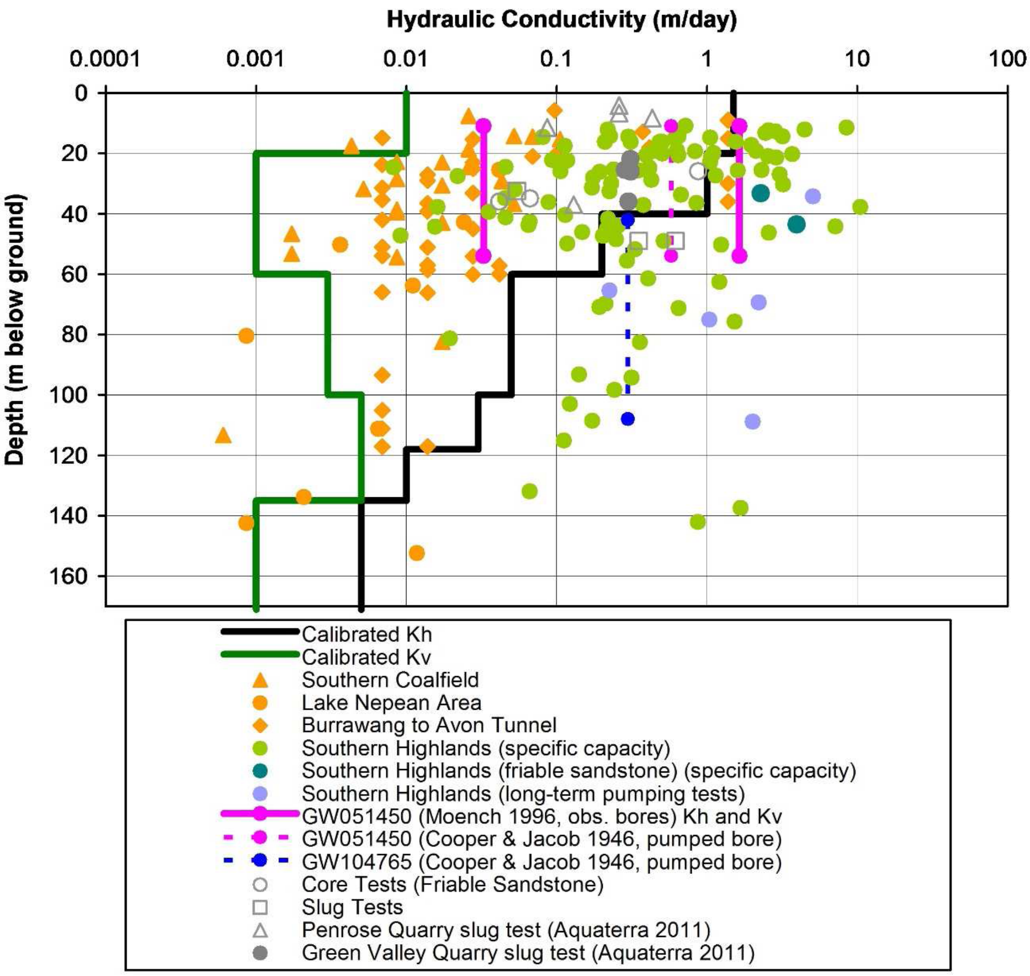

Figure 5.9. Comparison of calibrated and observed hydraulic conductivity.

Normalised to an annual period, incident rainfall at the Site over the calibration period was 1.43 times the long-term annual average. Calibrated rainfall recharge for the model area overall was 4.5% of incident rainfall over the calibration period.

The modelled average flow budget for the calibration period is listed in Table 7. The discrepancy is considered reasonable. The calibrated baseflow to Long Swamp creek (7.19 ML/day) compares reasonably with observations.

Table 7. Calibrated model average flow budget over the calibration period (1 February 2015 to 31 August 2015).

IN (ML/day)		OUT (ML/day)	
Rainfall recharge	5.15	Baseflow to Long Swamp, Long Swamp Creek and its tributaries	7.19
Release from media storage	5.43	Baseflow to remaining creeks (not Long Swamp Creek nor its tributaries)	2.80
		Lateral flow exiting the western boundary	0.01
		Pumping from bores	0.60
TOTAL	10.59	TOTAL	10.60
Discrepancy*: -0.2%			

* The discrepancy is calculated with unrounded results. Reported totals may differ slightly from summation of individual rounded components.

6. Predictive simulation

The following predictive scenarios were simulated:

- Site extraction active. This scenario provides drawdowns and inflows in the presence of extraction operations. One extraction schedule is simulated (as discussed in Section 4).
- Site extraction inactive (the null case). This scenario provides changes in the hydraulic head field in the absence of extraction operations, and allows calculation of impacts due to extraction operations only.

The simulation period covers 45 years of extraction followed by 20 years of recovery. Private pumping is active in both scenarios, at rates identical to those assigned for the calibration period.

Extraction was modelled using the drain mechanism. Drain conductance is not calibrated, but is set to a high value to allow drainage to be controlled by the host media, without consideration of effects on the K field from changes in subsurface stress from excavation activities.

6.1. Rainfall recharge

Rainfall recharge over long time periods is not a constant proportion of incident rainfall. Figure 6.1 shows estimates of rainfall recharge to the water table in uncovered Hawkesbury Sandstone terrain obtained from analysis of hydrographs and incident rainfall for five piezometers in the Southern Coalfield. A simple linear relationship fitted to the piezometer results is useful in estimating recharge proportions for reasonably small variations in annual rainfall. For the Site, the estimated recharge rate for long-term average rainfall conditions is 3.2%.

Both predictive simulations assume long-term average rainfall conditions. The applied rainfall recharge rate is 3.2%.

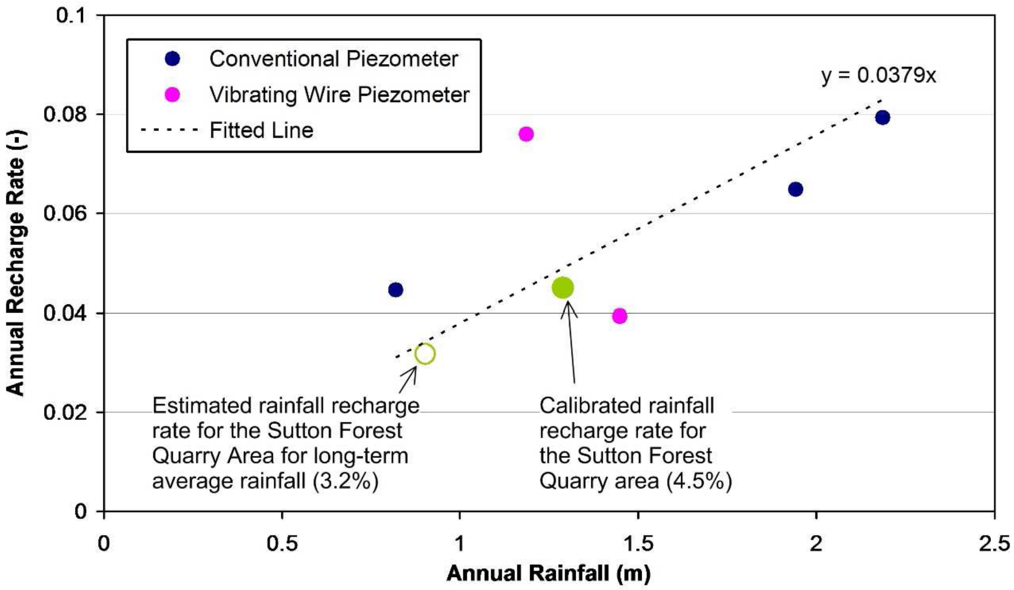

Figure 6.1. Interpreted recharge to the water table for Hawkesbury Sandstone overlain by residual soil, in the Southern Coalfield.

6.2. Results

6.2.1. Null case flow budget

The flow budget for the null case (extraction inactive, but private bores active) is listed in Table 8 as the average over the period of proposed future extraction (45 years).

Table 8. Modelled average flow budget for the predictive null case (Site extraction inactive) over the proposed period of extraction of 45 years.

IN (ML/day)		OUT (ML/day)	
Rainfall recharge	2.56	Baseflow to Long Swamp, Long Swamp Creek, and its tributaries	2.01
Release from media storage	0.01	Baseflow to remaining creeks (not Long Swamp Creek nor its tributaries)	0.29
		Lateral flow exiting the western boundary	0.01
		Pumping from bores	0.27
TOTAL	2.58	TOTAL	2.58
Discrepancy*: < 0.05%			

* The discrepancy is calculated with unrounded results. Reported totals may differ slightly from summation of individual rounded components.

The modelled baseflow to Long Swamp Creek is 2.01 ML/day. This accords with estimates based on baseflow analyses undertaken for similar catchments in the Southern Highlands (see Section 2.3 above), and is a better indicator of average baseflow than the calibration period result, since rainfall recharge for the predictive null case is for long-term average rainfall conditions.

6.2.2. Active extraction scenario

The results that follow are for the active extraction scenario.

Hydraulic heads

Figure 6.2 shows the drawdown of the water table at the end of Stage 5 extraction (Year 28). Figure 6.3 shows the drawdown at the water table at the end of extraction operations (end of Stage 7 at Year 45). These figures also show registered private bores in the vicinity of the extraction area (private pumping bores, and registered stock and domestic bores for which an allocation is not applicable).

The modelled contour of 0.2 m drawdown of the water table extends a maximum of about 1 km from the extraction area at the end of Stage 5 (Year 28), and about 1.2 km at the end of Stage 7 (end of extraction operations, Year 45).

The modelled maximum drawdown of the water table at each private bore is less than 0.5 m. Table 9 lists completion details and modelled drawdown for the four private bores closest to the extraction area. Given the depth of these bores and their recorded water levels, the modelled drawdown is unlikely to cause significant loss of available groundwater yield at these locations and is within the maximum interference drawdown of 2 m permitted in the Aquifer Interference Policy.

Table 9. Completion details and maximum modelled drawdown at the water table for the four registered private bores closest to the extraction area.

Bore Number	Easting (MGA)	Northing (MGA)	Depth (mbgl)*	Water Level (mbgl)*	Property	Authorised Purpose	Max. water table drawdown at end of Stage 5 (m)	Max. water table drawdown at end of Stage 7 (m)
GW035166	243271	6165304	65.2	40.8	Bridge-water	Domestic / stock	< 0.3	< 0.3
GW037967	243900	6165599	83.8	30.4	Danellan	Domestic / stock / irrigation	< 0.3	< 0.3
GW068897	243063	6165644	61.0	20.0	Unknown	Domestic	< 0.4	< 0.5
GW101872	243873	6165776	90.0	63.0	Bridge-water	Domestic / stock	< 0.3	< 0.3

* Denotes metres below ground level.

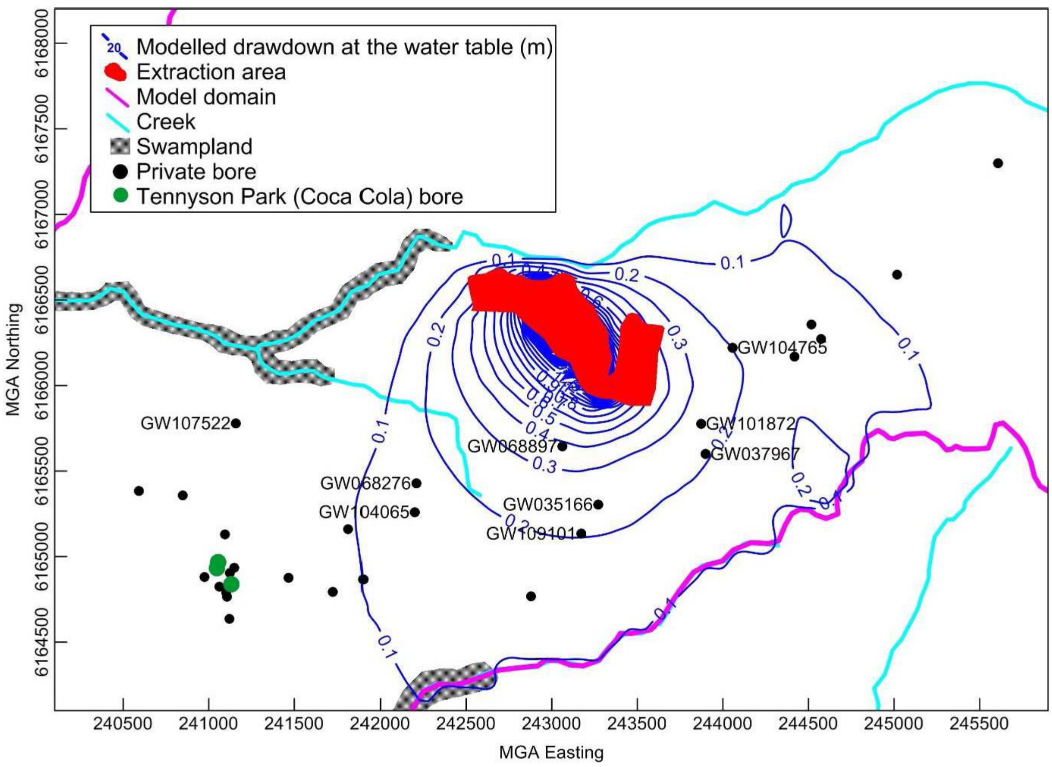

Figure 6.2. Modelled water table drawdown at the end of Stage 5 extraction (Year 28).

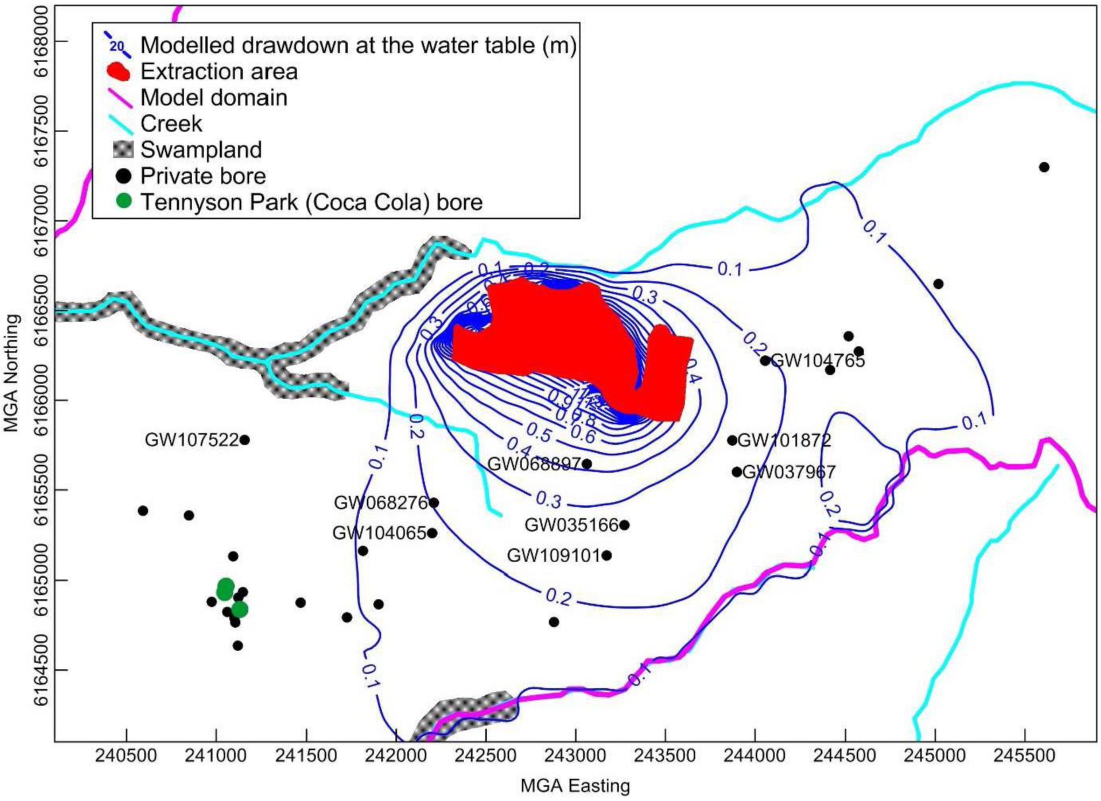

Figure 6.3. Modelled water table drawdown at the end of extraction operations (end of Stage 7) (Year 45).

The modelled water table drawdown at 20 years after cessation of extraction operations has reduced to less than 0.1 m throughout the model domain, and occurs only within the extraction area footprint.

Flows

Figure 6.4 shows the modelled groundwater inflow to the extraction area. Inflows would commence once extraction occurs below approximately 665 m AHD in Stages 0 and 1 (approximately the beginning of Year 3). They reach a maximum of about 0.2 ML/day, in the early part of Stage 6. Inflows do not include surface runoff generated in the pit.

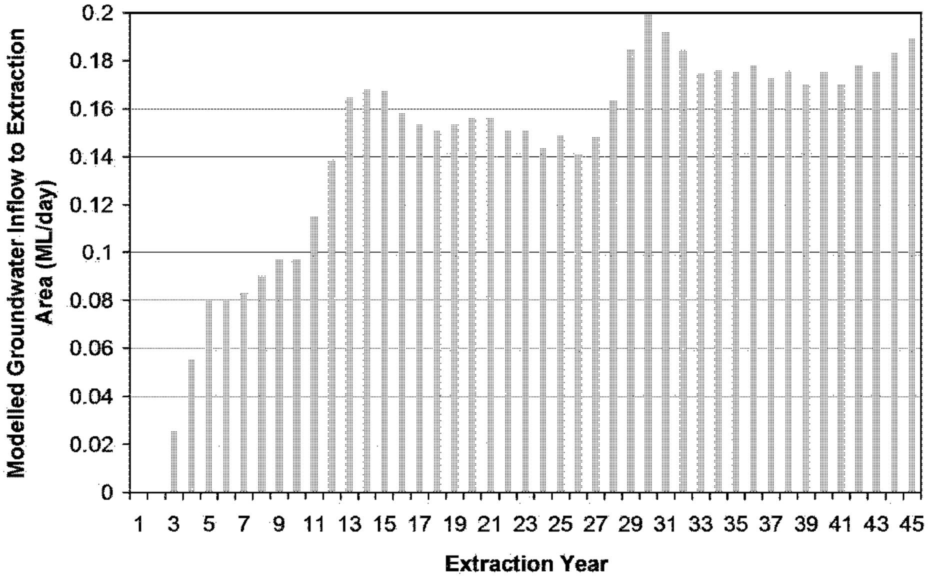

Figure 6.4. Modelled groundwater inflow to extraction area.

Extraction will drain the perched groundwater system overlying the extraction area footprint, and will draw down the perched system water table for a small distance outside the footprint. This component of drainage is not calculated by the model. The drainable storage in the perched system, based on a medium-term specific yield of 2%, is about 60 ML (which would drain at an average rate of about 0.004 ML/day over the 45-year period of extraction operations). The total inflow to the extraction area from the deeper groundwater system (the inflow calculated by the model), over the 45 years of operation, is 2332 ML; the drainage from the perched groundwater system is about 2.5% of this. This component is small but is identified as an additional inflow that combines with the inflow calculated by the model.

Groundwater inflows to the extraction area would cause a reduction in baseflow to Long Swamp and its associated creek, and to other watercourses. Figure 6.5 shows the modelled intercepted baseflow to Long Swamp, Long Swamp Creek, and its tributaries. The intercepted baseflow achieves a maximum of 0.052 ML/day in Year 45, or about 2.6% of the modelled baseflow for the null predictive case (2.01 ML/day, for average rainfall conditions with no extraction operations).

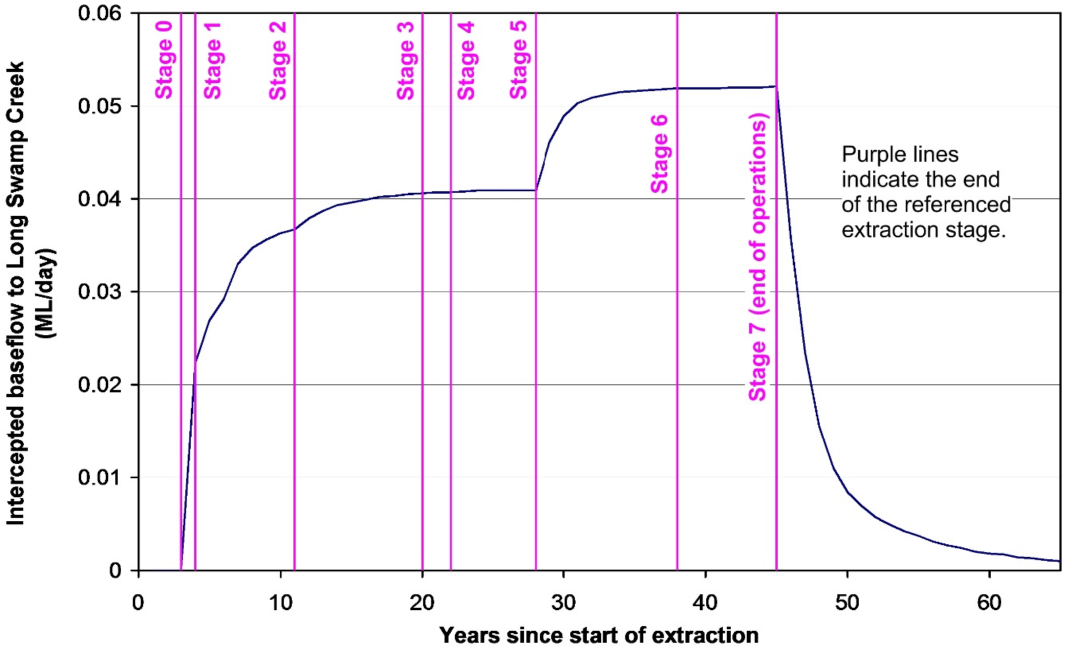

Figure 6.5. Modelled loss of baseflow to Long Swamp and Long Swamp Creek.

The modelled average flow budget over the period of future extraction (45 years) is listed in Table 10. The discrepancy is considered reasonable.

Table 10. Modelled average flow budget for the predictive active quarry extraction case over the proposed period of extraction (45 years).

IN (ML/day)		OUT (ML/day)	
Rainfall recharge	2.56	Baseflow to Long Swamp, Long Swamp Creek, and its tributaries	1.97
Release from media storage	0.02	Baseflow to remaining creeks (not Long Swamp Creek nor its tributaries)	0.29
		Lateral flow exiting the western boundary	0.01
		Pumping from bores	0.27
		Inflow to extraction area	0.14
TOTAL	2.58	TOTAL	2.68
Discrepancy*: -3.9%			

* The discrepancy is calculated with unrounded results. Reported totals may differ slightly from summation of individual rounded components.

6.2.3. Post-extraction groundwater regime

The final landform topography falls from the prior southern extraction boundary to the prior northern extraction boundary, in the direction of groundwater flow (see Figure 4.3). There are no remnant voids reaching down to the pit floor. Only minor undulations may be present which may allow transient ponding. The majority of transient ponding will be sourced from surface runoff.

Assuming a backfill material having a lateral K of 1 m/day after compaction under its own weight, and a recharge rate of 2% of average annual rainfall (allowing for the unfractured nature of the backfill media, with native vegetation), the equilibrated water table barely intersects ground surface in the extraction area. The long-term average groundwater discharge from the backfill in the extraction area is calculated as 0.002 ML/day; this is likely to be consumed by evaporation before being able to form free water drainage features. Where increased discharge occurs (during higher rainfall periods), the discharge (where not consumed by surface evaporation) will exit the area as streamflow.

7. Conclusions

A numerical groundwater flow model has been used to assess the impacts of operation of the proposed Sutton Forest Sand Quarry on groundwater available to private bores in the area, and on baseflow to Long Swamp and its associated creek.

The modelled intercepted baseflow to Long Swamp, Long Swamp Creek and its tributaries due to extraction is a maximum of about 2.6% compared to the calculated long-term average baseflow.

The modelled contour of 0.2 m drawdown of the water table (due to Site extraction operations) extends a maximum of about 1 km from the extraction area at the end of Stage 5 (Year 28), and about 1.2 km at the end of Stage 7 (end of extraction operations, Year 45).

The maximum modelled drawdown of the water table at the end of extraction operations (Year 45) at each private bore is less than 0.5 m. The maximum modelled drawdown of the water table (due to Site extraction operations) at Year 45 (end of extraction operations) in the vicinity of the four closest private bores to the extraction area is as follows:

- GW035166: < 0.3 m.
- GW037967: < 0.3 m.
- GW068897: < 0.5 m.
- GW101872: < 0.3 m.

Given the depths of the four closest bores to the extraction area, and their recorded water levels, this is unlikely to cause significant loss of available groundwater at these locations and is within drawdown limits set in the Aquifer Interference Policy.

Other private bores are unlikely to be influenced by the proposed extraction regime, including the Coca Cola mineral water bores located approximately 2 km south west of the extraction area.

The long-term average groundwater discharge from the backfill in the extraction area is calculated as 0.002 ML/day. This is likely to be consumed by evaporation before being able to form free water drainage features. Where increased discharge occurs (during higher rainfall periods), the discharge (where not consumed by surface evaporation) will exit the area as streamflow.

8. Limitations

The model developed in this study, and the predictions made by the model, are subject to various assumptions and limitations as described throughout this report.

Modelling is a useful tool to simulate complex subsurface media and to predict water balances and water levels when groundwater stresses are applied. In fractured media, the modelling results will not exactly represent conditions on a local scale but are more representative on a sub-regional to regional scale. Actual observations made in the future, during extraction operations at the Site, may differ from predictions made herein.

Model results also do not take into account disturbance of significant but unknown extraordinary defects or extraordinary structural geological features (those occurring as significant outliers of the typical defect population), which can increase the modelled drawdown associated with the extraction operations, as estimated herein, via the creation of extreme permeability pathways.

Model results should be reviewed 12 months following the first occurrences of observed groundwater inflow. Should predictions differ significantly from observations, model recalibration may be necessary.

The attached document, *Important information about your Coffey Report*, contains further information regarding the limitations of this report.

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coffey

Important information about your **Coffey** Report

As a client of Coffey you should know that site subsurface conditions cause more construction problems than any other factor. These notes have been prepared by Coffey to help you interpret and understand the limitations of your report.

Your report is based on project specific criteria

Your report has been developed on the basis of your unique project specific requirements as understood by Coffey and applies only to the site investigated. Project criteria typically include the general nature of the project; its size and configuration; the location of any structures on the site; other site improvements; the presence of underground utilities; and the additional risk imposed by scope-of-service limitations imposed by the client. Your report should not be used if there are any changes to the project without first asking Coffey to assess how factors that changed subsequent to the date of the report affect the report's recommendations. Coffey cannot accept responsibility for problems that may occur due to changed factors if they are not consulted.

Subsurface conditions can change

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

Interpretation of factual data

Site assessment identifies actual subsurface conditions only at those points where samples are taken and when they are taken. Data derived from literature and external data source review, sampling and subsequent laboratory testing are interpreted by geologists, engineers or scientists to provide an opinion about overall site conditions, their likely impact on the proposed development and recommended actions. Actual conditions may differ from those inferred to exist, because no professional, no matter how qualified, can reveal what is hidden by earth, rock and time. The actual interface between materials may be far more gradual or abrupt than assumed based on the facts obtained. Nothing can be done to change the actual site conditions which exist, but steps can be taken to reduce the impact of unexpected conditions. For this reason, owners should retain the services of Coffey through the development stage, to identify variances, conduct additional tests if required, and recommend solutions to problems encountered on site.

Your report will only give preliminary recommendations

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

Your report is prepared for specific purposes and persons

To avoid misuse of the information contained in your report it is recommended that you confer with Coffey before passing your report on to another party who may not be familiar with the background and the purpose of the report. Your report should not be applied to any project other than that originally specified at the time the report was issued.

coffey

Important information about your **Coffey** Report

Interpretation by other design professionals

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

Data should not be separated from the report*

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

Geoenvironmental concerns are not at issue

Your report is not likely to relate any findings, conclusions, or recommendations about the potential for hazardous materials existing at the site unless specifically required to do so by the client. Specialist equipment, techniques, and personnel are used to perform a geoenvironmental assessment. Contamination can create major health, safety and environmental risks. If you have no information about the potential for your site to be contaminated or create an environmental hazard, you are advised to contact Coffey for information relating to geoenvironmental issues.

Rely on Coffey for additional assistance

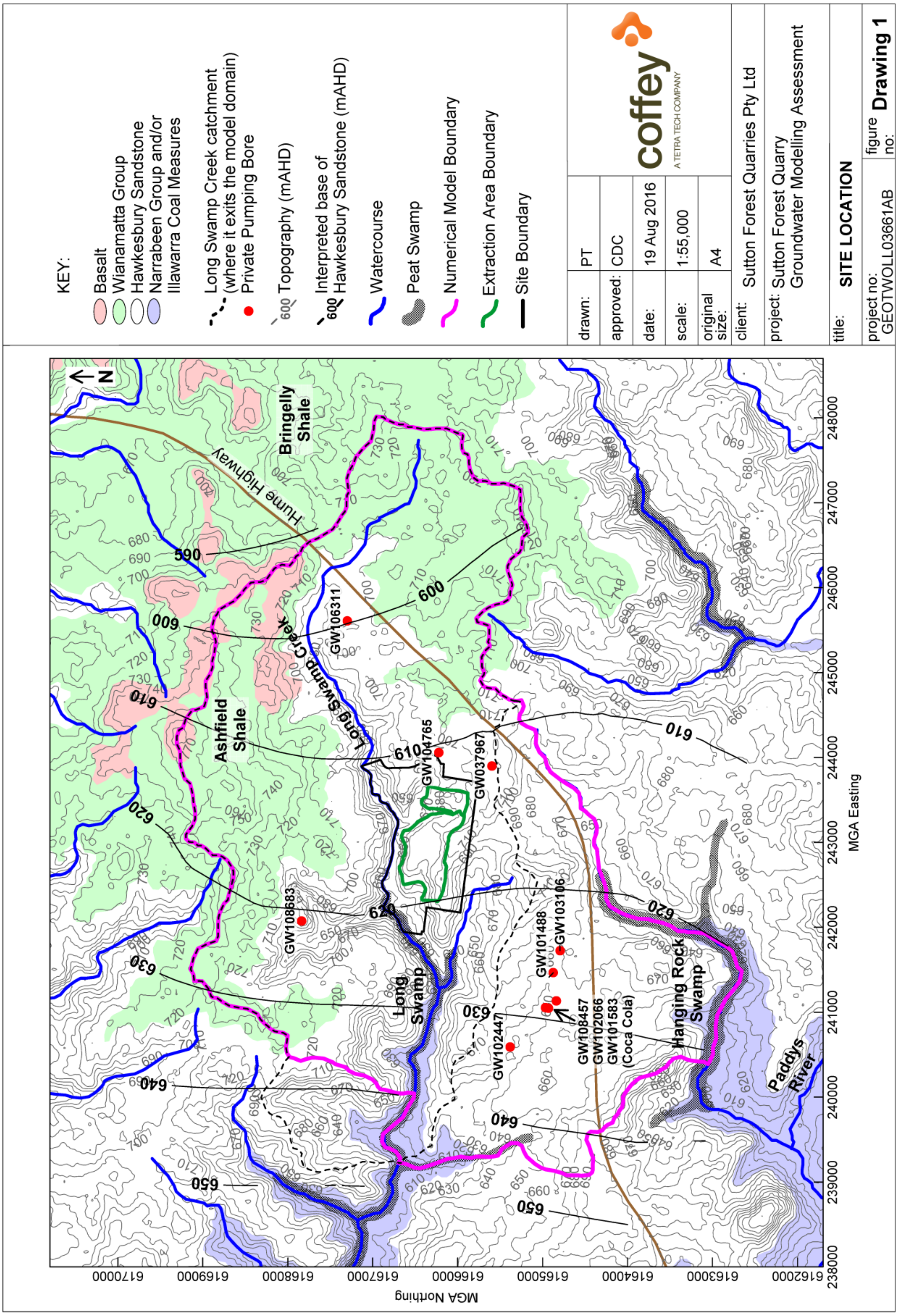
Coffey is familiar with a variety of techniques and approaches that can be used to help reduce risks for all parties to a project, from design to construction. It is common that not all approaches will be necessarily dealt with in your site assessment report due to concepts proposed at that time. As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

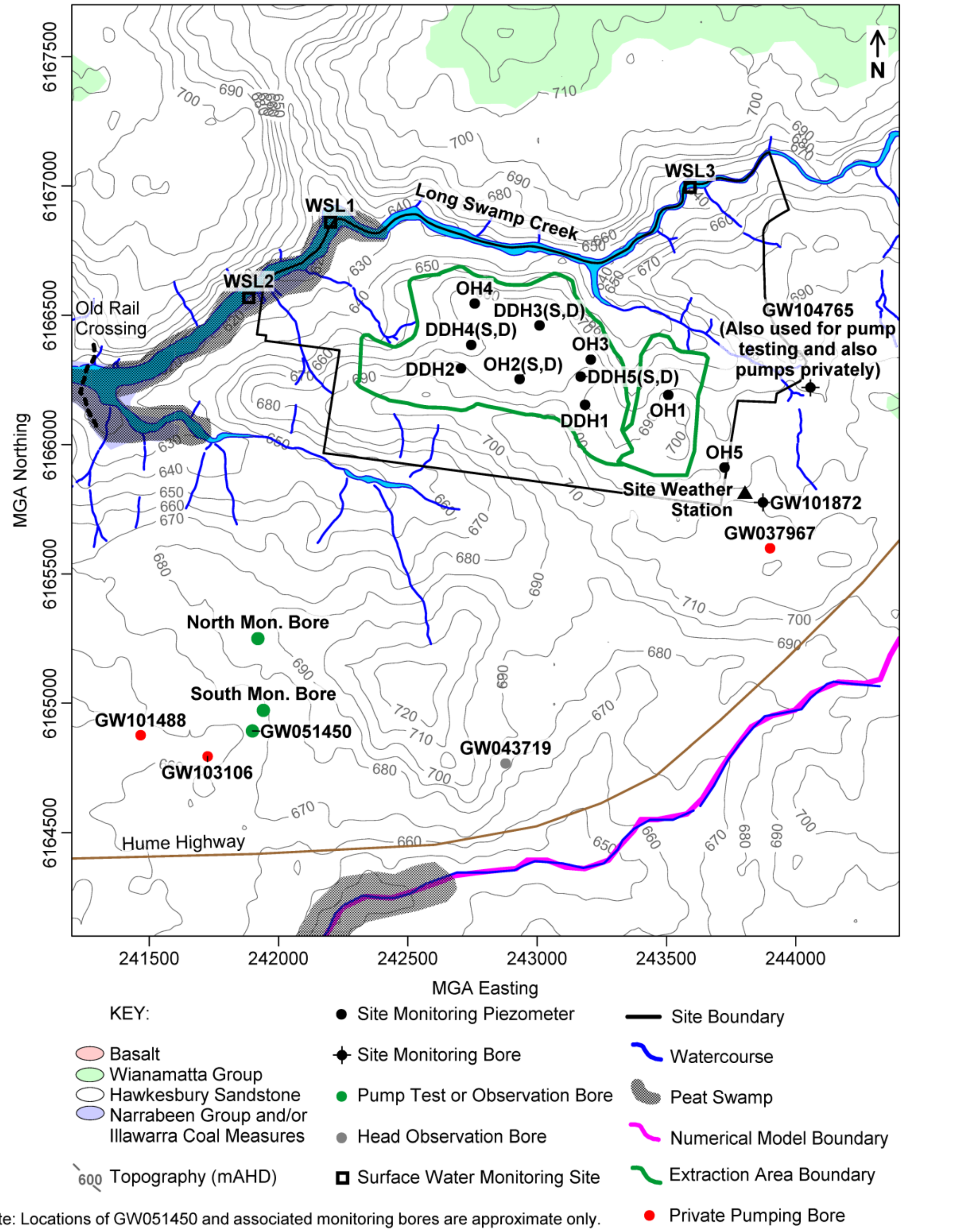
Responsibility

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

* For further information on this aspect reference should be made to "Guidelines for the Provision of Geotechnical information in Construction Contracts" published by the Institution of Engineers Australia, National headquarters, Canberra, 1987.

Drawings


KEY:
Basalt
Wianamatta Group
Hawkesbury Sandstone
Narrabeen Group and/or Illawarra Coal Measures
Long Swamp Creek catchment (where it exits the model domain)
Private Pumping Bore
Topography (mAHD)
Interpreted base of Hawkesbury Sandstone (mAHD)
Watercourse
Peat Swamp
Numerical Model Boundary
Extraction Area Boundary
Site Boundary
drawn: PT
approved: CDC
date: 19 Aug 2016
scale: 1:55,000
original size: A4
coffey
A TETRA TECH COMPANY
client: Sutton Forest Quarries Pty Ltd
project: Sutton Forest Quarry Groundwater Modelling Assessment
title: SITE LOCATION
project no: GEOTWOLL03661AB
figure no: Drawing 1
N
Bringelly Shale
Hume Highway
Ashfield Shale
Long Swamp Creek
Long Swamp
Hanging Rock Swamp
Paddys River
GW106311
GW104765
GW037967
GW108683
GW101488
GW103106
GW102447
GW108457
GW102066
GW101583
(Coca Cola)
MGA Easting
MGA Northing



drawn	PT	coffey A TETRA TECH COMPANY	client:	Sutton Forest Quarries Pty Ltd
approved	CDC		project:	Sutton Forest Quarry Groundwater Modelling Assessment
date	19 Aug 2016			
scale	1:20,000		title:	**PIEZOMETER AND BORE LOCATIONS**
original size	A4		project no: GEOTWOLL03661AB	figure no: **Drawing 2**

Appendix A - Specific Capacity Analysis

Specific capacity (Sc) is the pumping rate divided by the drawdown in the pumped bore at a specified time. Most tests in the database were of 1 day duration, so the drawdown at 1 day is selected or estimated.

An analysis is undertaken using tests where temporal drawdown data are available. For each test, Sc is calculated at 1 day. Transmissivity (Tj) is interpreted from temporal drawdown at the pumped bore using the Cooper and Jacob (1946) method for confined conditions. The quantity (Tj – Sc)/Tj is then plotted against pumping rate and the relationship approximated with a trendline. This relationship is then used to convert Sc for tests where temporal drawdown is unavailable (the majority of government records).

The method assumes the bores in the database are approximately similar in hydraulic behaviour (well loss component), reasonable for the current database. It also assumes that dissimilarities in screened lithology are minor.

Table 1 lists the 10 bores used to find a relationship, and Figure 1 shows the resulting relationship.

Table 1. Bore tests used for specific capacity analysis.

Bore	Hole dia. (mm)	Casing dia. (mm)	Pumping Rate (L/s)	Test Duration (days)	Tj* (m2/day)	Interpre-tation	Pumping Rate (m3/day)	Draw-down (m)	Sc# (m2/day)	(Tj - Sc)/Tj
Bore A	165	160	0.8	1	14	Unpublished Reports	69	7.4	9	0.33
Bore B			0.3	0.07	56		26	0.58^	45	0.20
Bore C	165	160	5.2	1	103		449	8.0	56	0.45
Bore D	200	N/A	20.0	7	243		1728	34.8	50	0.80
GW105950	200	N/A	11.4	2	180	This study (data from Pells 2013)	985	16.0	62	0.66
GW110236	200	N/A	9.2	1	56		795	20.5	39	0.31
GW108194	200	N/A	17.8	2	176		1538	14.6	105	0.40
GW108195	200	N/A	8.3	1.2	20		717	47.0	15	0.24
GW051450		150	2.0	1.1	29	This study	171	8.4	20	0.29
GW104765	165	160	3.0	2	20		259	11.1	23	-0.18

* Tj = Jacob Transmissivity.
^ Estimated for pumping time of 1 day.
# denotes specific capacity (at a pumping time of 1 day).

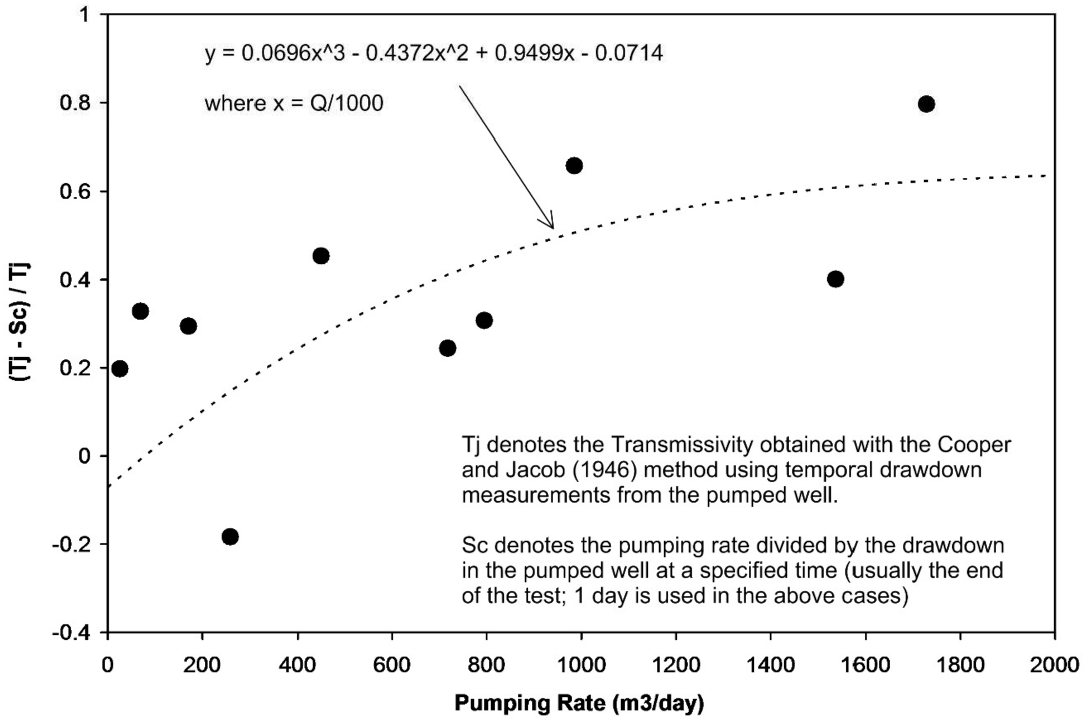


Figure 1. Results of specific capacity analysis for tests in Table B1.

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Annexure 7

Groundwater Modelling Assessment Peer Review

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KALF AND ASSOCIATES Pty Ltd
Hydrogeological, Numerical Modelling Specialists

KA Peer Review of Coffey Sutton Forest Quarry Project Modelling Assessment

Dr F. Kalf
B.Sc. M.App.Sc PhD
9 November 2016

Table of Contents

Background and Key Issues Summary

This report is the Kalf and Associates Pty Ltd (KA) peer review commissioned by Sutton Forest Quarries Pty Ltd for the Coffey Geotechnics Pty Ltd (CG) groundwater modelling assessment. This final KA review follows from contributions by KA to an earlier draft version of the CG report. For the modelling review herein, the available Modelling Guideline documents (NWC 2012, MDBC 2001) content have been taken into account in this assessment. A CG model appraisal is presented herein in Appendix A.

It should be noted that this project was a specialist modelling assignment that was part of a groundwater impact assessment conducted by Larry Cook Consulting in 2016[1]. Therefore there is no discussion in the CG report reviewed regarding the various licencing and regulations requirements, groundwater quality or predictions regarding water quality of any seepage should it occur into the adjacent drainage creek. Accordingly this review is limited to the modelling work, drawdown influence, inflow estimates and flow influence on nearby creeks as presented in the CG (2016) report. The key modelling issues presented by CG (2016) are as follows:

- Sutton Forest Sand Quarries Pty Ltd is seeking approval to construct a sand quarry within the Hawkesbury Sandstone Formation in the Southern Highlands. The proposed quarry would be situated close to Long Swamp Creek 12km west of Bundanoon and about 2km north-west of the Hume Highway.

- The quarry would be fully excavated in 8 stages over 45 years. Development consent is currently being sought for stages 0 to 5 over 30 years. Excavation floor elevation would be 630m AHD with pre-excavation topographic elevation of about 680mAHD. Excavation rate will vary over time from 0.25 million tonnes/year (Mt/y) to possibly 1 Mt/y.

- A field investigation program included establishment of 14 standpipe piezometers at nine locations and two private bores. The monitoring is being conducted by Larry Cook Consulting since July 2014. Monitoring also includes three surface water locations on Long Swamp creek adjacent to the proposed quarry.

- Numerous hydraulic parameter values derived from packer and pumping tests conducted by CG and others in the region, including core tests, were used for the modelling assessment.

- CG has interpreted the presence of a main groundwater system watertable overlain by a perched groundwater system (Figure 2.8 CG 2016) based on the presence of a number of 'dry' piezometers between these two groundwater systems. Such a separation is plausible and often occurs in various configurations in this layered Sandstone formation throughout the Sydney Basin where there is a decrease in vertical hydraulic conductivity. Limited groundwater flow from the upper system to the lower system would occur under unsaturated conditions.

[1] *Reference for this assessment is given in the CG 2016 report.*

- Modelling of quarrying at Sutton Forest site has been conducted with the well-known and established MODFLOW-SURFACT (MS) computer code. Model results indicate drawdown influence created by the quarry is limited due to the relatively low bulk horizontal hydraulic conductivity of the sandstone formation.

- Modelled excavation Inflow rates will increase rapidly for the first 13 years then level off and then increase to a maximum between 29 and 31 years to about 73 ML/year after excavation begins followed by an decrease over 8 years to 60 Ml/year and then a moderate increase over the following 6 years to 67 Ml/year (Figure 6.4 CG 2016). Cumulative gross total inflow is estimated to be to be 2332ML plus drainage from the perched zone of 60ML. The maximum gross predicted inflow and those plotted in Figure 6.4 does not account for losses due to evaporation from the excavation.

- Modelled baseflow loss to Long Swamp Creek due to interception by the excavation (Figure 6.5) increases slowly over 30 years to a maximum of 0.05 ML/day (18 ML/year) maintained until year 45 decreasing exponentially thereafter to less than 0.01 ML/day (3.7 ML/year) after year 50.

- Once the site is rehabilitated the seepage rate toward Long Swamp Creek from the quarry pit is estimated by the report to be 0.002 ML/day consumed by evaporation along a seepage face. However, as the watertable rises over time in the backfill, due to rainfall and surrounding groundwater inflow there would be a tendency of the previous interrupted baseflow caused by the excavation to be partly re-established. Quality of any seepage water is not stated but it would be expected to be of low salinity given the low salinity of groundwater in the Hawkesbury Sandstone and the backfill materials.

- There are no bores where quarry drawdown interference would exceed the AIP permissible 2m limit. Maximum drawdowns at three bores are predicted to be within 0.5m.

- No remnant water filled void is proposed for the rehabilitated land surface.

  KA is in agreement with the assessment of the key issues presented in the CG report as summarised above based on the CG reporting and model predictions and likely post mining conditions.

Peer Review Assessment

Previous Studies and Reviews

Previous studies in the region are listed in the CG (2016) report, in particular the Groundwater Impact Assessment by Larry Cook Consultants Pty Ltd in 2016. References for the review presented herein are given at the end of the report.

Hydrogeological and Modelling Description

There is a good description of the modelling work conducted in the CG (2016) report. The report covers a range of topics that include: *Executive summary; Site characteristics;*

Geology; Subsurface hydraulic properties; groundwater levels; Registered groundwater bores; Hydrogeological conceptual model; Proposed extraction operations; Model development and calibration; Predictive simulation; Conclusions; Limitations and References.

Model Conceptualisation, Design and Simulation Method

Model conceptualisation for the Sutton Forest sand quarry project is considered suitable. The model comprises 7 layers which have been divided into 102 columns and 80 rows with 50 by 50m cells over the extraction area and 100m x 100m elsewhere. The cell dimensions are 50m by 50m within the quarry area and fractions and whole dimensions of cells 100m by 100m elsewhere (Figures 5.1,5.2 CG 2016). This layering and sub-division is suitable and sufficient to delineate the hydrogeological units, in particular the Hawkesbury Sandstone Formation, and Narrabeen Group /Permian at depth for determining local and regional drawdown created by the proposed excavation.

The model area extent and boundaries chosen (Drawing1 and 2, CG 2016) are suitable as shown in the report, as well as the depiction of the adjacent Long Swamp Creek to the proposed excavation and other streams in the region. The boundaries included no flow at topographic divides, discharge/drainage at watercourses and drain methodology to simulate seepage faces in the layers within the creek valley. In addition a general head was applied in the western perimeter to establish a groundwater flux out of the model at Long Swamp Creek and Paddys River.

The model uses net recharge of up to 3% as input which is suitable, rather than application of gross recharge and evapotranspiration. In addition pumping bores in the area were included with pumping rate based on a 67% of the annual allocation.

Initial hydraulic parameters were based on measured values as determined by CG and others in the region and referenced in the CG (2016) report.

Steady-state was used to set up initial conditions and was combined with transient runs in the CG MS model. This is a suitable and desirable methodology. Excavation was simulated using the standard 'drain' methodology; with net rainfall recharge and limited streamflow modelled using the 'River package' but the majority of water courses near the extraction area were simulated using the drain package and therefore as drainage channels.

Perched systems are not normally simulated in these types of hydrogeological environments. This is due to the often isolated nature of the perched system that is hydraulically unconnected to the main groundwater system except by restricted unsaturated vertical flow from the perched groundwater to the main groundwater system. Hence some minor inflow from the perched system could be expected during excavation although a major proportion, and most likely the majority of inflow, would be lost by evaporation from the excavation high wall and on the pit floor.

Model Calibration

The MS model was calibrated after a prior steady state setup under transient conditions using manual methods. The calibration period extended over a period of 7 months. The transient calibration yielded a fit statistic of 7% NRMS (normalised root mean square) which is well within the target of up to 10% as suggested in the modelling guidelines document (MDBC 2001). The average residual was -1.69m and is reasonably normally distributed.

No sensitivity or uncertainty analysis was conducted as the calibration result was considered to be of sufficient accuracy given essentially only one hydrogeological unit is relevant. The calibration results are good enough to indicate that the model is 'fit-for-purpose'.

Comparison of plotted and simulated heads (Figure 5.8) is considered to be reasonable as is the plotted regional watertable elevation (Figure 5.7) including the modelled head and water table position in a north-south section of the main groundwater system (Figure 5.8).

Calibrated hydraulic parameters that included horizontal and vertical hydraulic conductivity and specific storage and specific yield are considered to plausible (Table 6). The calibrated horizontal hydraulic conductivity values are in good agreement with the approximate median value of the numerous observed horizontal hydraulic conductivity values distribution (Figure 5.9). Calibrated vertical hydraulic conductivity values are within the expected range.

Model Predictions

Predictions were conducted over a time period of 45 years active excavation followed by another 20 years of partial recovery. The scenarios included an inactive extraction null case and an active extraction case. Private pumping was included in both these cases. For the inactive case the long term mass balance is presented in Table 8 Section 6.2.1. For the active extraction scenario the long term mass balance is presented in Table 10 Section 6.2.2. For the active extraction watertable drawdown is shown in Figure 6.2 at the end of stage 5 (year 28) whilst Figure 6.3 depicts drawdown after Stage 7 at year 45. Drawdown contours are "compressed" near Long Swamp Creek seemingly suggesting that the creek is acting as a recharge boundary. This is due however to higher head on the opposite side of the creek in the HS formation and therefore groundwater on that side flowing toward the creek.

Groundwater Monitoring and Mitigation

No groundwater impact mitigation measures are currently anticipated for the Sutton Forest sand quarry project. However, excavation inflow data should be collected together with water quality once every six months once the excavation cuts into the perched watertable (if there is sufficient inflow). Two years before the excavation penetrates the main watertable, Long Swamp water quality sampling downstream of the pit but upstream of the peat deposits should commence on a six monthly basis. Also inflow estimation and water quality within the excavated pit should be conducted when inflow commences within the pit. In addition at least two observation bores in a line between the northern edge of the proposed excavation and Long Swamp Creek should be constructed and monitored over time. The bores should drilled to a depth below the creek invert level and 'screened' from the bottom of the hole to some metres above the elevation of the lowest excavation pit floor. These bores will allow hydraulic gradients and water quality to be assessed over the time.

Conclusions and Considerations

This peer review has assessed the adequacy of the hydrogeological data and the numerical model for predicting the drawdown influences of the proposed excavation at the proposed Sutton Forest sand quarry. The hydrogeological description, conceptualisation, model design, simulations and reporting have been conducted in a suitable manner. No fatal flaws have been detected in the description or modelling work conducted. All predictions, in particular water table drawdown and flow rates are considered plausible.

References

Coffey Geotechnics Pty Ltd. 2016 *Sutton Forest Sand Quarry Project. Transient Groundwater Modelling Assessment, May. Report prepared for Sutton Forest Quarries Pty Ltd, c/o R.W. Corkery & Co Pty Limited.*

Murray Darling Basin Commission (MDBC) 2001. *Groundwater Flow Modelling Guideline. Report prepared by Middlemis, H., Merrick, N., and Ross, J., Jan.*

National Water Commission (NWC) 2012 *Australian Groundwater Modelling Guidelines. Report by Barnett, B., and et al. Waterlines Report Series No 82, June.*

APPENDIX A

MODEL APPRAISAL

	ISSUES	Not applicable or Unknown					COMMENTS
1.0	**THE REPORT**						
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	**Very good**	
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	**Yes**		
1.3	Is a water or mass balance reported?		Missing	Deficient	Adequate	**Very good**	
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	**Very good**	
1.5	Are the model results of any practical use?			No	Maybe	**Yes**	
2.0	**DATA ANALYSIS**						
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	**Very good**	
2.2	Are groundwater contours or flow directions presented?		Missing	Deficient	**Adequate**	Very good	
2.3	Has all relevant potential recharge data been collected and analysed?		Missing	Deficient	**Adequate**	Very good	
2.4	Has all relevant potential discharge data been collected and analysed?		Missing	Deficient	**Adequate**	Very good	
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	**Adequate**	Very good	
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	**Yes**	
2.7	Have consistent data and standard elevation units been used?			No	**Yes**		
3.0	**CONCEPTUALISATION**						
3.1	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	**Yes**	
3.2	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	**Very good**	
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	**Very good**	
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	**No**		
4.0	**MODEL DESIGN**						
4.1	Is the spatial extent of the model appropriate?			No	Maybe	**Yes**	
4.2	Are the applied boundary conditions plausible and unrestrictive?		No	Deficient	Adequate	**Very good**	
4.3	Is the software appropriate for the objectives of the study?			No	Maybe	**Yes**	
5.0	**CALIBRATION**						
5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	**Adequate**	Very good	
5.2	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	Adequate	**Very good**	

5.3	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate	Very good	
5.4	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	Yes	
5.5	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	Very good	
5.6	Have performance criteria been met?		Missing	Deficient	Adequate	Very good	
6.0	**VERIFICATION**						
6.1	Is there sufficient evidence provided for model verification?		Not conducted	Deficient	Adequate	Very good	
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?		Not conducted	No	Maybe	Yes	
6.3	Are there good reasons for an unsatisfactory verification?		Missing	Deficient	Adequate	Very good	
7.0	**PREDICTION**						
7.1	Have multiple scenarios been run for climate variability?		No	Deficient	Adequate	Very good	
7.2	Have multiple scenarios been run for operational management alternatives?		No	Deficient	Adequate	Very good	
7.3	What is the time period for prediction compared to duration of the calibration period?		Less than	Equal to	Greater than		Calibration 4 months but no variation Prediction 50 years
7.4	Are the model predictions plausible?			No	Maybe	Yes	
8.0	**SENSITIVITY ANALYAIS**						
8.1	Is the sensitivity analysis sufficiently intensive for key parameters/		Not conducted	Deficient	Adequate	Very good	
8.2	Are sensitivity results used to qualify the reliability of model calibration?		Not conducted	Deficient	Adequate	Very good	
8.3	Are sensitivity results used to qualify the accuracy of model prediction?		Not conducted	Deficient	Adequate	Very good	
9.0	**UNCERTAINTY ANALYSIS**						
9.1	If required by the project brief, is uncertainty quantified in any way?		Not conducted	Deficient	Maybe	Yes	
9.2	Is model "fit-for- purpose"			No		Yes	