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Gunlake Quarries
Gunlake Quarry Project

ENVIRONMENTAL ASSESSMENT

VOLUME II

Part 3
Larry Cook and Associates Pty Ltd
Groundwater Impact Assessment. Gunlake Quarry Brayton Road via Marulan

February 2008

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GROUNDWATER IMPACT ASSESSMENT

GUNLAKE QUARRY
Brayton Road
Via Marulan

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Location of Proposed Development

The 230-hectare Project Site is located approximately eight kilometres northwest of Marulan and straddles the headwaters of ephemeral Chapmans Creek a tributary of Joarimin Creek. The surface elevation of the Project Site is approximately 660m Australian Height Datum (AHD).

Description of Proposed Development

The proponent (Gunlake Quarries) proposes to quarry a tuffaceous rhyodacite (Bindook Porphyry) and produce 500,000 tonnes of finished product per annum suitable for a large range of quarry products including concrete, sealing aggregates, rail ballast, manufactured sand and road base. The demonstrated volume of the porphyry resource is greater than 180 million tonnes. The resource extends to a depth greater than 100m below ground level.

The proposed quarry has been designated 'Major Development' with an expected life greater than 100 years. Approval to extract porphyry is sought for an initial period of 30 years.

Geological Setting

The Project Site straddles a folded and deformed basement sequence of Devonian age volcanic rocks collectively known as the Bindook Porphyry Complex which includes two important members; the Barralier Ignimbrite and the Joaramin Ignimbrite.

An extensive network of fractures, faults and thrusts dissects the district providing potential fluid pathways and conduits. Several 'strong' sets of complimentary, often orthogonal northeast and northwest trending linear features surround the Project Site that are reflected in linear drainage traces, vegetation anomalies and subtle colour texture contrasts on aerial photos. The interpreted aerial photo lineaments in this district including the linear trace of Chapmans Creek are believed to represent such fractures and faults.

Hydrogeological Setting

Two types of water-bearing zones (aquifers) are recognised in the Project Site:

- 'Alluvial' aquifers associated with alluvial deposits developed in the drainages associated with the Chapmans Creek system. This part of Chapmans Creek is a second-order drainage which has deposited varying but relatively small thicknesses of alluvium that has resulted from continuing erosion of the land surface.

  Potential low-yielding small-scale aquifers are associated with the poorly-developed relatively flat-lying sand/gravel units and lenses.

- 'Hardrock' aquifers associated with mainly sub-vertical geological discontinuities (joints, fractures and faults) that have dissected the porphyry.

  Enhanced hydraulic conductivity may be associated with the occurrence of relatively open joints and fractures or in areas containing a high density of fracturing and/or intersecting

fractures/faults. The occurrence of fractures in an impermeable host indicates that anisotropic hydrogeological conditions exist.

Neighbouring Bores

Five registered bores are charted by the DWE within a 5km search radius of the Project Site. However, two of these appear to have been incorrectly plotted on government maps and do not exist in this area. The neighbouring bores intersect Bindook Porphyry with recorded variable water quality and low yields which suggests low rock permeability.

The closest neighbouring registered bore is located 1500m east-southeast of the proposed quarry.

Aquifer Recharge

Aquifer recharge is primarily by way of precipitation (rainfall). Based on a recharge proportion from rainfall of 2% and adopting a 20-square-kilometre fractured basement recharge area, the estimated recharge into the ’hardrock’ aquifers is approximately 252 ML per annum.

A proportion of recharge will provide important base flow to the Chapmans Creek and Joarimin Creek systems. During periods of high flow, the structurally controlled creeks in the area and district would likely provide increased recharge into the deeper basement rock aquifers.

The mean annual district evaporation markedly exceeds the mean annual district rainfall.

Aquifer Discharge

A series of nine ‘water features’ or ‘springs’ were identified in the Chapmans Creek Catchment within approximately 1400m of the proposed quarry. The springs occur at the base of changes of slope and on elevated parts of distinct linear drainage traces. The location of the springs reveal a likely elevation control and in this regard, the springs appear to be clustered into at least two main groups located 1000 to 1400m distant from the proposed quarry on the south side of the Chapmans Creek Catchment and between 450 and 1100m distance on the north side.

The closest water feature to the proposed quarry (Spring 6) has a separation distance of 200m and located on the intersection of three interpreted geological discontinuities (fractures). The dominant geological structure is oriented north-northeast parallel to the western extremity of the proposed quarry. The feature is coincident with an existing small farm dam and general depression in the topography and is considered potentially significant in terms of potential impacts from the proposed quarry.

Measurements of Water Level and Direction of Groundwater Flow

The results of baseline and follow-up water level measurements in an extensive 42-bore monitoring network reveals that the direction of groundwater flow surrounding the proposed quarry is generally to the north sub-parallel to the topography.

The hydraulic gradient beneath the central and northern parts of the quarry footprint is between approximately 1 in 13 and 1 in 32. The hydraulic gradient beneath the southern part of the footprint is notably less and estimated at approximately 1 in 50.

Hydrographs constructed for 10 monitoring bores (existing open resource bores with surface casing) within and surrounding the Project Site reveal varying degrees of fluctuation in the water level which confirms the prediction that anisotropic hydrogeological conditions exist within the porphyry. Hydrographs for 7 of the 10 bores reveals a positive correlation between the observed rises in the piezometric surface and the main rainfall events recorded in the wider district which may be due to infiltration of rainfall down through the weathered zone into the open bore.

Permeability Testing

An attempt was made to carry out short-term pumping tests in the 10 selected monitoring bores in order to establish representative aquifer parameters including hydraulic conductivity and transmissivity. However, none of the monitoring bores could sustain pumping beyond between about several seconds and several minutes. The recovery of the water level in the majority of monitoring bores was almost non-existent to very slow due to the very low permeability of the porphyry host rock.

Dedicated ‘slug’ tests were then carried out in the same 10 monitoring bores. The results confirm low to very low rock permeabilities with the majority of tests revealing hydraulic conductivities of less than about 0.04m/day and transmissivities of less than approximately 0.6m^2/day. The results are consistent with:

- the occurrence of ‘tight’ fractures and joints in outcrop
- networks of fine fractures and veins in drill core
- a compressional regional tectonic regime
- the paucity of successful water bores in the local area
- high salinity levels in some district ‘hardrock’ aquifers

Water Quality Testing

The results of baseline groundwater sampling and water quality testing revealed that the groundwater is near neutral, ‘hard’ and moderately to highly saline and likely evolving along joint and fracture-controlled flow paths.

The groundwater can be classified as dominantly Magnesium-Chloride or Sodium-Chloride type with minor Sodium-Bicarbonate type. Some of the groundwater displays geochemistry expected at the discharge end of the hydrogeochemical cycle and others at the recharge end.

Assessment of Potential Impacts

There are considered to be four potential groundwater-related impacts associated with the proposed quarry development.

- Potential impact of the proposed extraction on any groundwater dependant ecosystems (GDEs).
- Potential impact associated with the extraction of porphyry, with any extraction of groundwater from the proposed quarry development on the local and district water table, on underlying ’hardrock’ aquifer systems and on any groundwater users. This includes the potential for impact on groundwater chemistry.

- Potential cumulative groundwater impact from the proposed quarry and other quarries in the district.
- Potential impact from acid mine leachate, if it is generated.

It is considered that eight (8) of the nine (9) springs will not be significantly impacted by the proposed quarry because they are distant from the proposed quarry and either downgradient or sidegradient.

However, one of the springs (Spring 6) may be at risk of potential impacts. Spring 6 is located approximately 200m west of the proposed quarry. The principle reasons for the assessment of any potential impact of porphyry extraction on Spring 6 are:

- The spring is in relative close proximity to the proposed quarry.
- The spring is interpreted to discharge from a sub-vertical fracture at elevation 650m AHD.
- The spring provides a small but beneficial water supply for the possible GDE that has formed by the construction of a small-scale on-line storage (dam) which appears to be largely perched.

The scientific evidence indicates that the groundwater discharging from Spring 6 may not be in direct hydraulic connection with the porphyry aquifer that will at least in part be intercepted by the proposed quarry. The likely source of groundwater feeding this spring is a prominent north-easterly oriented sub-vertical fracture parallel to the western boundary of the proposed quarry and upgradient, and will, in all probability, not be significantly affected by the operations.

However, it is recognised that it is possible that the water table, groundwater gradient and direction of flow close to the spring may be influenced by the artificial, permanent steepening associated with the resulting void.

The degree of encroachment is difficult to quantify but the results of the permeability testing indicate very low hydraulic conductivities throughout the porphyry.

Although the geometry of the fracture system is imperfectly understood, it is concluded that based on the available scientific evidence, it is unlikely that any proposed extraction will have any significant impact on the local or district water table and therefore on any spring flows. Nevertheless, a long-term program of flow and water quality monitoring of Spring 6 is recommended in order to detect and monitor any changes if they occur.

The low permeabilities measured in the porphyry indicate that the proposed extraction would not adversely impact on the district water table. However, on the local scale, the proposed quarrying will permanently alter hydrogeological conditions in close proximity to the quarry. Impacts are predicted to be confined to within tens of metres to possibly 100 to 200m of the active quarry limit.

Although small changes in hydraulic conditions such as increased hydraulic gradient may occur within tens of metres of the active quarry limit, the global water table would not be expected to fall significantly.

Assessment of the alluvial system associated with the upper reaches of Chapmans Creek confirmed the existence of a poorly developed system. The amount of water stored in the thin alluvium is predicted to be low and highly dependant on rainfall. In this regard, the quarry operations are not expected to impact on this poorly developed system.

The potential for significant impact from the proposed quarrying on any other water users surrounding the Project Site is considered to be very low. This prediction is based on the large separation distance between the nearest bore and the proposed quarry, and the demonstrated low global permeability values recorded for the porphyry mass in the Project Site. This prediction is supported by the occurrence of low yields in the three surrounding registered bores which indicates low rock permeabilities. The paucity of registered bores in the local area may indicate that past groundwater exploration has not been particularly successful; perhaps further confirmation of low rock permeabilities.

Based on the available geological and hydrogeological evidence and data, in particular the separation distances between the operational and proposed quarries in the district and demonstrated low rock permeabilities in each, there are no predicted cumulative impacts.

The issue of potential impact from any acid mine leachate from the proposed quarrying operations has been raised by the Department of Environment and Climate Change (DECC). Acid mine leachate relates to the production of low pH water usually associated with the oxidation of metal sulphide minerals, in particular pyrite. It is our view that based on geological investigations, the potential for the production of acid leachate from the proposed quarrying operations is very low because the ingredients for acid mine leachate (mainly disseminated pyrite) do not exist.

Inflow of Groundwater into the Excavation

The factors affecting the rate of inflow of groundwater into an excavation are the size, shape, location, rate of excavation and hydrogeologic properties of the host rock.

Although the demonstrated low rock permeabilities in the porphyry aquifer host are expected to result in small-scale inflow, the possible existence of rock defects such as fractures may increase the inflow potential. Estimates of groundwater inflow into the quarry were calculated using a simple analytical solution which predicts inflows into an excavation and projects water level declines proximal to the void.

It is considered that a three-dimensional computer model may not provide more accurate estimates of inflows because of the anisotropic hydrogeological conditions that exist in this type of ‘hardrock’ aquifer, the very low to low rock permeabilities and the complexity of the imperfectly understood three-dimensional geometry of the fracture network

Groundwater inflow during Years 1 through 2 is expected to be very low which is consistent with the results of permeability testing. Moderate increases in total inflow volumes are predicted as the quarry expands through Years 2 to 30 with flow estimates of up to possibly 3ML per annum in Year 30.

The amount of groundwater inflow into the quarry will be offset by evaporation. Therefore it is unlikely that significant ponding will occur in the quarry. The exception is quarry recharge from intense and/or extended rainfall events that will, from time to time likely result in potentially large-volume ‘bursts’ of water in the void. Any detention will be temporary and will dissipate naturally as a result of ensuing evaporation and infiltration into the groundwater system. The demonstrated very low rock permeabilities and relatively high evaporation rates indicate that the water table will remain beneath the void. That is, the quarry is a ‘groundwater sink’.

Staged Assessment of any Impacts

A staged approach to the assessment of any potential impacts from quarrying on groundwater inflows into the quarry and on the groundwater system will incorporate a formal review and reporting of the groundwater inflows into the quarry and the fluctuations in water levels in the network of monitoring bores at the end of Years 1, 2, 5, 10 and 20. The reviews will assess and compare the predicted impacts from the two-dimensional analysis against the actual (measured) impacts.

Long-Term Monitoring Program

Continuation of water level monitoring prior to commencement of quarrying and an ongoing program of long-term regular water level and water quality monitoring is recommended following commencement of mining operations. Water level measurements using automated water level data loggers and recorders are highly recommended.

A set of indicator analytes can be developed which will alert the Quarry Manager of any significant changes in water quality that may require action.

A representative network of existing monitoring bores should be maintained. The network includes a set of control bores that are not within or downslope of the proposed quarry area.

A total of three (3) new monitoring bores are recommended; two (2) shallow piezometers to monitor the water level fluctuations in and near Spring 6 and one (1) new 'hardrock' monitoring bores to fill in the existing network in the northern part of the Project Site. Specifications of the recommended monitoring bores have been developed.

A program of long-term water level, water quality and rainfall monitoring has been developed and incorporates regular automated water level and rainfall measurements and quarterly groundwater sampling for the first 12 months following commencement of quarrying and an assessment of results at the end of the period. The frequency of measurements and sampling may be decreased to 8-hourly water level measurements and 6-monthly groundwater sampling depending on the results and review of any trend. Real time rainfall data should be collected automatically on an event basis.

A representative of the proponent can be easily instructed on the programming and downloading of the data loggers, and appropriate data input and archiving of the data in an in-house electronic database.

Development of Trigger Levels

A set of statistically-derived trigger levels will be developed to provide early warning and monitoring of any adverse trends associated with water level decline and/or the quality of the groundwater. The methods would provide warning of any imminent exceedences of the limits and establish, and monitor, any impacts if they have already occurred associated with proposed quarrying

Reporting and Data Management Protocols

A series of protocols for in-house and statutory technical reporting has been developed for the project.

All water level data and groundwater quality monitoring results should be recorded, collated and duly reported in-house on an annual basis and reviewed by the consulting hydrogeologist. The review will include an assessment of any trends revealed from the statistical analysis of the monitoring data. The aim is to assess any changes in water levels and identify reasons for the changes if they occur. The monitoring schedule should be reviewed annually and changed if deemed appropriate by the consultant.

A series of protocols has also been developed for the management of technical data including importation into an electronic database or spreadsheet and viewed following each round of monitoring. A copy of the water level data should be sent to the hydrogeological consultant for assessment and a backup copy of the water level database kept in a secure **off-site** place.

Mitigation measures

The recommended mitigation measures are summarised as follows:

- The following options are presented if any deterioration in the discharge flow of **springs** in the local area surrounding the Project Site less than historical low flow rates that can, with the available scientific data, be linked to quarrying activities. The options are presented for consideration subject to any agreement/s between the owner and Gunlake Quarries.

    - Compensate the owner of the Property by supplying groundwater supplies to the property/s with a minimum flow equivalent to the measured and documented losses with water quality commensurate with the spring, or better.
    - Provide monetary compensation to the property owner for the measured and documented losses.
    - Drill a test bore on the Property for the owner in order to replace or improve the flow rate of the spring. The water quality must be similar to the spring water quality or suitable for the intended purpose.

- If the results of the proposed monitoring program indicate that there is a significant and demonstrable impact on **Spring 6** adjacent to the proposed quarry, the volume of groundwater lost as a consequence could be more accurately estimated and consideration given to designing an appropriate groundwater replacement system.
- Although the risk of significant impact on **registered water users** surrounding the Project Site is considered to be very low, long-term water level monitoring will detect any potential distance impacts.

    If there is a scientifically demonstrated significant impact on any neighbouring water users surrounding the Project Site, for example, a fall in bore water level that can, with the available scientific data, be linked to quarrying activities, the following compensatory options are presented for consideration subject to any agreement/s between the property owners and Gunlake Quarry Pty Limited.

    - Compensate the owner of the Property by supplying 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.
    - Provide monetary compensation to the property owner for the measured and documented losses.
    - Drill a test bore on the Property for the owner in order to replace or improve the flow rate of the existing registered bore. The water quality must be similar to the existing bore water quality or suitable for the intended purpose.

Conclusions

The principle conclusions relevant to any potential impacts from the proposed quarry are summarised as follows:

- The results of hydrogeological investigations indicate that the risks of any significant impacts from the proposed quarry on **springs surrounding the project Site** are considered low.

    In the event of any impact that is demonstrated to be associated with the proposed quarry, mitigation measures include supplying water to replace the losses, monetary compensation for losses or test drilling for a useful ’hardrock’ groundwater supply to supplement the affected spring flow.

- The results of hydrogeological investigations over the Project Site in particular the results of water level monitoring and permeability testing, and the large separation distances between the proposed quarry and the three registered bores in the local area indicate that the district water table and **registered groundwater users** will not be significantly affected by the quarry, if at all.

  In the event of any impact that is demonstrated to be associated with the proposed quarry, mitigation measures have been developed and include supplying water commensurate with the demonstrated loss, monetary compensation for losses or test drilling for a replacement ’hardrock’ groundwater supply.

- The risk of any significant impact from the proposed quarry on **Spring 6**, the nearest water feature to the proposed quarry, is considered low to moderate. The increased risk of impact is mainly predicated on the relatively close proximity to the proposed quarry and the permanent changes in the water table and hydraulic gradient close to the void.

  In the event of any impact that is demonstrated to be associated with the proposed quarry, mitigation measures include supplying water to replace the losses or test drilling to obtain a useful ’hardrock’ groundwater supply to supplement the spring flow.

- It is our view that the conceptual geological model and the results of the hydrogeological investigations, in particular the results of water level monitoring and aquifer permeability testing enables an appropriate assessment of impacts from the proposed quarry.

  Although the development of a three-dimensional groundwater computer model for assessments of groundwater impacts is now common place, the main limitation in the assessment of any impacts relating to the proposed Gunlake Quarry is the complex anisotropic nature of the hydrogeological system and the uncertainty of the fracture network geometry beneath the Project Site. Although a three-dimensional numerical groundwater flow model can accommodate certain degrees of aquifer anisotropy, the density, distribution and the three-dimensional geometry of the fracture network beneath the Project Site is very difficult to delineate and as a consequence, simulations of the observed aquifer head distribution may not be achieved with suitable accuracy.

  The trace of surface lineaments interpreted from aerial photos within and surrounding the Project Site provide an indication of local fracture control for the aquifers but the geometry of the fracture network likely to be intercepted on the quarry scale cannot be delineated with any certainty.

  The implication is that a three-dimensional computer model may not provide more accurate estimates of drawdown in the water level surrounding the quarry or inflows of groundwater into the quarry because of the uncertainty of the fracture geometry. As is the case with most mine developments, the actual geometry of small to medium-scale secondary defects such as joints, fractures and small-scale faults can only be determined with any accuracy during mining.

  The nature and properties of the Bindook Porphyry, demonstrated low global permeabilities and knowledge of the degree of impacts associated with similar quarry developments in igneous rocks is consistent with the prediction that any significant drawdown of the local water table will occur within close proximity to the void.

  The implication of this is that the potential for impacts on the identified distal spring systems and any associated GDEs, and the three registered bores are low.

  If there are any linear, sub-vertical sheet-like discontinuities within the proposed quarry footprint unknown at this time, that may influence the degree, extent and distribution of any impacts, it is our view that a three-dimensional computer model will not improve the accuracy of any distant impact predictions.

- There are no predicted cumulative impacts.
- The potential for the generation of **acid leachate** from the proposed quarrying operations is considered to be very low due mainly to the paucity of disseminated pyrite and/or other metal sulphides in the porphyry beneath the Project Site.

1.0 INTRODUCTION

1.1 Background

As requested by *Gunlake Quarries (*a division of *Rollers Australia Pty Limited)*, *Larry Cook & Associates* has carried out hydrogeological investigations and office-based studies on and surrounding a property on Brayton Road approximately eight kilometres north of Marulan in southern New South Wales (the Project Site).

This report has been prepared as part of an Environmental Assessment (EA) relating to the proposed extraction of porphyry on the Project Site. *Gunlake Quarries* propose to develop the quarry. The preparation of the Environmental Assessment Report (EAR) was commenced by *Valerie Smith and Associates* and is now being managed by *Olsen Environmental Consulting Pty Ltd*.

1.2 Author

This groundwater impact assessment report was prepared by Larry Cook who is qualified to undertake the assessment. Relevant qualifications include a Master of Science Degree in Hydrogeology and Groundwater Management conferred by the University of Technology, Sydney (UTS) in 1998 and a Bachelor of Science Degree in Applied Geology from UTS in 1976.

1.3 Objectives and Scope of Work

The objectives of this hydrogeological assessment are to:

- Establish and assess local and district hydrogeological conditions.
- Establish the existing groundwater utilisation in the district.
- Estimate recharge volumes in the area centred on the Project Site.
- Carry out analytical testing to characterise the groundwater.
- Assess any potential impacts of the proposed extraction of rhyodacite (Bindook Porphyry) on district aquifer systems, local and district water tables, groundwater dependant ecosystems, groundwater chemistry and local water users.
- Provide recommendations including operational safeguards, mitigation measures and contingency planning.
- Develop a long-term groundwater monitoring program, and reporting and database management protocols.

1.4 Location, Access and Topography

The 230-hectare Project Site is located within largely cleared rolling hills located adjacent to, and on the west side of, sealed Brayton Road approximately eight kilometres northwest of the village of Marulan and about 24 kilometres east of the major regional commercial centre of Goulburn. The Project Site is in the Parish of Uringalla, County Argyle.

Access to the Project Site is due north-northwest from Marulan along Brayton Road for approximately eight kilometres with the present entrance to the Project Site immediately south of Chapmans Creek.

The location of the Project Site is shown in **Figure 1** and on a copy of the latest state government aerial photo presented in **Figure 2**. The topographic map sheet covering the Project Site is the 1:25,000-scale *Towrang* topographic map sheet (8828-1-S). The approximate AMG coordinates of the centre of the Project Site are Easting 771700m Northing 6159000m.

The Project Site straddles the headwaters of a small-scale northeast trending valley. The valley hosts the ephemeral Chapmans Creek, which flows northeast beneath the Brayton Road then flows into Joarimin Creek approximately 1.3km east of the road. The highest point of the 'watershed' ridge system in the western part of the Project Site is Stony Range Hill (Billyrambija Trig) at an elevation of 762m Average Height Datum (AHD). The lowest part of the Project Site is at an elevation of approximately 615m AHD where Chapmans Creek crosses the Brayton Road.

1.5 Proposed Extractive Industry

Gunlake Quarries propose to produce 500,000 tonnes of finished product per annum. Extensive drilling on the Project Site has demonstrated a resource of approximately 180 million tonnes of tuffaceous rhyodacite (Bindook Porphyry) to a depth of up to 100m below ground level.

Geotechnical tests have determined that the material is suitable for use in a full range of quarry products including concrete, sealing aggregates, rail ballast, manufactured sand and road base.

The proposed quarry has an expected life of over 100 years. Approval is sought for an initial period of 30 years.

The development is considered 'Major Development' and the preparation of an EA is current.

1.6 Report Format

The key issues and assessment requirements relevant to groundwater flagged by Department of Planning (DoP) are documented in Section 2. The methodology adopted for this assessment is described in Section 3 and a description of the regional, district and local geological setting given in Section 4.

Documentation of the hydrogeological setting follows in Section 5 and includes a description of the aquifers beneath the Project Site, data and information for a small number of neighbouring registered bores, identification and description of areas of groundwater discharge (springs) and an estimate of local recharge volume from rainfall.

Sections 7, 8, 9 and 10 provide information and specifications for the extensive network of monitoring bores and the results of water level monitoring, water quality testing and permeability testing.

A description of a spring system relatively close to the proposed quarry considered to have the highest potential risk of impacts from quarrying is provided in Section 11. An assessment of potential impacts from quarrying on the district groundwater system, water features (springs), GDEs and surrounding water users is provided in Section 12.

Estimates of groundwater inflow into the progressively expanding quarry are provided in Section 13. A proposed long-term water level and water quality monitoring program and protocols for technical data management and statutory, and in-house, reporting is given as sections 14, 15 and 16.

A set of mitigation measures and options has been developed for the project and is given in Section 17. The measures have been formulated in order to manage any demonstrable impacts associated with the quarrying. A set of recommendations are given in Section 19.

2.0 DIRECTOR GENERAL'S REQUIREMENTS

The key groundwater issues flagged by the DoP and the relevant Director General's Requirements in relation to *Part 3A* and Section 75A of the *Environmental Planning and Assessment Act (1979)* are summarised in **Table 1**. The requirements were prepared by the DoP following consultation with, and submissions from, relevant government authorities.

Table 1
Director General's Requirements and Key Issues Relating to Groundwater
Section 75F of the *Environmental Planning and Assessment Act (1979)*

General Requirements	A detailed assessment of the key issues specified below and any other significant issues identified in the general overview of environmental impacts of the project which include: • A description of the existing environment • An assessment of the potential impacts of the project, including any cumulative impacts; • A description of the measures that would be implemented to avoid, minimise, mitigate, offset, managed and/or monitor the impacts of the project.
Key Issues	**Surface and Ground Water** – including details of surface and ground water impacts and a site water balance; details of the proposed water management system including any creek diversions and sediment/water supply dams (both for the quarry site and haul road); consideration of the relevant provisions of *Drinking Water Catchments Regional Environmental Plan No 1;* and a surface and ground water contingency strategy setting out appropriate measures to ensure continued water supplies for surrounding landowners and the environment.

3.0 METHODOLOGY

The methodology employed in meeting the objectives identified in **Section 1.3** and the Director General's Requirements in Section 2 included a comprehensive combination of literature review, data collection and field assessments.

Specifically the work comprised:

- A review of recent and historic published geological mapping of the district at various scales including 1:250,000 and 1:100,000. This review incorporated a review of relevant unpublished geological documents.
- A review of published aerial geophysical mapping of the district.
- Inspections of the Project Site that incorporated geological and hydrogeological mapping.
- Examination and detailed interpretation of recent state government colour aerial photographs taken over the district in 1997 and the latest photography in 2004 (Goulburn 1:25000-scale, Run 5).
- A review of data and information for registered boreholes in the district held by the DWE.
- Established location of any neighbouring bores and other groundwater sources in order to assess any potential for interference effects with any existing users.
- Inspected and assessed any 'spring' systems on the Project Site and in the district immediately surrounding the Project Site.
- Established types of aquifers.
- Investigated the location of a large network of existing resource exploration drill holes.
- Carried out aquifer testing and drawdown analysis of selected test bores used as monitoring bores.
- Installed a representative network of automated water level data loggers and recorders.
- Measured and recorded water levels in a large number of monitoring wells.
- Collected baseline sets of water level and water quality data.
- Assessed any potential impacts of proposed quarrying on local water users.
- Assessed any potential impacts of proposed quarrying on surrounding spring systems.
- Preparation of this report describing the rationale for, and detailing results of, the hydrogeological investigation, and providing results of the groundwater impact assessment.

4.0 GEOLOGY

4.1 Research

A comprehensive literature and data search was carried out. Geological data and information was obtained from geological maps published by the Geological Survey of New South Wales, in particular the current Goulburn 1:100000-scale Geology Sheet (Thomas O.D et.al, 2000) and from the notes accompanying the structural map of New South Wales (Scheibner E, 1993). Aeromagnetic datasets acquired by the State government were also reviewed and interpreted.

Useful geological information was also obtained for several registered water bores in the Marulan area, the data and information for which is held by the NSW Department of Water and Energy (DWE) in their computerised bore database.

Other valuable sources of information included two campaigns of state government colour aerial photography flown over the Goulburn area, the first in 1997 and the most recent in 2004. Topographical information was obtained from the 1:25000-scale *Towrang* topographic map sheet (8828-1-S) and an orthophotomap privately commissioned by *Gunlake Pty Ltd.*

4.2 District Geology

The reader is referred to the published 1:100,000-scale provisional Goulburn Geology Map (Thomas O.D. et.al., 2002). The district geology is shown in **Figure 3**. The Project Site is located within the south-eastern extension of the Molong-South Coast Anticlinorial Zone a major broadly north-south trending geological structural zone in the eastern central part of the Lachlan Fold Belt.

The Project Site straddles a folded and deformed basement sequence of Devonian age volcanic rocks collectively known as the Bindook Porphyry Complex. The volcanic complex is located at the northern end of the Marulan Granite and incorporates a series of volcanic members which as a group is oriented broadly north-northwest. The Devonian sequence in the district is observed to be steeply dipping with a series of sub-parallel north-northeast trending anticlinorial and synclinorial structures.

4.3 Local Geology

The Bindook Porphyry beneath the Project Site can be divided into two definable and mappable units; the Barralier Ignimbrite and the Joaramin Ignimbrite. These have been described by Simpson, C.J. et.al (1997) a summary of which is provided in the following sections.

4.3.1 Barralier Ignimbrite

The Barralier Ignimbrite is described as a blue-grey, welded ignimbrite of dacitic composition. The rock contains fractured phenocrysts of quartz, plagioclase, hornblende, enstatite and minor biotite set in a recrystallised quartzo-feldspathic aphanitic (fine grained) groundmass. Recent field investigations by other geoscientists reveal that the Project Site is largely underlain by Barralier Ignimbrite with Joaramin Ignimbrite noted in the southeast.

4.3.2 Joaramin Ignimbrite

The Joaramin Ignimbrite is older than the Barralier Ignimbrite and immediately underlies it. The Joaramin Ignimbrite is described as a densely-welded, crystal rich ignimbrite of rhyolitic composition. The rock contains fractured phenocrysts of quartz, plagioclase, potassium (K) feldspar, biotite, minor hornblende and common amounts of relict welded shards set in a recrystallised, aphanitic quartzo-feldspathic groundmass. The rhyolite classification is due mainly to the presence of potassium (K) Feldspar which indicates that the rock is more acidic in composition than the Barralier Ignimbrite.

It is noted that the formal geological name for this ignimbrite is spelt *Joaramin* (Simpson, C.J. et.al 1997, Thomas O.D, et.al 2000) whereas the name of the creek in the area centred on the Project Site on the 1:25,000-scale *Towrang* topographic map sheet (8828-1-S) is spelt *Joarimin.* They are one of the same.

4.3.3 Petrology

Samples of ignimbrite were collected by *Valerie Smith & Associates* in 2006 for petrological examination as part of the resource assessment. Two samples were collected from test pits and four samples collected from selected drill core.

The petrological examination confirmed the presence of ignimbrite of general rhyo-dacitic composition. The main difference noted was the variability in the degree of alteration. The examination revealed the presence of common crosscutting veins of calcite and quartz.

4.4 Structural Geology

Government and research geologists have delineated a network of faults in the area mainly within and bounding the extensive and deformed, generally north-northeast trending sequence of early Devonian age volcanics, volcanoclastics and intrusive lithologies. The structural and geological framework of the region developed by the state government geologists is shown in **Figure 4**.

Review and interpretation of the government colour aerial photographs flown over this area reveals several 'strong' sets of complimentary, often orthogonal northeast and northwest trending linear features that are reflected in linear drainage traces, vegetation anomalies and subtle colour texture contrasts.

One of the most prominent features on the Project Site is the linear trace of Chapmans Creek. The main interpreted linear features on and surrounding the Project Site are annotated in **Figure 5**.

The older basement rocks in the district have been subjected to several phases of progressive deformation (folding, thrusting and faulting) over an extended period. These tectonic upheavals have resulted in the imposition of structural discontinuities that dissect the rock masses providing potential fluid pathways and conduits. The interpreted aerial photo lineaments in this district are believed to represent such structural discontinuities.

5.0 HYDROGEOLOGY

5.1 Aquifers

A review of published maps combined with our recent field observations, knowledge of the geology of the district and experience in these settings indicates that several types of water-bearing zones (aquifers) exist in the local area centred on the Project Site. Two aquifer 'sub-types' or 'hydrogeological domains' are recognised. These are listed as follows and are described in sections 5.1.1 through 5.1.2.

- 'Alluvial' aquifers associated with alluvial deposits developed in the drainages associated with Chapmans Creek and first order tributaries.
- 'hardrock' aquifers associated with sub-vertical and possibly sub-horizontal geological discontinuities (joints and fractures) that have dissected the Palaeozoic basement porphyry.

5.1.1 Alluvial (unconsolidated) Aquifers.

The first aquifer domain essentially covers the upper parts of the Chapmans Creek system which flows from west to east and bounds the western and northern boundaries of the Project Site. The headwaters of the creek system are located on the eastern flank of Stony Range Hill in the western part of the Project Site. This part of Chapmans Creek is a second order drainage which has deposited varying but relatively small thicknesses of alluvium that has resulted from continuing erosion of the land surface.

Potential low-yielding aquifers may be associated with relatively flat-lying sand/gravel units and lenses hosted by the ignimbrite-derived alluvial sequence. The sands and possibly gravel would be expected to be interbedded and interlensed with a sequence of clay and silt. There is no data or information for any registered alluvial bores in the local area. Although the water quality is unknown, records from bores in similar settings indicate that relatively 'fresh' supplies are likely.

5.1.2 Basement 'Hardrock' Aquifers

As discussed in Section 4.4, the Palaeozoic basement rocks in the district have been subjected to several phases of progressive deformation (folding, thrusting and faulting) over an extended period. These tectonic upheavals have resulted in the imposition of structural discontinuities that dissect the rock masses providing potential fluid pathways and conduits. The various geological mapping campaigns over the district have provided testimony of the structural history and revealed the presence of such geological structures of which the Towrang and Yarralaw faults are just two. The linear trace of north-northwest trending Lockyersleigh Creek and sub-parallel Naranbulla Creek approximately 3.5 to 5.5km west of the Project Site and the linear segments of the Wollondilly River to the north-northwest are also believed to be the surface traces of pervasive sub-vertical structural discontinuities.

The interpreted aerial photo lineaments in this district are believed to include such structural discontinuities. For instance, the east-northeast trending linear surface trace of Chapmans Creek reflects the presence of underlying geological discontinuities such as joints, fractures and faults that have dissected the relatively 'brittle' basement rocks.

The interpreted linear features centred on the Project Site are shown in **Figure 5**. A structural geometry is revealed with continuous and pervasive east-northeast trending lineaments and dominant sets of complimentary north-northwest and north-northeast lineaments.

Within the porphyry (rhyodacite) beneath the Project Site, enhanced hydraulic conductivity may be associated with the occurrence of relatively open joints and fractures or in areas containing a high density of fracturing and/or intersecting fractures/faults. Geological mapping over the Project Site carried out by *Valerie Smith and Associates* and *Larry Cook and Associates* revealed networks of fractures and joints in outcrop. This included logging of drill core from the Project Site by *Valerie Smith and Associates* and rock quality testing. The logging recorded networks of fractures and individual discontinuities some with common vein infill comprising quartz and calcite.

5.2 Bore Data and Information

A search of data and information for registered bores held by the DWE, the former DNR, revealed the existence of five registered bores within a 5km search radius centred on the Project Site. However, it is noted that the DWE have charted the locations of two registered bores (GW010600 and GW015362) which are incorrect. The work summaries for these bores have license numbers with 40BL prefixes and the geological descriptions are inconsistent with the known geology surrounding the Project Site. However, the map references and bore location coordinates recorded on the work summaries are consistent with the area covered by the *Towrang* topographical; sheet. These bores have been omitted from Figure 6

Inquiries have been directed to the Groundwater Licensing Section of the DWE however, no reply has been received at the time of writing.

The locations of the three bores are plotted on the 1:25000 *Towrang* topographic sheet and presented in **Figure 6**. A summary of the details for the three registered bores is presented in **Table 2**. Work summaries for the bores are provided in **Appendix A**.

Table 2
Summary Details of Registered Bores

Bore	Coordinates		Depth (m)	Aquifer Type	Year Drilled	Aquifers/ Yield (L/s)	Water Level (m)	Water Quality	Bore Geology
	E	N							
GW055436 10BL120421 S, D	768435	6157040	76.2	'hardrock'	1981	7.9-11.0m/0.4 48.8-49.1/0.4	4.6	'Good'	0.0-0.3 Soil 0.3-1.5 Clay 1.5-10.7 Granite 10.7-19.8 Gran.Por 19.8-76.2 Granite
GW056376 10BL121918 S	773185	6158085	51.0	'hardrock'	1982	22.0-23.0m/0.2	12.0	nil	0.0-51.0 Granite
GW105357 10BL161170 S, D	771176	6161580	60.0	'hardrock'	2002	nil	nil	nil	0.00-1.5 Soil 1.5-60.0 Gran.

Note: 'nil' denotes no recorded data
Gran. denotes granite
Por denotes porphyry
S, D denotes authorised **S**tock and **D**omestic supply

The records indicate that the three bores were drilled into Bindook Porphyry and variously described as granite and granite porphyry. Final depths of the three bores range from 51.0 to 76.2m. The deepest bore GW055436 is located approximately 3.7km southwest of the Project Site (**Figure 6**).

Low yields were recorded for two of the bores that have yield records. Yields ranged between 0.2 and 0.4L/s (160 to 220gal/hr) with the best yields recorded in bore GW055436.

The available water quality records were almost certainly noted from the driller's 'taste tests' during drilling. The records available for just one of the registered bores (GW055436) reveal that the groundwater quality is 'good' which indicates low salinity.

The implications of this finding are that the existing porphyry-hosted registered bores surrounding the Project Site are all low yielding which suggests low hydraulic conductivity values (low permeability).

5.3 Groundwater Availability and Utilisation

The three registered bores are licensed for the extraction of groundwater and are approved for either 'stock & domestic' or 'stock' use. This indicates relatively 'small' annual volume allocations with amounts of approximately 1 to 2ML each.

It is noted that the allocations for the three licensed bores in **Appendix A** are not listed on the schedule supplied from the DWE. The combined allocation for the three bores is believed to be between approximately 6 and 20 ML per annum.

5.4 Aquifer Recharge

Aquifer recharge is primarily by way of precipitation (rainfall). The immediate recharge zone for the aquifers in the district centred on the Project Site is complex and very difficult to quantify. However, based on the occurrence of dense, relatively impervious metasedimentary and crystalline igneous basement rocks and interpretation of the extensive network of fractures and faults that have been imposed on the basement rocks, a 20-square-kilometre recharge area is adopted for recharge estimation purposes. The choice of a 20-square-kilometre recharge area is not based on quantitative studies, rather it is a likely conservative estimate. In this regard, it is considered that the recharge area is likely to be significantly larger.

Rainfall data for the region was obtained from the Bureau of Meteorology. The two closest and representative weather stations are in Goulburn, Station 070037 – Goulburn and Station 070263 – Goulburn Tafe. The climate statistical data sheets for the two stations are provided in **Table 3**. The rainfall data indicates a range of precipitation of between approximately 460mm (decile 1) and 920mm (decile 9) per annum. The median precipitation is approximately 630mm per annum.

Based on these average data, broad estimates of recharge for a 20 square kilometre area were calculated using a recharge proportion of 2%. Global recharge into the basement 'fractured' aquifers is very difficult to quantify without long-term regional research. Although this estimate is difficult to quantify and there is little available worldwide research data, recent government research in the Yass basement rocks of similar age and rock types in the Yass district indicates that a recharge proportion of between about 1% and 5% is realistic. It is noted that almost all of the direct local recharge will be via infiltration down through structural discontinuities. It is also noted that the Wollondilly River is structurally controlled and a likely line source of recharge into the underlying granite and porphyry aquifer systems.

Table 3
Rainfall Data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years	
Goulburn Tafe - 070263															
Mean rainfall (mm)	64.5	56.9	54.7	46.8	45.1	51.0	43.9	54.9	50.6	55.5	65.9	54.2	644.0	32	1971 2007
Decile 5 (median) rainfall (mm)	58.9	48.7	49.6	30.0	36.9	39.8	43.4	43.7	48.2	50.0	66.4	44.2	634.6	30	1971 2007
Mean number of days of rain ≥ 1 mm	5.7	5.3	5.2	4.8	5.6	6.2	6.6	7.1	7.1	7.2	7.6	5.8	74.2	32	1971 2007
Goulburn - 070037															
Mean rainfall (mm)	64.8	60.6	55.6	48.5	51.5	56.3	47.8	49.1	50.0	62.5	56.1	62.9	666.1	103	1857 1967
Decile 5 (median) rainfall (mm)	61.4	46.4	41.6	40.3	31.0	44.2	35.3	42.4	43.3	57.8	45.2	48.6	625.8	102	1857 1967
Mean number of days of rain ≥ 1 mm	5.7	5.4	5.4	5.5	6.3	7.5	7.5	7.3	7.1	7.3	6.1	6.0	77.1	103	1857 1967

Note: Red denotes maximum statistic
Blue denotes minimum statistic

On this basis, recharge would be in the order of 252 megalitres (ML) per annum. In terms of the local area, some of this will provide important base flow to the Chapmans Creek and Joarimin Creek systems. During periods of high flow, the structurally controlled creeks in the area and district would likely provide increased recharge into the deeper basement rock aquifers.

Evaporation data is available from the Progress Street weather station in Goulburn (Station 70263). The record is for a continuous period between 1973 and 2000. The mean evaporation statistic for this 27-year period is 1643mm per annum. Although it is uncertain whether this statistic reflects the district mean over the longer term for which rainfall data is recorded, it is readily apparent that the mean evaporation for the district markedly exceeds the mean rainfall.

5.5 Aquifer Discharge

A series of ‘water features’ or ‘springs’ which are essentially areas of shallow groundwater discharge were identified in the headwaters of Chapmans Creek and on both the southerly facing north flank and the northerly facing southern flank of the upper part of the Chapmans Creek Catchment. These springs were revealed on aerial photos as subtle colour (often green) texture contrasts and vegetation anomalies. The springs occur at the base of changes of slope and on elevated parts of distinct linear drainage traces. The locations of the nine (9) water features identified on colour aerial photographs within an approximate 1400m distance from the proposed quarry are shown in **Figure 7**.

The following points describe the general setting and likely controls on the locations of the nine spring features which are herein identified as Springs 1 through 9.

- The elevations of the springs reveal a likely elevation control and in this regard, the springs appear to be clustered into at least two main groups. The approximate elevations of the springs are listed in **Table 4**.

Table 4
Elevation of Water Features (Springs)

Spring	**Coordinates (AMG Grid)**		**Approximate Elevation (m AHD)**
	Easting (m)	Northing (m)	
1	770700	6160000	665
2	770960	6160160	660
3	771240	6160335	660
4	770786	6159420	665
5	770570	6158940	685
6	771540	6158865	655
7	772165	6158950	650
8	772297	6159168	645
9	772530	6159720	640

The apparent elevation control may reflect the local potential energy in the groundwater system (position of the piezometric surface in a confined aquifer). That is, although the groundwater gradient and direction of groundwater flow is expected to generally mirror the topography on the local scale, the potentiometric surface is likely also influenced by the hydraulics within individual fault or fracture-bound blocks. This suggests that anisotropic hydrogeological conditions exist within the porphyry and in other ‘old’ basement host rocks in the district.

- The locations of the springs coincide with linear geological features which as suggested in sections 4.4 and 5.1.2, are likely sub-vertical fractures (geological defects) imposed on the igneous rock mass during past regional deformation. These features are likely fault (fracture) springs.
- Springs 1, 2, 3 on the north side of the Chapmans Creek and Spring 4 in the upper central part of the catchment are at an elevation of between 660m and 665m AHD. The springs appear to be controlled by sub-vertical discontinuities.
- Springs 7. 8 and 9 appear to be controlled by a north-northeast trending linear and continuous sub-vertical fracture with the discharge points at elevations of between about 640m and 650m AHD.
- Spring 6 is the water feature proximal to the proposed quarry. This water feature is also structurally controlled and although it is located on the intersection of three interpreted discontinuities, the dominant structure is oriented north-northeast parallel to the western extremity of the proposed quarry and sub parallel to the lineament on which springs 7, 8 and 9 are located.
- It is our view that Spring 6 is the most likely candidate for any potential impact from the proposed quarry. Although the geological and hydrogeological evidence suggests that the proposed quarry will not intercept the groundwater flow to the spring, there is the potential for the extraction to indirectly affect the spring by possibly changing the direction of groundwater flow and increasing the hydraulic gradient in the close vicinity of the spring.
- It also our view that the other springs will not be affected by the proposed quarry.

- Springs 1 through 4 are north of, and a significant separation distance from the proposed quarry. Springs 7, 8 and 9 are closer to the quarry footprint however, the groundwater flow in these discontinuities will not be impeded by the proposed extraction. This may indeed be the situation with Spring 6 however, the proximity to the proposed extraction may cause a local change in the hydraulic gradient thus potentially inducing flow from the area near the spring towards the quarry.

The location of Spring 6 is broadly coincident with an existing small farm dam and general depression in the topography. That is, the dam is an 'artificial' man-made structure. It is suggested that the 'old' dam was likely constructed to retain spring discharge. Anecdotal evidence suggests that during the current drought, the dam has apparently always retained water. The dam is shown in **Figure 7**.

It is noted that two additional historic, man-made dams associated with 'springs' occur in the district. These small dams are observed on aerial photos immediately downstream from Spring 3 located on the northern side of Chapmans Creek approximately 1.4km north of the proposed quarry and Spring 4 about 900m northwest (**Figure 7**).

The water features in the district are likely to be 'depression springs' and/or a 'fault springs'

Depression springs form in low topographic spots when the piezometric surface intersects the ground surface. A fault spring can develop where a fault dissecting an impermeable rock mass forms a hydraulic barrier and can force groundwater to discharge along the fault to the surface.

This association is also consistent with springs that are associated with a fault where the aquifer comes into contact with a fault-bound impermeable rock mass such as the 'old' basement rocks forming a district, possibly regional hydrogeological boundary. If this happens, shallow groundwater is forced to discharge as a fault spring.

An alternate interpretation is that they are joint springs or fracture springs as described by Fetter (1988) where groundwater permeates through jointed or permeable fracture zones hosted by relatively impermeable rock and forms springs where these zones come into contact with land surfaces with low elevations.

Although the discharges from these types of springs likely vary in response to seasonal and climatic factors, anecdotal evidence indicates that they are low-volume semi-permanent flows.

This spring system is further discussed in **Section 12.3.1** of this report in regard to potential impacts from the quarry development.

6.0 PREVIOUS HYDROGEOLOGICAL INVESTIGATIONS

Apart from state government regional geological and airborne geophysical mapping programs in this part of the Lachlan Fold Belt and specific studies on parts of the Bindook Porphyry in the region, *Larry Cook & Associates* is not aware of any previous hydrogeological investigations carried out over the Project Site.

However, detailed hydrogeological studies are known to have been carried out as part of Department of Planning requirements for the Readymix Lynwood Quarry and the Boral South Marulan Quarry.

7.0 MONITORING BORES

A detailed inspection of existing resource/exploration drill holes on, and surrounding, the Project Site was carried out to establish whether any of these 'open' drill holes could be utilised for monitoring and testing purposes.

The search revealed that many of the bores have collapsed. The depth of the rediscovered open bores was considered suitable for hydrogeological monitoring within the porphyry resource because all bores fully penetrate the depths to which the proposed quarry is planned.

A total of 42 bores were rediscovered and identified within the project area. The majority of these bores were assessed to be suitable for at least water level monitoring.

A representative network of 10 of these monitoring bores (piezometers) was selected from the field assessment and accordingly resurrected. The location of the monitoring network is shown in **Figure 8**.

The monitoring bores were strategically located in order to measure and record baseline water levels, enable ongoing water level monitoring and hydraulic testing, and collect groundwater samples for a baseline set of geochemical data. Summary details of the 10 representative monitoring bores are provided in **Table 5.**

Table 5
Register of Representative Monitoring Bores – Gunlake Quarry

Monitoring Bore	Coordinates MGA Grid		Depth of Bore (m)	Surface Elevation (m AHD)	Casing Stickup (m)	TOC Elevation of Representative (m AHD)
	Easting (m)	Northing (m)				
GM5	771856	6159495	22.50	650.80	0.60	651.40
GM6	771916	6159367	25.88	657.40	0.54	657.94
GM11	771937	6159186	23.35	662.80	0.50	663.30
GM13	771816	6159042	22.36	665.20	0.50	665.70
GM18	771743	6159110	24.10	662.00	0.58	662.58
GM21	771788	6159255	22.71	660.40	0.54	660.94
GM22	771662	6159294	11.70	650.10	0.57	650.67
GM24	771676	6158934	21.00	659.90	0.53	660.43
GM35	771961	6159027	27.54	664.90	0.79	665.69
GM36	771920	6158843	17.12	666.60	0.60	667.20

Note: TOC denotes **T**op **O**f **C**ollar.

Automated 'Odyssey' (*Dataflow*) submersible Pressure and Temperature Data Recorders were installed in the 10 representative bores listed in **Table 5**. These loggers are vented to the atmosphere and were programmed to take measurements of water level and temperature at a sample frequency of four (4) hours. The loggers are currently operational.

8.0 WATER LEVEL MEASUREMENTS, DIRECTION OF GROUNDWATER FLOW AND HYDRAULIC GRADIENT.

Baseline measurements of water level were collected in April 2007 from 42 bores within the network of resource/exploration bores. As stated in Section 7, these bores were resurrected for monitoring purposes. Progressive water level measurements have been, and continue to be, collected.

The measurements of water levels recorded in the 42 monitoring bores are listed in **Table 6**.

Contours of the elevation of the piezometric surface with respect to Australian Height Datum (AHD) are shown in **Figure 9**. The highest water tables are located in the elevated parts of the area and conversely, the lower water tables in the lower elevations.

The direction of groundwater flow surrounding the proposed quarry is generally to the north and sub-parallel to the topography. The directions of flow determined in different parts of the Project Site are annotated in **Figure 9**.

The hydraulic gradient is often described as the driving force for groundwater flow. It is essentially the difference in hydraulic head between two points which implies a hydraulic gradient where the gradient is along the direction of the lower head and the gradient direction indicates the potential for groundwater to flow in that direction.

The hydraulic gradient beneath the central and northern parts of the quarry footprint is between approximately 1 in 13 (0.076) and 1 in 32 (0.031). The hydraulic gradient beneath the southern part of the footprint is notably less and estimated at approximately 1 in 50 (0.020).

8.1 Hydrographs

Individual hydrographs for the 10 monitoring bores are provided in **Appendix B**. A chart showing composite hydrographs for the monitoring bores with local daily rainfall for the period 7.6.07 to 21.7.07 is shown in **Figure 10**.

In summary, the hydrographs reveal varying degrees of fluctuation in the piezometric surface beneath the Project Site which we believe confirms the prediction that anisotropic hydrogeological conditions exist within the igneous (porphyry) body. It is noted that the since the commencement of automated water level logging, the fluctuation in piezometric surface for all bores is positive. That is, the piezometric surface has risen in all 10 monitoring bores.

Hydrographs constructed for 7 of the 10 monitoring bores show marked fluctuations in the piezometric surface with the greatest degree of fluctuation revealed in bores GM11, GM13, GM21, GM35 and GM36. In contrast, the hydrographs for bores GM5, GM6 and GM18 reveal very little rise or fluctuation.

There does not appear to be a pattern in the aerial distribution of the degree of fluctuations in the piezometric surface which tends to support the prediction of anisotropic conditions in the aquifer system.

Table 6
Water Level Measurements – Monitoring Bores

Bore	Host Geology	5.4.07 (Baseline)		6.6.07		21.7.07	
		SWL (m)	Elev. (m AHD)	SWL (m)	Elev. (m AHD)	SWL (m)	Elev. (m AHD)
GM1	Porphyry	Collapsed					
GM2	Porphyry	14.08	643.4	15.07	642.43		
GM3	Porphyry	18.10	634.2	17.84	634.46		
GM4	Porphyry	10.36	645.0	11.12	644.28		
GM5	Porphyry	15.78	635.0	15.38	635.42	15.38	635.42
GM6	Porphyry	21.10	636.3	20.96	636.44	21.04	636.36
GM7	Porphyry	18.70	639.2	18.78	639.12		
GM8	Porphyry	7.30	653.4	dry		dry	
GM9	Porphyry	17.05	644.9	16.92	644.98		
GM10	Porphyry	Collapsed					
GM11	Porphyry	19.10	643.7	18.68	644.12	17.99	644.81
GM12	Porphyry	13.60	651.9	15.57	649.93		
GM13	Porphyry	11.34	653.9	12.10	653.10	11.04	654.16
GM14	Porphyry	Collapsed					
GM15	Porphyry	8.40	651.6	8.60	651.40		
GM16	Porphyry	3.40	653.3	3.55	653.15		
GM17	Porphyry	8.10	650.7	8.30	650.50		
GM18	Porphyry	10.50	651.5	10.22	651.78	9.76	652.24
GM19	Porphyry	2.10	655.5	3.58	654.02		
GM20	Porphyry	12.84	646.9	13.00	646.70		
GM21	Porphyry	14.55	645.9	15.31	645.09	11.68	648.72
GM22	Porphyry	5.00	645.1	4.93	645.17	4.62	645.48
GM23	Porphyry	6.00	652.9	6.00	652.90		
GM24	Porphyry	7.50	652.4	7.52	652.38	6.89	653.01
GM25	Porphyry	Collapsed					
GM26	Porphyry	17.30	645.2	17.35	645.15		
GM27	Porphyry	17.20	649.0	Collapsed			
GM28	Porphyry	Collapsed					
GM29	Porphyry	11.08	653.4	11.20	653.30		
GM30	Porphyry	7.15	653.5	7.30	653.30		
GM31	Porphyry	7.70	653.9	7.77	653.83		
GM32	Porphyry	Collapsed					
GM33	Porphyry	11.33	653.6	11.30	653.60		
GM34	Porphyry	16.95	648.0	17.09	647.81		
GM35	Porphyry	15.10	649.8	15.11	649.79	12.13	652.77
GM36	Porphyry	12.00	654.6	11.71	654.89	7.42	659.18
GM37	Porphyry	13.18	653.0	13.78	652.42		
GM38	Porphyry	10.81	651.5	10.88	651.42		
GM39	Porphyry	13.17	653.8	14.00	653.00		
GM40	Porphyry	12.51	658.0	12.50	658.00		
GM41	Porphyry	Collapsed					
GM42	Porphyry	11.80	657.7	11.90	657.60		

Note: Water Level Measurements are manual measurements taken from Ground Level
Porphyry is Barralier Ignimbrite

A review of the fluctuations in the piezometric surface measured in the monitoring bores between the period 7th June and 21st July 2007 reveals a positive correlation between the observed rises in the piezometric surface and the main rainfall events recorded in the wider district. Although the piezometric surface measured in bores GM5, GM6 and GM18 reveals very little change during the period, there is nevertheless a subtle and measurable positive correlation with district rainfall events. It is noted that the majority of the main rises in the piezometric surface generally correspond to the peak rainfall events recorded in Goulburn approximately 24km to the west. Secondary peaks in the hydrographs reveal the temporal variation in the distribution and intensity of the events expected in the district.

This district variation in rainfall is demonstrated by a rise in the piezometric surface in the monitoring bores on 9th July 2007, particularly in Monitoring Bore GM21. This rise coincides with a small (2.2mm) rainfall event in Goulburn on 8th July. Clearly there was a significant local rainfall event at about this time. It is also noted that Monitoring Bore GM21 is the only bore that clearly responds to several relatively smaller rainfall events in the local area.

It is difficult to quantify the time lag between the rainfall events and recharge into the shallow part of the porphyry-hosted aquifer system because the rainfall data is from Goulburn, the nearest official weather station. Nevertheless, the hydrographs for at least four of the monitoring bores (GM11, GM103, GM21 and GM35) indicate that the relatively shallow aquifer response to a recharge event is relatively rapid.

These recharge responses appear to conflict with the very low to low permeabilities estimated from hydraulic conductivity testing in the same monitoring bores (see Section 9) and the geological evidence of fine fractures, joints and veins in drill core, and in outcrop. However, although the collars of the monitoring bores were effectively sealed and do not permit any direct rainfall infiltration into the bore, the apparent rapid response to recharge in Bores GM11, GM103, GM21 and GM35 is likely due to infiltration into the open monitoring bores through the relatively weathered vadose zone.

That is, the results of the permeability testing are valid for the fractured porphyry aquifer and the hydrographs reflect the use of existing open resource bores for monitoring bores. This conclusion is supported by the shape of the hydrographs, for example bores GM11, 21 and 35. The segments of the hydrographs following a recharge event resemble recession curves or more appropriately the response from a falling head slug test in a low permeability aquifer.

9.0 AQUIFER TESTING

9.1 Introduction

An attempt was made to carry out short-term pumping tests in the 10 representative monitoring bores in order to establish a set of representative aquifer parameters including hydraulic conductivity and transmissivity. However, none of the monitoring bores could sustain pumping beyond between about several seconds and several minutes. The recovery of the water level in the majority of monitoring bores was almost non-existent to very slow due to the very low permeability of the porphyry host rock.

Dedicated ‘slug’ tests were then designed and performed in the same 10 monitoring bores to measure hydraulic conductivity.

9.2 Methodology

A pressure transducer was first installed at the base of the selected monitoring bore to measure and record water level fluctuations. The logger was programmed to measure the water level at the frequency of one reading per second.

The ‘slug’ test was performed by lowering a ‘slug’ into the water column. The displacement caused the water level to initially rise in the bore. The ‘slug’ was then rapidly removed. The slug and pressure transducer were removed from the bore following the second test once the water surface from the first test either returned to its pre-test level or reached a pseudo steady state level. In this way, two permeability tests could be performed in each bore. The first test is a ‘falling head’ test and the second a ‘rising head’ test. The results from each test were then compared and a representative global estimate of hydraulic conductivity (K) in this part of the aquifer system calculated and a global Transmissivity (T) and Storativity (S_o) estimated.

9.3 Slug Test Results

Analysis of the slug test results was carried out using aquifer models developed by Hvorslev (1951), Bower and Rice (1976), Cooper et.al (1967) and KGS (1994). Aquifer parameters calculated and estimated from the slug tests are summarised in **Table 7**. The range of aquifer parameters for each bore and the adopted figures used in the assessment of potential impacts are listed in **Table 8.** Slug test charts for each monitoring bore tested are provided in **Appendix C**.

The results indicate low to very low rock permeabilities with the majority of tests revealing hydraulic conductivities of less than about 0.04m/day and transmissivities of less than approximately 0.6m^2/day.

The paucity of district stock and irrigation bores and the low yields recorded in the relatively successful test bores supports the thesis of generally low rock permeabilities. This suggests that the bores may have intersected unfractured porphyry or the geological discontinuities intersected in the bore are relatively ‘tight’. This also indicates that the last major tectonic activity in the region was largely compressive (‘closed’) rather than extensional (‘open’). The results of regional geological mapping in the district and region by state government geologists supports this thesis with the existence of an extensive network of northerly-trending and westerly dipping thrust faults (**Figure 4**).

Geological mapping over the Project Site revealed ‘tight’ fractures and joints in outcrop and networks of fine fractures and veins in drill core. This evidence supports the findings of low permeability materials.

The common occurrence of moderate to high salinity levels recorded in district water bores and in the network of monitoring bores on the Project Site documented in Section 10 may also indicate low rock permeabilities.

Table 7
Summary Details and Results of Hydraulic (Slug) Testing

Monitoring Bore	Screened Interval	Host Geology	Test Date	Hvorslev Model (1951)			Bower and Rice Model (1976)			Cooper et.al Model (1964)			KGS Model (1994)		
				K (m/day)	T (m^2/day)	S_o	K (m/day)	T (m^2/day)	S_o	K (m/day)	T (m^2/day)	S_o	K (m/day)	T (m^2/day)	S_o
GM5	Open hole	Bindook Porphyry	22.6.07	0.7766	5.0634	5×10^{-4}	0.5275	3.4393	5×10^{-4}	0.8244	5.3750	6.4×10^{-4}	0.8235	5.3692	5×10^{-4}
GM6	Open hole	Bindook Porphyry	22.6.07	Test abandoned. Slug stuck in bore.											
GM11	Open hole	Bindook Porphyry	22.6.07	0.0298	0.3320	1×10^{-4}	0.02097	0.2334	1×10^{-4}	0.0043	0.0483	1×10^{-4}	0.0048	0.0532	1×10^{-4}
GM13	Open hole	Bindook Porphyry	22.6.07	0.0437	0.1692	5×10^{-4}	0.0287	0.1112	1×10^{-4}	0.0061	0.0235	1×10^{-4}	0.0061	0.0235	1×10^{-4}
GM18	Open hole	Bindook Porphyry	22.6.07	Test abandoned. Bore partially blocked.											
GM21	Open hole	Bindook Porphyry	22.6.07	0.0299	0.2934	1×10^{-4}	0.0205	0.2005	5×10^{-4}	0.0088	0.0859	1×10^{-4}	0.0180	0.1766	1×10^{-4}
GM22	Open hole	Bindook Porphyry	22.6.07	0.7743	2.8194	5×10^{-4}	0.4155	1.5272	5×10^{-4}	0.6372	2.3450	5×10^{-4}	0.6372	2.3449	5×10^{-4}
GM24	Open hole	Bindook Porphyry	22.6.07	0.0446	0.6054	1×10^{-4}	0.0328	0.4448	1×10^{-4}	0.0044	0.0603	1×10^{-4}	0.0044	0.0568	1×10^{-4}
GM35	Open hole	Bindook Porphyry	22.6.07	0.0161	0.2762	1×10^{-4}	0.0124	0.2136	1×10^{-4}	0.0012	0.0200	1×10^{-4}	0.0014	0.0234	1×10^{-4}
GM36	Open hole	Bindook Porphyry	22.6.07	0.0101	0.1207	1×10^{-4}	0.0072	0.0862	1×10^{-4}	0.0010	0.0124	1×10^{-4}	0.0010	0.0124	1×10^{-4}

Notes:

Parameter		*Unit*	
K:	Hydraulic Conductivity	m/day	(metres per day)
T:	Transmissivity	m^2/day	(metres squared per day)
S_o:	Storativity (Storage Coefficient)	dimensionless	

Table 8
Range of Aquifer Parameters

Monitoring Bore	Hydraulic Conductivity K (m/day)		Transmissivity T (m^2/day)		Storativity S_o		Adopted Parameters for the Assessment of Potential Impacts		
	Min.	Max.	Min.	Max.	Min.	Max.	K (m/day)	T (m^2/day)	S_o
GM5	0.5275	0.8244	3.4393	5.3750	5×10^{-4}	6.4×10^{-4}	0.82	5.38	5×10^{-4}
GM11	0.0043	0.0298	0.0483	0.3320	1×10^{-4}	1×10^{-4}	0.03	0.33	1×10^{-4}
GM13	0.0061	0.0437	0.0235	0.1692	1×10^{-4}	1×10^{-4}	0.04	0.17	1×10^{-4}
GM21	0.0088	0.0299	0.0859	0.2934	1×10^{-4}	1×10^{-4}	0.03	0.30	1×10^{-4}
GM22	0.4155	0.7743	1.5272	2.8194	5×10^{-4}	5×10^{-4}	0.77	2.82	5×10^{-4}
GM24	0.0044	0.0446	0.0568	0.6054	1×10^{-4}	1×10^{-4}	0.05	0.61	1×10^{-4}
GM35	0.0012	0.0161	0.0200	0.2762	1×10^{-4}	1×10^{-4}	0.02	0.28	1×10^{-4}
GM36	0.0010	0.0101	0.0124	0.1207	1×10^{-4}	1×10^{-4}	0.01	0.12	1×10^{-4}

10.0 WATER QUALITY TESTING

Baseline groundwater sampling and water quality testing was carried out in early 2007. The objective of the sampling and testing is to establish a preliminary baseline set of water quality data for the known 'hardrock' aquifer/s prior to quarry development.

10.1 Objective and Methodology

Sampling was conducted using latex disposable gloves and samples stored in laboratory-supplied plastic bottles and chilled in an esky. The samples were submitted to *Sydney Analytical Laboratories* at Seven Hills for a suite of tests and determinations in order to characterise the chemistry of the groundwater.

A register of groundwater samples collected is provided in **Table 9**.

Field measurements of pH and EC were undertaken on all samples. Samples were submitted for a suite of analytes and tests as listed in **Table 10**.

10.2 Analytical Results

The analytical results are summarised in **Table 11**. The laboratory certificate and Chain of Custody documentation is provided in **Appendix D**.

In summary,

- The pH of the groundwater samples measured in the laboratory are all similar. The pH ranges from 6.7 in Bores GM5 and GM6 to 7.3 in Bore GM36. This indicates that the groundwater is near neutral which reflects the composition of the porphyry host rock.
- Laboratory measurements of EC reveal that the groundwater in all bores is moderately to highly saline with measurements ranging from 720 uS/cm in Bore GM36 to 7210 uS/cm in

Bore GM18. This is believed to reflect the mineral composition of the porphyry. The EC levels are reflected in the elevated concentrations of chloride and sodium.

Table 9
Register of Groundwater Samples

Sample No.	Bore	Sample Type	Sample Date
GM5	GM5	Primary	11.5.07
GM6	GM6	Primary	11.5.07
GM11	GM11	Primary	11.5.07
GM13	GM13	Primary	11.5.07
GM18	GM18	Primary	11.5.07
GM21	GM21	Primary	11.5.07
GM22	GM22	Primary	11.5.07
GM24	GM24	Primary	11.5.07
GM35	GM35	Primary	11.5.07
GM36	GM36	Primary	11.5.07
GMDup1	GM24	Duplicate of GM24	11.5.07
GMB	nil	Blank - Ultra-distilled water	11.5.07

Note: See **Table 5** for bore details and **Figure 8** for the locations of the bores

- Concentrations of ammonia were detected in all but one sample. The levels were generally low with the highest concentration (4.5mg/L) recorded in sample GM15 collected from Bore GM15.
- Concentrations of other cations (Ca, K and Mg) were unremarkable. The elevated calcium and magnesium levels suggest that the groundwater is ‘hard’.
- Sulphate concentrations were generally low with the highest level recorded in Bore GM13 (44mg/L).
- Elevated levels of bicarbonate were recorded in all bores with the highest concentration recorded in Bore GM6 (760mg/L). This is not unexpected in groundwater hosted by igneous rock complexes of this composition.
- Concentrations of Nitrate were generally low to slightly elevated. The exception is a high level of 40mg/L recorded in Bore GM21. The presence of highly water-soluble nitrate in groundwater is usually associated with past agricultural activities (e.g. fertilizers).
- Concentrations of Nitrite were generally low to slightly elevated and generally lower than the nitrate levels for the same samples.

Table 10 List of Baseline Analytes and Tests	
Tests	***Metals***
pH	Copper (Cu)
Electrical Conductivity (EC)	Lead (Pb)
	Zinc (Zn)
Cations	Total Iron (Fe)
Sodium (Na)	Dissolved Iron (Fe)
Calcium (Ca)	Cadmium (Cd)
Potassium (K)	Chromium (Cr)
Magnesium (Mg)	Nickel (Ni)
Ammonia (NH4-N)	Mercury (Hg)
	Arsenic (As)
Anions	
Chloride (Cl)	
Sulphate (SO4)	
Bicarbonate Alkalinity (as CaCO3)	
Carbonate Alkalinity (as CaCO3)	
Nitrate (NO3-N)	
Nitrite (NO2-N)	
Phosphate (PO4)	
Total Alkalinity (as CaCO3)	
Total Phosphorus (Total P)	
Hardness as CaCO3	

- Phosphate was detected at trace levels in 9 of the 10 groundwater samples. The highest concentration of 0.06mg/L was recorded in Bore GM5. The presence of nutrients such as nitrate and phosphate in groundwater is usually associated with past agricultural activities. These results indicate that there is minor contamination of the groundwater system.
- Total phosphorus was detected in all groundwater samples. The highest concentration of 4.0mg/L was recorded in Bore GM18.
- Dissolved iron was detected at trace levels in five of the ten samples. The exception is Sample GM36 which returned a concentration of 0.69mg/L. This level may cause staining of fixtures and may cause deposits to form in irrigation equipment. Iron (and manganese) can be satisfactorily managed by aeration and other readily available methods if required.
- Trace concentrations of copper and zinc were recorded in all 10 samples. All other metal concentrations with the exception of Total Iron were less than the Method Detection Limit (MDL).

Table 11 Summary of Water Quality Analytical Results

SAMPLE		Guidelines			Method Detection Limit (MDL)	GM5	GM6	GM11	GM13	GM18	GM21	GM22	GM24	GM35	GM36	GM DUP1	GM BLANK	Lab Duplicate
DESCRIPTION		Drinking Water Guidelines [1]		Trigger Value for the Protection of Freshwater Aquatic Ecosystems [2]		Monitoring Bore	Monitoring Bore	Monitoring Bore	Monitoring Bore	Monitoring Bore	Monitoring Bore	Monitoring Bore	Monitoring Bore	Monitoring Bore	Monitoring Bore	Monitoring Bore	Monitoring Bore	GM18 DUP
DATE						Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07
ANALYTE	UNIT	Health Based	Aesthetic Based															
pH (lab)	pH Units	ISD	6.5-8.5		0.1	6.7	6.7	6.8	6.8	6.9	6.8	6.8	6.9	6.8	7.3	6.8	6.9	6.9
Electrical Conductivity (lab)	µS/cm				0.1	4100	6590	2560	1300	7210	1090	2750	0880	6200	0720	0880	1.2	7120
Cations																		
Sodium Na+	mg/L		180		0.1	320	520	300	145	575	60	280	120	460	130	110	<0.1	585
Calcium Ca++	mg/L				0.1	280	500	130	85	530	73	160	45	500	17	45	<0.1	540
Potassium K+	mg/L				0.1	13	18	11	7.6	16	8.6	6.6	6.8	12	2.5	7.0	<0.1	16
Magnesium Mg++	mg/L				0.1	245	435	140	49	410	94	140	35	335	17	34	<0.1	400
Ammonia NH4-N	mg/L	ISD	0.41	0.9	0.1	4.5	0.8	2.2	0.5	1.4	1.4	0.8	0.2	0.2	<0.1	0.2	<0.1	1.4
TOTAL CATIONS						48.710	83.889	31.498	14.813	85.713	14.309	31.912	10.535	72.852	7.966	10.022		85.824
Anions																		
Chloride Cl-	mg/L	250			1	1420	2540	710	250	2620	330	910	250	2210	110	240	<1	2590
Sulphate SO4--	mg/L	500	250		2	19	34	9	44	22	9	3	5	20	14	5	<2	22
Bicarbonate HCO3-	mg/L				1	560	760	710	430	740	240	350	220	670	290	210	<1	740
Carbonate CO3--	mg/L				1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrate NO3-N	mg/L	50		0.7	0.01	0.58	3.5	<0.1	7.1	3.2	40	0.31	0.22	2.4	1.1	0.27	<0.1	3.2
Nitrite NO2-N	mg/L	3			0.01	0.10	0.13	<0.1	0.13	0.33	4.5	0.33	<0.1	0.13	0.10	<0.1	<0.1	0.36
Phosphate PO4-P	mg/L				0.01	0.06	0.02	0.04	0.02	0.02	0.05	0.01	0.01	<0.01	0.04	0.01	<0.01	0.02
TOTAL ANIONS						49.640	84.860	31.857	15.136	86.539	14.176	31.477	10.767	73.768	8.173	10.321		85.694
Total Phosphorus	mg/L				0.1	1.2	2.0	0.85	0.33	4.0	0.21	0.49	0.76	0.73	0.46	0.84	<0.1	3.9
Copper (Cu)	mg/L	2	1	0.0014	0.001	0.002	0.002	0.001	0.003	0.002	0.002	0.001	0.002	0.002	0.001	0.001	<0.001	0.002
Lead (Pb)	mg/L	0.01		0.0034	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc (Zn)	mg/L	ISD	3	0.008	0.001	0.011	0.005	0.010	0.009	0.005	0.011	0.006	0.005	0.002	0.003	0.004	<0.001	0.006
Cadmium (Cd)	mg/L	0.002		0.0002	0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Chromium (Cr)	mg/L	05 as CrVI		0.001	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nickel (Ni)	mg/L	0.02		0.011	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total Iron (Fe)	mg/L				0.1	41	35	34	16	45	8.4	14	43	61	82	45	<0.01	43
Dissolved Iron (Fe)	mg/L	ISD	0.3	ISD	0.01	<0.01	<0.01	0.05	0.02	<0.01	0.01	<0.01	0.02	<0.01	0.69	0.02	<0.01	<0.01
Arsenic (As)	mg/L	0.007		0.013	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mercury (Mg)	mg/L	0.001		0.00006	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[1] **Drinking Water Guidelines**: ANZECC, 1996 and National Water Quality Management Strategy 2004

note : ISD denotes insufficient data to set a guideline value based on health considerations

[2] **Protection of Freshwater Aquatic Ecosystems** (ANZECC 2000)

10.3 Hydrochemical Classification

The major ion proportions are plotted on a Piper diagram (trilinear plot) in order to characterise the chemistry of the groundwater. The plot is shown in **Figure 11**.

The ion proportions for the ten groundwater samples indicate that the groundwater is grouped into at least three main clusters. This suggests that groundwater is likely evolving along joint and fracture-controlled flow paths within the porphyry host rock. Samples with higher salinity (higher TDS and EC) tend to be clustered in the upper part of the diamond field which reflects the increased proportion of chloride in the samples. The chemistry of four of these highly saline samples (GM5, GM6, GM18 and GM35), their ion proportions and the mineralogy of the geological host is consistent with the geochemistry expected at the discharge end of the hydrogeochemical cycle.

In contrast, the chemistry and ion proportions for Sample GM36 collected in the southern more elevated part of the Project Site may reflect the geochemistry expected close to a recharge part of the hydrogeochemical cycle.

The chemistry and ion proportions for samples GM11, GM13 and GM24 appear to fall somewhere between the geochemistry expected for discharge and recharge areas.

The geochemical facies is largely determined by lithologies (host rocks), groundwater hydraulics (flow patterns) in the aquifer and solution kinetics. The possible evolution in groundwater chemistry from recharge parts of the geochemical cycle through to discharge zones as suggested in the diamond field on the Piper plot is also indicated in the anion and cation fields. In summary, although several samples have no dominant cation type, the groundwater appears to evolve along flow paths from sodium bicarbonate type through mainly sodium chloride type to possibly magnesium chloride type. These data also suggest that mixing of groundwater along flow paths is likely. The interpreted geochemical classification is listed in **Table 12**. The groundwater chemistry and geochemical classifications are consistent with water quality testing in samples collected by others from the Bindook Porphyry in the district.

Although the Piper plot suggests that geochemical evolution is occurring along flow paths, the three-dimensional geometry is clearly complex. This thesis is supported by the predicted existence of anisotropic hydrogeological conditions in the porphyry-hosted fractured aquifer.

A set of five chemical ratio plots was constructed for the groundwater samples. The plots are shown in **Figures 12 and 13** and also suggest that chemical evolution of the groundwater is occurring along flow paths. This is consistent with the interpretation of evolving chemistry along fracture-controlled flow paths interpreted from the piper diagram.

Table 12 Geochemical Classification	
Bore	**Classification**
GM5	Magnesium Chloride*
GM6	Magnesium Chloride*
GM11	Sodium Chloride*
GM13	Sodium Chloride*
GM18	Magnesium Chloride*
GM21	Magnesium Chloride
GM22	Magnesium Chloride*
GM24	Sodium Chloride*
GM35	Magnesium Chloride*
GM36	Sodium Bicarbonate

Note: * denotes no dominant cation type

11.0 PROXIMAL SPRING SYSTEMS

This section provides a more detailed description of Spring 6, the small-scale 'spring' immediately west of, and in relative close proximity to the Project Site. The location of the spring is shown in **Figure 7**. This water feature and any groundwater dependant ecosystem (GDE) that may be associated with it are considered to represent the highest risk of any potential significant impact from the quarry development.

The following points summarise the geological and hydrogeological setting of Spring 6.

- The position of the spring, the nature of the topography near the Project Site and distribution of the northerly trending basement igneous rocks in this area indicates that the spring is likely associated with a sub-vertical geological discontinuity such as a major joint or fracture, or a network of closely spaced sub-parallel joints or fractures.
- The groundwater discharge appears to be at least in part associated with the linear part of the creek upon which the dam has been constructed.
- The elevation of the spring is estimated to be approximately 650m AHD.

12.0 ASSESSMENT OF POTENTIAL IMPACTS

12.1 Introduction

There are considered to be four potential groundwater-related impacts associated with the proposed quarry development. This section identifies the potential impacts and provides an assessment of risk associated with each. The identified risks are listed below and discussed in the following sections.

- Potential impact of the proposed extraction on any groundwater dependant ecosystems (GDEs).
- Potential impact associated with the extraction of porphyry on the local and district water table, on underlying 'hardrock' aquifer systems and on any groundwater users. This includes the potential for impact on groundwater chemistry.
- Potential cumulative groundwater impact from the proposed quarry and other quarries in the district.
- Potential impact associated with the possible generation of acid mine leachate.

12.2 30-Year Quarry Plan

The quarry operations will commence in the north of the Project Site and migrate to the south and south-east. For the purposes of assessment, the proposed quarry development has been divided into five main stages which are listed in **Table 13**. The quarry footprints for each of the stages are shown in **Figures 14, 15, 16, 17 and 18**. Pre-development (baseline) contours of the elevation of the groundwater surface and interpreted direction of groundwater flow are also shown.

Table 13
Proposed Stages of Quarry Operations

Stage	Years	Approx. Depth to Quarry Floor BGL (m)	Quarry Floor Elevation (m AHD)
1	0-1	13m	647
2	1-2	13m	647
3	2-5	39m in north 26m in south	621m in north 634m in south
4	5-20	65m	595
5	20-30	78m	582

Note: BGL denotes **B**elow **G**round **L**evel
AHD denotes **A**ustralian **H**eight **D**atum

12.3 Potential Impact of Proposed Quarry Operations on any Groundwater Dependant Ecosystems

A series of 'water features' which are essentially areas of shallow groundwater discharge have been identified in the local area surrounding the Project Site. The location of the closest water feature that is considered significant in terms of potential impact (Spring 6) is shown in **Figure 7**, listed in **Table 4** and described in Section 5.5.

Spring 6 is located approximately 200m west of the proposed quarry. An assessment of the potential impact on Spring 6 and the other springs identified on aerial photos in the local area are described in sections 12.3.1 and 12.3.2

12.3.1 Spring 6

The principle reasons for the assessment of any potential impact of porphyry extraction on Spring 6 are:

- The spring is in relative close proximity to the proposed quarry.
- The spring is interpreted to discharge from a sub-vertical fracture at elevation 650m AHD.
- The spring provides a small but beneficial water supply for the suspected GDE that has formed by the construction of a small-scale on-line storage (farm dam).

The scientific evidence indicates that the artificial ponding downstream of Spring 6 may be largely perched and the groundwater discharging from Spring 6 may not be in direct hydraulic connection with the porphyry aquifer that will at least in part be intercepted by the proposed quarry.

Interpretation of aerial photos indicates the existence of three lineaments in the vicinity of the discharge area (**Figure 7**). It is considered that the north-northeast lineament is the dominant structure and possibly the main controlling feature for the spring. This lineament is in close proximity and broadly sub-parallel to the western limit of the quarry. This sub-vertical fracture will not be intercepted by the quarry at any time during its planned 30-year quarry life. The implication is that although this controlling structure is not directly impacted by the quarry, there may be indirect hydraulic connection within a fracture/joint network that may be exposed during quarrying.

It is noted that the likely source of groundwater feeding this spring is upgradient of the proposed quarry and will in all probability not be significantly affected by the operations.

Nevertheless, it is possible that the groundwater gradient and direction of flow close to the spring may be influenced by the artificial steepening associated with the progressive westerly advance of the western batters of the quarry.

The degree of encroachment is difficult to quantify but the results of the permeability testing indicate very low hydraulic conductivities throughout the porphyry. Numerical groundwater modelling would be required to quantify the potential impacts.

The assessment of potential impact takes into account the predicted permanent change in hydrogeological conditions in close proximity to the porphyry extraction that may cause an impact on water table levels near Spring 6 in the global confined porphyry aquifer possibly resulting in a small decrease of discharge flows in Spring 6. Although the geometry of the geological and hydrogeological system is imperfectly understood, it is concluded that based on the available scientific evidence, it is unlikely that the proposed quarry will have any significant impact on the local or district water table and therefore on any spring flows. Nevertheless, a long-term program of flow and water quality monitoring of Spring 6 will be implemented to detect any changes if they occur. A program of monitoring is presented in Section 14.0.

The identification and significance of any on-site and off-site GDE associated with this spring or other springs in the immediate area has been assessed by the specialist fauna and flora consultants as part of the EA.

It is noted that in the event of an impact from proposed quarrying on the Spring 6 dam ecological community, a set of mitigation measures has been developed and documented in Section 17.2. It is noted that the development of an additional set of mitigation measures may be required depending on the findings of the specialist's fauna and flora assessment.

The planned staged extraction of porphyry may lead to localised minor changes in groundwater quality due to small physico-chemical changes that may result from localised groundwater mixing, chemical equilibration and possible increased exposure to the atmosphere. Apart from possible precipitation of some metal species (if they exist) and a possible local increase in dissolved oxygen levels there would be no mixing of surface runoff outside the quarry water and groundwater inflow. It is therefore considered unlikely that proposed quarrying will have any significant impact on the water quality. A long-term program of water quality monitoring in the monitoring wells will continue in order to detect any changes if they occur.

The chemistry of groundwater inflow and possible chemical changes within the quarry are further discussed in Section 12.4.1.

The potential for contamination of the groundwater system is largely related to hydrocarbon contamination that may occur from leaks from quarry machinery entering the excavation site. This potential problem can be effectively managed by the implementation of 'good' maintenance practice and the utilisation of machines in 'good' condition.

12.3.2 Springs 1, 2, 3, 4, 5, 7, 8 and 9

The springs in the district surrounding the Project Site are described in Section 5.5. The majority of the spring systems are considered to be at a distance from the proposed development such that the planned staged extraction of porphyry would not adversely impact on them. The distances of the springs from the proposed extraction areas are listed in **Table 14**.

Table 14 Distance Between Known Springs and Proposed Porphyry Extraction Area		
Spring	**Relative Hydrogeological Position to Quarry**	**Approximate Distance from Proposed Quarry (m)**
1	Downgradient	1400
2	Downgradient	1400
3	Downgradient	1400
4	Sidegradient	1000
5	Upgradient	1500
6	Sidegradient	200
7	Sidegradient	450
8	Sidegradient	600
9	Downgradient	1100

12.4 Potential Impact of Proposed Quarry Operations on the ’Hardrock’ and ‘Alluvial’ Groundwater Systems, and other Groundwater Users

12.4.1 ’Hardrock’ Aquifers

The very low hydraulic conductivities measured in the porphyry indicate that the proposed extraction would not adversely impact on the district groundwater system in the area. However, the proposed staged extraction of porphyry has the potential of altering hydrogeological conditions in close proximity to the void at the end of Year 30 will be permanently altered. The changed hydrogeological conditions are predicted to be peripheral to the void and confined to a zone extending to no more than about 100 to 200m from the quarry. The newly established hydraulic gradient surrounding the void may potentially impact on Spring 6.

The proposed porphyry extraction method will from time to time incorporate dewatering of excavation areas in order to maintain relatively dry working conditions. A sump system will be developed in the pit and a program implemented for the recycling of water for dust suppression and processing operations, and if required, the transfer of any excess pit water to a detention pond/s elsewhere on the Project Site designed by the surface water consultants.

However, the district evaporation rate documented in Section 5.4 indicates that the amount of water evaporated from the pit floor will greatly exceed the estimated rate of groundwater inflow into the quarry at any stage. For example, in Year 30, evaporation would potentially remove approximately 29.6ML of water from the pit; about 10 times the estimated annual groundwater inflow volume.

The implication is that it is unlikely that significant ponding will occur in the quarry. That is, the amount of groundwater inflow will be offset by evaporation. The exception is water ingress from intense rainfall events, in particular storms, that may temporarily and sometimes significantly increase the volume of sump water. This temporarily detained water will dissipate naturally as a result of evaporation and infiltration into the groundwater system. The demonstrated very low rock permeabilities and relatively high evaporation rates which markedly exceed groundwater inflows indicate that the water table will remain beneath the void. That is, the quarry is a ‘groundwater sink’.

Small volumes of groundwater may also be removed from the excavation during the removal process. It would be expected that the large proportion of any adsorbed water would drain from the excavated material prior to loading into trucks.

baseline groundwater sampling carried out in the monitoring bores. Although evaporation may result in increasing salinity levels of the sump water, this is not expected to be a potentially adverse environmental issue because of the predicted very low volumes of inflow and the unlikely requirement to transfer any detained water from the quarry to outside detention ponds.

In the event that rainfall events, in particular storms, may contribute relatively high volumes of recharge into the quarry in the short term, the overall chemistry of the temporarily detained water would be improved and not constitute an impact if transferred to detention ponds.

12.4.2 ‘Alluvial’ Aquifers

The results of field observations and the results of earlier exploration and resource drilling indicate the existence of a poorly developed alluvial system associated with the upper reaches of Chapmans Creek to the west of the proposed quarry footprint. The amount of water stored in the thin (0.1 to 2.5m) alluvium is predicted to be low and highly dependant on rainfall. In this regard, the storage in the alluvial system is predicted to be low and the quarry operations are not expected to impact on this poorly developed system.

The exception is the small-scale development of creek alluvium associated with Spring 6 proximal to, and directly upstream of associated with the small farm dam on Chapmans Creek. A large proportion of this part of the alluvium is likely saturated because of the detention storage in the dam and the occurrence of the spring system. However, long-term monitoring of the water table will be carried out as prescribed in Section 14.0 in order to monitor any potential impacts from quarrying.

12.4.3 Other Groundwater Users

The interrogation of the DWE groundwater works database for surrounding water users revealed five registered bores of which two (GW010600 and GW015362) do not appear to exist in this area. The closest neighbouring registered bore (GW056376) is located near the Brayton Road approximately 1500m east-southeast of the proposed eastern side of the final 30-year quarry footprint (**Figure 6**). This bore is approximately 51.0m in depth, licensed for stock use and extracts a low flow (0.2L/s) of groundwater from between 22.0 and 23.0m-depth.

The potential for significant impact from the proposed mining on any other water users surrounding the Project Site is considered to be very low. This prediction is based on the large separation distance between the nearest bore GW056376 and other bores, and the proposed quarry, and the low permeability values recorded for the porphyry mass in the Project Site. This prediction is supported by the occurrence of low yields in the three surrounding registered bores which indicates low rock permeabilities. The paucity of registered bores in the local area may indicate that past groundwater exploration has not been particularly successful: perhaps a further indication of low rock permeabilities.

12.5 Potential Cumulative Impact

The Gunlake Quarry is one of three proposed and operational quarries in the immediate district north of Marulan. The other developments are the *Lynwood* and *Johnniefelds* operations. All three extractive operations are hosted by the Bindook Porphyry.

The demonstrable very low to low permeabilities of the Bindook Porphryry indicate that any impact on the porphyry-hosted groundwater system appear to be confined to the local scale at each of the *Lynwood* and *Johnniefelds* quarry operations and is predicted to be similarly confined close to the proposed Gunlake Quarry limits.

Predictions of drawdown on the northern side of the *Lynwood* quarry towards the Gunlake Quarry as shown in the Groundwater Assessment for the Proposed Lynwood Quarry Environmental Impact Assessment (Appendix 9) area do not extend more than about 500m beyond the northern boundary.

The approximate distances between the quarry developments are as follows:

Approximate Distances Between Quarries (km)			
	Gunlake	Johnniefelds	Lynwood
Gunlake	-	1.8	2.9
Johnniefelds	1.8	-	3.2
Lynwood	2.9	3.2	-

It is concluded that based on the available geological and hydrogeological evidence and data, in particular the separation distances between the quarries and demonstrated low rock permeabilities, there are <u>no</u> predicted cumulative impacts.

12.6 Potential Acid Mine Leachate

The issue of potential impact from any acid mine leachate from the proposed quarrying operations has been raised by the Department of Environment and Climate Change (DECC). The DEC require demonstration "*that acid mine leachate will not occur from the site*" (the Project Site). The DEC note that "*acid producing ore has caused problems in other quarries in the region*".

Acid mine leachate relates to the production of low pH water usually associated with the oxidation of metallic sulphide minerals in particular pyrite (iron sulphide) when the minerals are exposed to the atmosphere during quarrying (excavation and dewatering). The breakdown of pyrite in the presence of oxygen and water effectively produces sulphuric acid which can dissolve other metals and produce a relatively toxic solution.

It is our view that the potential for the production of acid leachate from the proposed quarrying operations is very low. The basis for this conclusion is that the ingredients for acid mine leachate do not exist. Rock quality testing reported by *Valerie Smith & Associates* did not record the presence of any disseminated or vein pyrite or other metal sulphide mineralisation within the porphyry samples inspected. The pH of the groundwater sampled from the monitoring bores is near neutral with samples recording measurements between 6.7 and 7.3.

13.0 INFLOW OF GROUNDWATER INTO EXCAVATION

The factors affecting the rate of inflow of groundwater into an excavation are the size, shape, location, rate of excavating and hydrogeologic properties of the host rock. The rate of inflow of groundwater into the progressively expanding excavation on the Project Site is also controlled by local geologic and structural elements.

Although a quarry constructed in the low-permeability porphyry host rock in the Project Site is expected to have little inflow, the rock defects (secondary openings) such as fractures increases the inflow potential. That is, the inflows associated with the porphyry depend on the geometry and degree of fracturing, degree of fracture dilation, on their continuity and on the hydraulic connectivity between fractures.

As the excavation intercepts the piezometric surface, hydraulic gradients will begin to slope toward the excavation, inducing flow towards the quarry. A seepage face will develop on the walls of the excavation. That is, dewatering of the excavation will effectively lower the groundwater levels in the ‘hardrock’ aquifer proximal to the pit and reduce the pore pressures on the quarry walls which, in some rocktypes, can improve slope stability.

Estimates of groundwater inflow into the quarry were calculated using a simple analytical solution developed by Ibrahim and Brutsaert in 1965 (in Domenico and Schwartz, 1990). The method predicts inflows into an excavation and projects water level declines proximal to the excavation.

The limitation of the Ibrahim and Brutsaert solution is that it is a two-dimensional homogeneous isotropic model whereas the scientific evidence for the hydrogeological setting beneath the Project Site indicates a moderate to locally high degree of anisotropy. However, although a three-dimensional steady-state numerical groundwater flow model can model certain degrees of aquifer anisotropy, the density, distribution and the geometry of the fracture network is very difficult to delineate. In addition, the inflow estimates are predicated on water level data collected during the baseline data surveys. The data to date reveals the dynamic nature of the hydrogeological system with a demonstrated range of water table fluctuations which would influence the amount of groundwater inflow into the void at any one time.

The trace of surface lineaments interpreted from aerial photos within and surrounding the Project Site as shown in **Figure 5** provide an indication of local fracture control for the aquifers but the geometry of the fracture network likely to be intercepted on the quarry scale cannot be delineated with any certainty. The implication of this is that although field tests indicate widespread low rock permeabilities, increased inflow in parts of the quarry can result if individual, narrow, relatively ‘high’ permeability fractures are intercepted.

A widely-used approach to minimise this ‘lack of data’ problem is to carry out a designed long-term pump test in a bore or bores within the proposed quarry footprint and monitor the fluctuations in the water table in strategically-positioned observation wells located within and outside the quarry area. In this way, the drawdown associated with quarrying can be simulated and modelled as a pseudo porous media.

As noted in Section 9.1, pump tests were attempted early in the investigation phase in the 10 representative monitoring bores located within the proposed quarry footprint. However, none of the monitoring bores could sustain pumping beyond between about several seconds and several minutes. The recovery of the water level in the majority of monitoring bores was almost non-existent to very slow due to the very low permeability of the porphyry host rock.

Dedicated ‘slug’ tests were then designed and performed in the same 10 monitoring bores to measure hydraulic conductivity.

It is concluded that a three-dimensional computer model may not provide more accurate estimates of inflows because of the uncertainty of the fracture geometry. As is the case with most mine developments, the actual geometry of small to medium-scale secondary defects such as joints, fractures and faults can only be determined with any accuracy during mining. An inherent problem in the computer modelling of this type of aquifer system is accurately simulating the observed aquifer head distribution. This limitation is due mainly to the anisotropic hydrogeological conditions that exist in this type of ‘hardrock’ aquifer, the very low to low rock permeabilities and the complexity of the imperfectly understood three-dimensional geometry of the fracture network. It is noted that estimates of groundwater inflow into excavations using numerical steady state groundwater computer models or even simple analytical models such as that used in these calculations can be overestimated by as much as 30%. As discussed earlier in this section, increased inflow in parts of the quarry may result if individual, relatively ‘high’ permeability fractures are intercepted.

Based on the available data, the Ibrahim and Brutsaert method is therefore considered to provide a reasonable and sensible estimate of likely groundwater inflows into the progressively expanding excavation.

Estimates of groundwater inflows for the five main mine stages are provided in **Table 15.**

For calculation purposes, the inflow estimates for each stage are based on a scenario where the pit is instantly excavated to its designed floor elevation, that is, at the end of the respective stages. The decrease in inflow volume and flow rate over time for each stage (estimated 100 to 400 days in stages 3, 4 and 5) reflects the abovementioned scenario. For this reason, the estimates for Stages 1 and 2 are likely more realistic than those listed for Stages 3, 4 and 5.

In Stages 1 and 2 (Years 1 through 2), the water table will only be intersected in the western half of the excavation and indeed not intersected until late in the respective stages. The rate of groundwater inflow is expected to be very low, consistent with the low to very low permeabilities revealed from the hydraulic conductivity testing.

The rate of excavation in Stages 3, 4 and 5 (Years 5 through 30) will be such that the water table proximal to the pit walls will gradually decrease at a rate commensurate with the rate of excavation. That is, as discussed in Section 12.4.1, progressive deepening and expansion of the cone of depression will occur around the void as quarrying progresses. In this regard, the low inflow rates estimated for each stage are considered realistic.

Table 15
Estimates of Daily Groundwater Inflow into the Proposed Quarry

Stage	Years	Aggregate Inflow (m^3/d)	Aggregate Inflow (L/s)	Aggregate Inflow (ML/year)	Comments
1	**0-1**	<1.0	<0.02	<0.3	• The water table is only intersected in the western half of the pit during Stage 1
2	**1-2**	<1.0	<.0.02	<0.4	• The quarry extends to the south at the same floor elevation as Stage 1. • The water table is only intersected in the western half during Stage 2
3	**2-5**	1.4	0.02	0.5	• The quarry extends further south and the northern half is deepened. • The water table is intersected in the western half of the southern extension. • Northern part of the quarry floor is beneath the water table
4	**5-20**	6.9	0.08	2.5	• Whole quarry floor is beneath the water table
5	**20-30**	9.6	0.11	3.5	• Whole quarry floor is beneath the water table

The cone of depression in these very low-permeability igneous rocks will be predictability narrow and steep sided, and be largely confined within close proximity to the void. Any significant groundwater interference effects from quarrying are predicted to be confined to between tens of metres and 100 to 200m of the void which is consistent with the demonstrated low rock permeabilities.

In summary, the prediction of insignificant global impacts from proposed quarrying on the district watertable is supported by:

- a compressional regional tectonic regime,
- very low to low rock permeabilities demonstrated by the results of slug tests within the proposed quarry area and the impossibility of conducting any worthwhile pumping tests combined with the occurrence of ‘tight’ fractures and joints in outcrop,
- low global rock permeability indicated by the paucity of successful water bores in the local area and high salinity levels in some of the few district ‘hardrock’ aquifers
- very low to low rock permeabilities obtained from tests carried out in the Bindook Porphyry during hydrogeological investigations as part of the EA processes at the nearby *Lynwood* and *Johnniefelds* quarries.

13.1 Proposed Staged Approach to the Assessment of any Impacts

As discussed in Section 13.0, the usefulness of a three-dimensional steady-state numerical groundwater flow model is, in our opinion compromised because the density, distribution and the geometry of the fracture network are very difficult to delineate.

Therefore, in lieu of the limited monitoring data, the inability to conduct any useful pumping tests and the imperfectly understood structural geometry of the Bindook Porphyry hostrock, a staged assessment of any impacts is recommended in order to assess groundwater inflows into the expanding quarry and the nature and degree of any impacts on the local groundwater system, and surrounding environment that may be associated with the proposed quarrying.

A program of continuous (automated) water level monitoring in monitoring bores and recording of any groundwater discharge points and inflows into the quarry is proposed in Section 14.0,

A staged approach to the assessment of any potential impacts from quarrying on groundwater inflows into the quarry and on the groundwater system will incorporate a formal review and reporting of the groundwater inflows into the quarry and the fluctuations in water levels in the network of monitoring bores at the end of Years 1, 2, 5, 10 and 20. The reviews will assess and compare the predicted impacts from the two-dimensional analysis against the actual (measured) impacts. A 'significant' impact may require the development of a three-dimensional computer model to predict further impacts. Data management and reporting protocols are documented in Sections 15 and 16.

14.0 PROPOSED MONITORING PROGRAM

Measurements of water level should be continued in the monitoring network prior to the commencement of any quarry operations in order to build on the existing baseline database. It is noted that water level monitoring and water quality testing to date has provided a set of important water level data.

An ongoing long-term program of regular water level and water quality monitoring will be carried out following commencement of mining operations. These monitoring data will be statistically analysed in order to establish a set of 'trigger levels' which will be used to alert any imminent or occurring impact/s from the proposed quarrying. The development of trigger levels is discussed in Section 15.

It is highly recommended that measurements of water level be collected using the existing installed automated water level data loggers and recorders in the representative monitoring bores.

The water level data loggers should be programmed to take and record measurements of water level in the representative monitoring bore at a sample frequency of one measurement every 4 hours. The data should be downloaded initially on a monthly basis. In this way, real time water level data can be collected and regularly analysed, and hydrographs constructed for each monitoring bore.

It is recommended that sampling and testing of groundwater in the representative monitoring bores should be carried out on a three (3) monthly basis for 12 months following the commencement of mining operations then on a six (6) monthly basis. In this way, analysis of the results will establish any trends in water quality. 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 will 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 in the first 12-month period following commencement of quarrying is provided in **Table 16**.

Table 16

Proposed List of Analytes and Tests

pH	Copper (Cu)
Electrical Conductivity (EC)	Lead (Pb)
Total Dissolved Solids (TDS)	Carbonate Alkalinity (as $CaCO_3$)
Sodium (Na)	Total Alkalinity (as $CaCO_3$)
Calcium (Ca)	Total Phosphorus (Total P)
Potassium (K)	Nitrate (NO_3-N)
Magnesium (Mg)	Nitrite (NO_2-N)
Ammonia (NH_4-N)	Phosphate (PO_4)
Chloride (Cl)	Zinc (Zn)
Sulphate (SO_4)	Total Iron (Fe)
Bicarbonate Alkalinity (as $CaCO_3$)	Dissolved Iron (Fe)
Oil and Grease	

A representative network of monitoring bores will be maintained at the locations marked in **Figure 8**. The monitoring bore network incorporates selected existing ‘open’ bores some of which can be readily converted to permanent monitoring bores. The network includes a set of control bores that are not within or downslope of the proposed quarry area.

A total of three (3) new monitoring bores are proposed:

- Two new monitoring bores, herein labelled GM100 and GM101 are recommended to monitor the water level fluctuations associated with Spring 6. One monitoring site is designed to monitor the fluctuations in water level within the dam at Spring 6. The second site is a relatively shallow monitoring bore (piezometer) positioned close to the dam (GDE) (**Figure 8**). This latter bore is designed to monitor any shallow groundwater in the vicinity of the GDE. The depth of the bore will depend on the progressive results of the drilling.

  These new monitoring bores should be equipped with automated ‘real time’ water level data loggers. The dual-sensor *‘Odyssey’* pressure transducer (water level) and temperature data loggers made by *Dataflow* are recommended. These monitoring sites are supplemented by existing monitoring bores GM17, GM 18 and GM 19 that should also be utilised for water level monitoring throughout the life of the quarry while they remain operational and are not destroyed by the advancing pit, access roads or mine infrastructure.

- One additional 'hardrock' monitoring bore herein labelled GW102 s also recommended in order to fill in the existing network in the northern part of the Project Site (**Figure 8**). It is noted that existing monitoring bore GM21 will be lost during Stage 1 of quarrying operations. The final depth of this bore will be similar to the depth of existing resource holes in, and surrounding the Project Site.

The recommended design and depth of the monitoring bores are provided in **Table 17**.

Table 17
Design and Specification for Proposed Monitoring Bores

Monitoring Bore	Coordinates (GPS-AMG)		Depth (m)	Screen Position	
	Easting (m)	Northing (m)		From (m)	To (m)
GM5	771856	6159495	22.50	19.50	22.50
GM6	771916	6159367	25.88	22.80	25.80
GM11	771937	6159186	23.35	20.30	23.30
GM13	771816	6159042	22.36	19.30	22.30
GM18	771743	6159110	24.10	21.40	24.10
GM21	771788	6159255	22.71	19.70	22.70
GM22	771662	6159294	11.70	8.70	11.70
GM24	771676	6158934	21.00	18.00	21.00
GM35	771961	6159027	27.54	24.50	27.50
GM36	771920	6158843	17.12	14.10	17.10
GM100	771628	6159144	Approx. 2.0	0.50	2.00
GM101	771644	6159128	TBA	TBA	TBA
GM102	771764	6159372	Approx. 30.0	27.00	30.00

In summary, bore construction should be achieved using 50mm-diameter blank Class 12 uPVC, machine slotted uPVC with 0.4mm apertures (slots) and rubber ringed screw fittings, centralisers, base caps, acid washed commercial 8/16 gravel pack (1.2-2.0mm), bentonite pellets, cement and lockable steel monument.

For existing 'open' bores, the screen should be set at the base of the bore and the bore constructed in accordance with the DNR (now DWE) *Specifications and Methods for the Construction of Departmental Groundwater Monitoring Bores in NSW*.

For the new monitoring bores, a 100 to 150mm-diameter borehole would be drilled using a suitable drilling technique. The 50mm pipe and a 3.0m-length of screen with a base cap securely fitted should then be centrally positioned in the bore using centralisers with the screen positioned at the designed depth. The length and position of the screen will depend on the depth of the bore and aquifer zone targeted for monitoring. The gravel pack is then injected into the annulus between the casing and open bore with the top of the gravel pack positioned approximately 0.4 to 0.5m above the top of the screen. A 0.5m-thick bentonite pellet seal will be positioned above the gravel pack and the remainder of the annulus grouted to surface using a cement-bentonite mix.

The bore should have a reasonable 'stickup', approximately 0.5 to 0.7m above ground level. An *'envirocap'* or similar product should be fitted in the top of the blank casing. A suitable lockable steel monument should be grouted into the ground surrounding the pipe to provide protection against animal or vehicle damage. The bore identification should be labelled in an appropriate place inside the monument and a mark placed on the casing so that measurements of water level are taken from the same spot every time. The constructed monitoring bore should be suitably developed if groundwater is intersected (best results with compressed air), in order to develop the gravel pack.

The recommended monitoring program is summarised in **Table 18** and the detail described in the following paragraphs.

- A company representative can be easily instructed on the programming and downloading of the data loggers, and appropriate data input and archiving of the data in an electronic database. The *'Odyssey'* pressure sensor water level data loggers installed in the monitoring bores should be initially programmed to collect a measurement of water level and temperature once every 4 hours. The company representative would download water level data in the monitoring bores on a weekly basis for 8 weeks following commencement of mining then following a review of the data by the hydrogeological consultant the frequency of downloads may be decreased to monthly. Initial frequent downloads would also enable a check on the integrity and operation of the loggers. Monitoring and charting would detect and track any significant fluctuations in the water level over time.

- A template field form for the interrogation of the water level data loggers in the monitoring bores is provided (with entry examples) in **Appendix E**. The field forms should be kept and filed in an appropriate place.

- Analysis of the water level data should be carried out by the hydrogeological consultant in order to establish the cause of any adverse trends and assess the degree of any impacts. That is, any significant decrease in water level may be a consequence of several factors including but not necessarily limited to pumping interference from neighbouring bores, cumulative interference of mining and third party bore pumping or due partly to long-term environmental effects.

- All water level data and groundwater quality monitoring results should be recorded, collated and duly reported in-house on an annual basis and reviewed by the consulting hydrogeologist. The aim is to assess any changes in water levels and identify reasons for the changes if they occur. The monitoring schedule should be reviewed annually and changed if deemed appropriate by the consultant.

- Monitor any groundwater inflows into the quarry. The flow/volume can be estimated and any change in activity noted in a field diary/notebook. The location of any discharge should also be recorded and monitored.

Table 18 **Recommended Water Level and Water Quality Monitoring Program**			
Monitoring Type	**Activity**	**Sample Frequency**	**Comment**
Water Level	Automatic water level measurements in *'Odyssey'* data logger in monitoring bores	• *Initial* 4-hourly (1 sample every 4 hours) • *Assess* data after 12 months • *Depending* on results and trends, decrease frequency to 8-hourly (1 sample every 8 hours)	This sample frequency is designed to provide adequate, real time good quality water level data, optimise the logger battery life and optimise logger memory.
Water Quality	Groundwater sampling in representative monitoring bores	• *Initial* 3-monthly (1 sample per bore every 3 months) for 12 months • *Assess* data after 12 months • *Depending* on results and trends decrease frequency to 6-monthly (1 sample every 6 months)	This sample frequency is designed to provide adequate water quality data to assess any significant changes in groundwater chemistry that may be due to the proposed quarry operations.
Rainfall	Automatic rainfall measurements in *tipping bucket rain gauge* data logger on site	• *Continuous* logging at every 0.5mm tip with time/date stamps	This sample frequency is designed to provide adequate, real time good quality rainfall data, optimise the logger battery life and optimise logger memory.

- Collect and record rainfall data for the Project Site using a *Bureau of Meteorology* approved automated tipping bucket rain gauge. The data should be downloaded on a monthly basis and collated in an electronic database or spreadsheet.

14.1 Development of Trigger Levels

At this stage, with limited available monitoring data, it is considered very difficult to establish a set of absolute water levels or water quality guidelines that if 'exceeded' may indicate that an impact or impacts are occurring

It is recognised that any significant decrease in water level and/or changes on water quality in monitoring bores and monitoring sites may be a consequence of several factors including but not necessarily limited to pumping interference from neighbouring bores, interference of mining or due partly to long-term environmental effects.

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

It is therefore proposed that continuous ‘real time’ monitoring of water levels and regular monitoring of water quality be continued in the monitoring bore network (as proposed in Section 14.0) in order to establish *control ranges* that take into account, as best as possible, natural variation and fluctuations in climate and rainfall, and possible artificial changes induced by pumping from the network of existing district and neighbouring bores.

The control ranges and trigger levels will be developed using the pre-quarrying monitoring data, the progressively-collected Year 1 monitoring data, and a statistical analysis. The selected statistical analytical methods will be designed to provide early warning and monitoring of any adverse trends associated with potential contamination of the groundwater system. The methods would provide warning of any imminent exceedences of the limits and establish, and monitor any impacts if they have already occurred.

The selected statistical methods are designed to provide early warning and monitoring of any adverse trends associated with water level decline and/or the quality of the groundwater. The methods would provide warning of any imminent exceedences of the limits and establish, and monitor, any impacts if they have already occurred.

There are a range of statistical control chart methods that are used in the processing industry. Two well documented methods are the *Exponentially Weighted Moving Average* (EWMA) method and the *Cumulative Sum* (Cusum) method which are considered to be relevant to the assessment of any potential impacts associated with sand mining or production bore pumping on the Property. It is recommended that the two methods be integrated into one statistical analysis and implemented. The methods are described as follows.

The EWMA control chart is a data analysis technique for determining if a measurement process has got out of control. The EWMA chart plots a weighted average of the current data and the previously plotted point and uses statistical control limits. The chart is sensitive to drift and therefore in the context of the potential impacts from sand mining and/or production bore pumping would effectively detect any water level declines or geochemical changes in groundwater due to the project.

The Cusum chart is similar to the EWMA method. The chart is sensitive to drift and will detect small changes in the mean. The chart does not use fixed or parallel statistical control limits but plots the cumulative sum of the deviations between each plotted value (sample average) and a background value. The interpretation of the chart is more concerned with the slope of the plotted line, not just the distance between the plotted values and the centreline.

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 will depend at least in part on the measured inflows into the quarry and the degree of fluctuations in water levels in the monitoring bores, and the assessment of the significance of any impacts.

Mitigation measures have been developed in Section 17 of the EA. 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.

15.0 DATA MANAGEMENT

The recommended protocol for data management is summarised as follows:

- The water level data downloaded from the loggers in the monitoring bores should be imported into an electronic database or spreadsheet and viewed following each round of monitoring. This process will 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. If a problem with the data is discovered, for example the corrected water level in the data logger does not reasonably correspond with the manual measurement taken at the time of downloading, remedial measures can be implemented immediately. If there is a problem, the worst case scenario is that water level data may be lost for that period or part of the monitoring period since the last downloading was carried out. In this way, any problem should not be carried through in the medium to long term.
- Email a copy of the water level data to the hydrogeological consultant for assessment and keep a backup copy of the water level database or spreadsheet in a secure **off-site** place.
- Develop and maintain an electronic water quality database or spreadsheet. This database can also be part of the electronic water level monitoring database. A suitable database and progressive charting can be developed.
- Develop and maintain an electronic rainfall database or spreadsheet.

16.0 REPORTING

The recommended 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 by the consulting hydrogeologist. The aim is 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 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 to the *Senior Hydrogeologist DWE* on an annual basis. This may be a condition of any development approval.

  The report should include but not necessarily limited to:

  - A progressive record of the water level measurements in the monitoring bores
  - 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 geochemistry
- Progressive assessment of any statistical trends (impacts)
- Conclusions and recommendations

The report should be submitted in hard copy and electronic format to the *Senior Hydrogeologist, DWE* and to the Quarry Manager. The raw water level and water quality data will be appended to the report in electronic form.

17.0 MITIGATION OF ANY IMPACTS ASSOCIATED WITH THE PROPOSED QUARRY DEVELOPMENT AND COMPENSATORY MEASURES

17.1 Proposed Mitigation Measures

Although the scientific data indicates that the probability of any potential significant adverse impacts of the proposed quarry operations on the district water table and therefore on Spring 6 or indeed on any other springs surrounding the Project Site is low, the assessment is based on the available data and results of field and laboratory studies and investigations.

It is recognised that the conceptual geological and hydrogeological model is not perfectly understood and therefore potential for impact remains. For this reason, if there is a scientifically demonstrated significant impact on any of the springs or registered bores surrounding the Project Site, a set of options has been developed for each.

17.2 Springs

Any deterioration in the discharge flow of springs in the local area surrounding the Project Site less than historical low flow rates that can, with the available scientific data, be linked to quarrying activities, the following options are presented for consideration subject to any agreement/s between the owner and Gunlake Quarries.

- Compensate the owner of the Property by supplying groundwater supplies to the property/s with a minimum flow equivalent to the measured and documented losses with water quality commensurate with the spring, or better.
- Provide monetary compensation to the property owner for the measured and documented losses.
- Drill a test bore on the Property for the owner in order to replace or improve the flow rate of the spring. The water quality must be similar to the spring water quality or suitable for the intended purpose.

17.3 Neighbouring Registered Bores

The results of hydrogeological investigations within and surrounding the Project Site and the large separation distances between the proposed quarry and registered bores in the local area indicate that registered groundwater users will not be significantly affected by the quarry.

Although the risk of significant impact on registered water users is considered to be very low, long-term water level monitoring will be required peripheral to the quarry in order to detect any potential distance impacts.

If there is a scientifically demonstrated significant impact on any neighbouring water users surrounding the Project Site, for example, a fall in bore water level that can, with the available scientific data, be linked to quarrying activities, the following options are presented for consideration subject to any agreement/s between the property owners and Gunlake Quarries.

- Compensate the owner of the Property by supplying 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.
- Provide monetary compensation to the property owner for the measured and documented losses.
- Drill a test bore on the Property for the owner in order to replace or improve the flow rate of the existing registered bore. The water quality must be similar to the existing bore water quality or suitable for the intended purpose.

18.0 CONCLUSIONS

An extensive hydrogeological investigation has established the district and local hydrogeological conditions beneath and immediately surrounding the Project Site. The conclusions are summarised as follows:

- The hydrogeological investigations revealed the existence of one main aquifer type beneath the Project Site, a 'hardrock' aquifer where groundwater storage and flow is associated with structural discontinuities (fractures and faults) hosted by porphyry basement.
- Evidence of fracture control is revealed in the results of surface geological mapping, logging of project drill core, regional state government geological mapping, air photo lineament analysis and the results of other hydrogeological investigations in the region.
- The results of hydraulic conductivity testing in a network of representative monitoring bores that penetrated the full depth of proposed extraction indicate low to very low rock permeabilities with the majority of tests revealing hydraulic conductivities of less than about 0.04m/day and transmissivities of less than approximately $0.6m^2$/day. The results are consistent with:

    - the occurrence of 'tight' fractures and joints in outcrop
    - networks of fine fractures and veins in drill core
    - a compressional regional tectonic regime
    - the paucity of successful water bores in the local area
    - high salinity levels in some district 'hardrock' aquifers

- Baseline and ongoing water level monitoring in an extensive network of monitoring bores reveals that the fracture-controlled groundwater is flowing to the north beneath the Project Site sub-parallel to the local topography.
- The water levels in the majority of monitoring bores appear to rise rapidly in response to rainfall events. Although this appears to be inconsistent with the results of aquifer tests that

generally indicate very low rock permeabilities, the water appears to have infiltrated the 'open' monitoring bores via the relatively thin weathered zone.

- Detailed analysis and testing of groundwater samples collected from representative monitoring bores reveals that the groundwater chemistry is likely evolving along joint and fracture-controlled flow paths.

  The groundwater is near neutral, 'hard' and moderately to highly saline.

  The groundwater can be classified as dominantly Magnesium-Chloride or Sodium-Chloride type with one sample classified as Sodium-Bicarbonate type.

  The ion proportions reveal that some of the groundwater displays geochemistry expected at the discharge end of the hydrogeochemical cycle. Other samples display geochemistry expected at the recharge end and some between the discharge and recharge ends.

- Several water features (springs) were identified in the local area during the investigation. The springs appear to be associated with sub-vertical fractures and have an elevation control with the large majority between about 650 and 665m AHD. The majority of springs are located more than about 900m from the proposed quarry and either downgradient or sidegradient from the quarry. It is considered that these distant spring systems will not be impacted by the proposed quarry.

  The exception is Spring 6 located approximately 200m west of the proposed extraction area and likely controlled by a north-northeast linear fracture sub-parallel to the western limit of the quarry. Elevation control is also suspected. The scientific evidence indicates that the fracture will not be intercepted by the quarry. However, although the spring groundwater may not be in direct hydraulic connection with the porphyry aquifer beneath the proposed quarry, there may be indirect hydraulic connection within a fracture/joint network that may be exposed during quarrying.

  The spring discharge is retained by a small on-line storage (dam) that possibly supports a minor (insignificant) GDE.

  There is the potential for the westerly advancing excavation near Spring 6 to cause a change in the groundwater gradient and direction of flow close to the spring.

  However, the demonstrated very low rock permeabilities and the geological evidence that the source of groundwater feeding this spring is upgradient of the proposed quarry suggests that a significant impact on the spring from the quarry operations is unlikely. Nevertheless, long-term monitoring will be required.

- The demonstrated low rock permeabilities also indicate that the inflow volumes and rate of flow of groundwater into the excavation will likely be very low. This implies that apart from a permanent steepening in the local piezometric surface in close proximity to the final void, it is highly unlikely that there will be any significant adverse impacts on the district water table.

- Estimates of groundwater inflow into the excavation during the five design stages of quarrying indicate very low flows during Stages 1 and 2 which are consistent with demonstrated low rock permeabilities and the likelihood that groundwater will only be encountered late in the respective stages.

  Moderate increases in inflow are predicted as the quarry expands; up to possibly 0.1L/s (3ML per annum) in Year 30. However, because the density, distribution and geometry of the porphyry-hosted fracture network in the Project Site are very difficult to delineate, increased inflow in parts of the quarry may result if relatively 'high-permeability' fractures are intercepted.

- It is unlikely that significant ponding will occur in the quarry. The district mean annual evaporation exceeds the district mean annual rainfall and markedly exceeds the estimated groundwater inflows. That is, the amount of groundwater inflow will be offset by evaporation. However, it is recognised that intense and/or extended rainfall events will, from time to time likely result in potentially large-volume 'bursts' of water in the void. Any detention will be temporary and will dissipate naturally as a result of ensuing evaporation and infiltration into the groundwater system. The demonstrated very low rock permeabilities and relatively high evaporation rates indicate that the water table will remain beneath the void. That is, the quarry is a ‘groundwater sink’.

- Small localised changes in groundwater quality may result from localised groundwater mixing, chemical equilibration and oxygenation. Apart from a possible local increase in dissolved oxygen levels there would be no mixing of surface runoff water and groundwater. It is therefore considered unlikely that proposed quarrying will have any significant impact on the water quality. A long-term program of water quality monitoring in the monitoring wells will continue in order to detect any changes if they occur.
- The results of hydrogeological investigations over the Project Site and the large separation distances between the proposed quarry and the small number of registered bores in the local area indicate that registered groundwater users will not be affected by the quarry. Although the risk of impact is considered to be very low, long-term water level monitoring will be required peripheral to the quarry in order to detect any potential distance impacts.
- It is concluded that the risks of any significant impacts from the quarry on the district water table or on Spring 6 is considered small and that the development can be suitably managed provided there is a contingency plan for any impacts. These include mitigation measures such as monitoring programs and possible injection wells, and other options including supplying water, monetary compensation for losses or test drilling for a useful ’hardrock’ groundwater supply to supplement the spring flow.
- The potential for the production of acid leachate from the proposed quarrying operations is very low. The ingredients for acid mine leachate do not appear to exist and the pH of the first groundwater samples purged from the monitoring bores is near neutral.
- The nature and properties of the Bindook Porphyry, demonstrated low global permeabilities and knowledge of the degree, and extent, of impacts associated with similar quarry developments in igneous rocks is consistent with the prediction that any significant drawdown of the local water table will occur within close proximity to the quarry periphery.

  The implication of this is that the potential for impacts on the identified distal spring systems and any associated GDEs, and the three registered bores is low.

  If there are any linear, sub-vertical sheet-like discontinuities within the proposed quarry footprint unknown at this time, that may influence the degree, extent and distribution of any impacts, it is our view that a three-dimensional computer model will not improve the accuracy of any distant impact predictions.
- A staged assessment of any impacts is recommended in order to assess groundwater inflows into the quarry and the nature and degree of any impacts on the local groundwater system, and surrounding environment that may be associated with the proposed quarrying.
- A set of statistical control ranges and trigger levels will be developed to provide early warning and monitoring of any adverse trends associated with water level decline and/or the quality of the groundwater. The methods would provide warning of any imminent exceedences of the limits and establish, and monitor, any impacts if they have already occurred associated with proposed quarrying
- The demonstrable very low to low permeabilities of the Bindook Porphryry that hosts several quarries in the area and their separation distances indicate that any impact on the porphyry-hosted groundwater system appear to be confined to the local scale at each quarry operation. This indicates that there will be no cumulative impact.

19.0 RECOMMENDATIONS

The recommendations are listed as follows:

- A long-term program of water level and water quality monitoring in the monitoring bores within and surrounding the Project Site should continue in order to monitor any changes. If deemed necessary, the bores that are destroyed during the staged extraction process could be replaced with strategically positioned and suitably installed new monitoring bores. The consultant should review the water level data and make appropriate decisions on the ongoing frequency of measurements.
- A long-term program of water level and water quality monitoring of Spring 6 in accordance with Table 18 be implemented to monitor any changes. Measurements of flow and testing of water quality should be carried out on a six-monthly basis.
- Samples of groundwater should be collected in all monitoring bores in accordance with Table 18 and submitted to a NATA registered laboratory for the testing of pH, Electrical conductivity (EC), Total Dissolved Solids (TDS) and the determination of major anions, major cations and dissolved iron. This will enable the monitoring and assessment of any changes in groundwater chemistry.
- Construct dedicated monitoring bores at locations delineated in Section 14.0 and shown in **Figure 8**. Construction should be in accordance with the *DNR Specifications and Methods for the Construction of Departmental Groundwater Monitoring Bores in NSW.*
- Prepare applications for individual monitoring bore licenses in accordance with the *Water Act 1912*. Submit completed forms to the DWE for registration. There is no government fee required for a monitoring bore license.
- The company representative or hydrogeological consultant must maintain the monitoring bore network on a regular basis. This includes general maintenance checks on the operational status of the '*Odyssey'* water level data loggers in the monitoring bores. This can be conveniently undertaken during the scheduled downloading of the loggers. A set of replacement parts for the loggers should be kept on site and include a small stock of desiccant satchels, 'O' rings, spare battery packs and spare 4mm-diameter plastic vent tube.
- Import water level data into an electronic spreadsheet following each round of logger downloads. Email a copy of the water level data to the hydrogeological consultant for assessment and keep a backup copy of the water level database or spreadsheet in a secure **off-site** place.
- All water level and groundwater quality monitoring records should be recorded, collated and duly reported in-house on an annual basis and reviewed by the consulting hydrogeologist as recommended in sections 15 and 16. The aim is to assess any changes in water levels and water quality and identify reasons for the changes if any. The DWE may require such a reporting regime and copies of the reports. The monitoring schedule should be reviewed annually and changed if deemed appropriate by the consultant.
- Develop and maintain a record of the number and locations of any groundwater discharge into the quarry with date stamps. This record should include an estimate of flow/volume. The database or spreadsheet can constitute part of the electronic water level and water quality monitoring database. The records can be readily printed and copied for attachment to the annual report to the DWE.
- Adopt the water level monitoring program proposed in Section 14 and summarised in **Table 18**.

- Adopt the water quality monitoring program proposed in Section 14 and summarised in **Table 18.**
- Make representation to the owner/s of Registered Bore GW056376 to seek their non-objection to measure water levels in their bore from time to time. Ideally a water level data logger could be installed.
- The hydrogeological consultant should:
  - review the water level, water quality and rainfall data as prescribed in Section 16,
  - carry out assessments as proposed in Section 16 and,
  - prepare an annual report suitable for submission to the DWE as described in Section 16.

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GLOSSARY OF TERMS

ADAMELLITE—Quartz Monzonite (see monzonite).

ALLUVIUM--Unconsolidated clay, silt, sand, or gravel deposited during recent geologic time by running water in the bed of a stream 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 (HYDRAULIC) DIFFUSIVITY--ratio of aquifer transmissivity to storativity (or hydraulic conductivity to specific storage); it indicates how fast a transient change in head will be transmitted throughout the aquifer system.

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.

AQUIFUGE--body of earth material which is impervious to water and unabsorbtive.

AQUITARD--A part of a geologic formation (or one or more geologic formations) that is of much lower permeability than an aquifer and will 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.

ARTESIAN WELL or ARTESIAN SPRING--A well or spring that taps ground water under pressure beneath an aquifuge or aquiclude so that water rises (though not necessarily to the surface) without pumping. If the water rises above the surface, it is known as a flowing artesian well.

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

BICARBONATE--The anionic constituent HCO_3 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 $CaCO_3$) 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.

CALCIUM-BICARBONATE TYPE--The constituents with the largest concentrations in this type of water are calcium (Ca) and bicarbonate (HCO_3).

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 CO_3 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.

CLEAVAGE--The breaking of a mineral along its crystallographic planes, mirroring crystal structure. Cleavage is one of the characteristics used to identify 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 will 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.

CONSERVATION STORAGE--storage of water in a reservoir for later release for useful purposes such as municipal and industrial water supply, water quality, or irrigation.

CONSUMPTIVE USE--use that makes water unavailable for other uses, usually by

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.

DARCY's EQUATION OR LAW--formula stating that the flow rate of water through a porous medium is proportional to the hydraulic gradient. The factor of proportionality is the hydraulic conductivity.

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 stream.

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.

DISCRETE FRACTURED AQUIFER**--**An aquifer consisting of low-permeability, primary porosity matrix and discrete high permeability, secondary porosity fissures (e.g., a single vertical or horizontal plane fracture).

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).

DRAINAGE AREA--Of a stream at a specified location is that area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the stream above the specified location.

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.

EROSION--The wearing away, breaking down, or dissolving of rock and other material by wind or water. The eroded material is often carried off and deposited in other areas. Types of erosion include solution, corrosion, and abrasion. Most limestone and gypsum caves are formed mainly by solution. Shelter caves and many sandstone caves are formed by abrasion.

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.

FRACTURE SKIN**--**A thin, low-permeability material coating the surface of fractures (e.g., mineral deposit) that restricts flow of water.

FRACTURED AQUIFER**--**See Discrete Fractured Aquifer or Double-Porosity Fractured Aquifer.

FRESHWATER--Water containing only small quantities (generally less than 1,000 milligrams per litre) of dissolved materials.

GEOGRAPHIC INFORMATION SYSTEMS (GIS)--Computer-based systems for storing and manipulating geographic (spatial) information.

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 stream) 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 MINING--pumping ground water from a basin at a rate that exceeds safe yield, thereby extracting ground water that had accumulated over a long period of time.

GROUND-WATER OVERDRAFT--pumpage of ground water for consumptive use in excess of safe yield.

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

HARD WATER--See hardness.

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 CONTINUITY--property of the rock framework on a given time scale whereby a change in hydraulic head in any point of the region can cause a head change in any other point of the same region by means of pressure transfer through the rock pores and within a time interval measurable at that time scale.

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.

HYDRAULIC POTENTIAL--see soil-water potential.

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 stream 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 drainage 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.

IGNIMBRITE—The rock formed by the deposition and consolidation (usually widespread) of ash flows and nuees ardentes derived from usually violent volcanic eruptions.

INTRUSION--An igneous rock formed from magma that pushed its way through other rock layers. Magma often moves through rock fractures, where it 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.

MAGMA--Hot, liquid rock. Igneous rocks are formed when magma cools.

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.

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.

MATHEMATICAL MODEL--mathematical equations expressing the physical system and including simplifying assumptions. The representation of a physical system by mathematical expressions from which the behaviour of the system can be predicted.

METAMORPHIC ROCK--Rock that has changed from one form to another by heat or pressure.

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 LITER (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.

MODELING--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.

MONZONITE—Plutonic (igneous) rock intermediate in composition between syenite and diorite. Contains approximately equal amounts of alkali feldspar and plagioclase.

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.

PERENNIAL YIELD--maximum quantity of water that can be withdrawn annually from a ground water supply under a given set of conditions without causing an undesirable result.

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

PERMANENT WILTING PERCENTAGE OR POINT--water content of soil when indicator plants growing in that soil wilt and fail to recover when placed in a humid chamber.

PERMEABLE--Permeability is a measure of the ease with which a fluid will 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.

PHYSIOGRAPHY--Description of the natural physical features (landforms) of the earth.

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.

PORPHYRY—An igneous rock of any composition that contains conspicuous phenocrysts (crystals) set in a fine-grain groundmass.

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 will 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 (SiO_2) 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.

RESIDUAL DRAWDOWN--See Residual Displacement.

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 will 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.

SODIUM-CHLORIDE TYPE--Water in which the constituents with the larges dissolved concentrations are sodium (Na) and chloride (Cl). Sodium-chloride type water is usually derived from dissolution of rock salt (the mineral halite with the composition NaCl).

SODIUM-SULFATE TYPE--Water in which the constituents with the largest dissolved concentrations are sodium (Na) and sulphate (SO_4). Calcium is also usually present in substantial concentrations in this type of water, but the calcium is limited from being at higher levels due to the solubility limits of minerals such as calcite ($CaCO_3$) and gypsum ($CaSO_4.2H_2O$).

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 will 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 streams or lakes.

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

TECTONICS--The study of the movement of the earth's outer crust. Tectonics includes the study of earthquakes and other faulting, mountain uplifting, and plate tectonics.

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).

UPCONING--The upward movement of ground water from a deeper to shallower position in the aquifer, usually induced by pumping a well or discharge to the surface.

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 stream 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.