Green Valley Sand Quarry

GROUNDWATER ASSESSMENT

Prepared by:
Aquaterra Consulting Pty Ltd

January 2011

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GROUNDWATER ASSESSMENT

of the

Green Valley Sand Quarry

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Aquaterra Consulting Pty Ltd
EXECUTIVE SUMMARY ............................................................................................................. 1-7

1. INTRODUCTION....................................................................................................................... 1-11

2. GROUNDWATER INVESTIGATIONS ....................................................................................... 1-12
   2.1 PREVIOUS INVESTIGATIONS – PENROSE SAND QUARRY ............................................. 1-12
   2.2 RECENT INVESTIGATIONS – GREEN VALLEY SAND QUARRY PROJECT SITE .......... 1-13
      2.2.1 Piezometer Installation and Monitoring ................................................................. 1-14
      2.2.2 Hydraulic Testing of Piezometers ........................................................................ 1-15
      2.2.3 Groundwater Supply Investigation .................................................................... 1-15
      2.2.4 Groundwater Quality ........................................................................................ 1-16
   2.3 SEARCH OF NOW GROUNDWATER DATABASE .............................................................. 1-17

3. EXISTING ENVIRONMENT .................................................................................................... 1-18
   3.1 TOPOGRAPHICAL SETTING .......................................................................................... 1-18
   3.2 CLIMATE ....................................................................................................................... 1-18
      3.2.1 Rainfall and Evaporation ..................................................................................... 1-18
   3.3 GEOLOGY ...................................................................................................................... 1-19
      3.3.1 Regional Geology ................................................................................................. 1-19
      3.3.2 Project Site Geology ............................................................................................ 1-19
   3.4 HYDROGEOLOGY .......................................................................................................... 1-20
      3.4.1 Regional ................................................................................................................ 1-20
      3.4.2 Local Aquifers – Project Site ................................................................................ 1-20
      3.4.3 Groundwater Levels and Flow ............................................................................. 1-20
      3.4.4 Aquifer Hydraulic Properties .............................................................................. 1-21
         3.4.4.1 Hawkesbury Sandstone .................................................................................. 1-21
         3.4.4.2 Berry Formation ............................................................................................ 1-22
      3.4.5 Groundwater Quality ........................................................................................... 1-22
      3.4.6 Recharge and Discharge ........................................................................................ 1-25
      3.4.7 Interaction with Surface Water ............................................................................ 1-26

4. PROJECT OVERVIEW ............................................................................................................ 1-28
   4.1 PROJECT DESCRIPTION .................................................................................................. 1-28
   4.2 POTENTIAL GROUNDWATER-RELATED PROJECT CONSTRAINTS ................................ 1-28
      4.2.1 Potential Impacts on Other Groundwater Users ..................................................... 1-28
      4.2.2 Potential Changes to Baseflow Discharges to Hanging Swamp and Paddys River 1-29
      4.2.3 Project Water Supply ............................................................................................ 1-29
      4.2.4 Licensing and Downstream Water Quality Impacts ............................................. 1-30

5. GROUNDWATER IMPACT ASSESSMENT ............................................................................ 1-31
   5.1 BACKGROUND ................................................................................................................ 1-31
   5.2 CONCEPTUAL GROUNDWATER MODEL DESIGN ...................................................... 1-31
   5.3 GROUNDWATER MODEL SET-UP ............................................................................... 1-31
      5.3.1 Modelling Software .............................................................................................. 1-31
      5.3.2 Model Set-up .......................................................................................................... 1-32
         5.3.2.1 Model Domain and Boundary Conditions ....................................................... 1-32
         5.3.2.2 Aquifer Representation .................................................................................... 1-32
         5.3.2.3 Recharge .......................................................................................................... 1-33
         5.3.2.4 Discharge to Hanging Swamps ......................................................................... 1-34

Aquaterra Consulting Pty Limited
CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.4 MODEL CALIBRATION</td>
<td>1-34</td>
</tr>
<tr>
<td>5.4.1 Steady State Calibration</td>
<td>1-34</td>
</tr>
<tr>
<td>5.4.2 Sensitivity Analysis</td>
<td>1-36</td>
</tr>
<tr>
<td>5.5 MODEL PREDICTED GROUNDWATER IMPACTS</td>
<td>1-38</td>
</tr>
<tr>
<td>5.5.1 Approach</td>
<td>1-38</td>
</tr>
<tr>
<td>5.5.2 Simulation of Sand Extraction and Void Backfilling</td>
<td>1-38</td>
</tr>
<tr>
<td>5.5.3 Predicted Inflow Rates and Swamp Baseflow</td>
<td>1-39</td>
</tr>
<tr>
<td>5.5.4 Predicted Water Level Drawdowns</td>
<td>1-41</td>
</tr>
<tr>
<td>5.5.5 Recovery Simulation</td>
<td>1-41</td>
</tr>
<tr>
<td>5.6 POTENTIAL DOWNSTREAM WATER QUALITY IMPACTS</td>
<td>1-42</td>
</tr>
<tr>
<td>5.7 IMPACTS ON EXISTING GROUNDWATER USERS</td>
<td>1-42</td>
</tr>
<tr>
<td>6. RECOMMENDED CONTROLS AND MITIGATION MEASURES</td>
<td>1-44</td>
</tr>
<tr>
<td>6.1 SITE WATER MANAGEMENT</td>
<td>1-44</td>
</tr>
<tr>
<td>6.2 GROUNDWATER MANAGEMENT</td>
<td>1-44</td>
</tr>
<tr>
<td>6.3 MITIGATION MEASURES</td>
<td>1-44</td>
</tr>
<tr>
<td>6.4 GROUNDWATER MONITORING</td>
<td>1-45</td>
</tr>
<tr>
<td>7. SUMMARY AND CONCLUSIONS</td>
<td>1-48</td>
</tr>
<tr>
<td>8. REFERENCES</td>
<td>1-51</td>
</tr>
<tr>
<td>9. GLOSSARY OF TECHNICAL TERMS</td>
<td>1-52</td>
</tr>
</tbody>
</table>

APPENDICES

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appendix A</td>
<td>Hydraulic Test Data</td>
<td>1-81</td>
</tr>
<tr>
<td>Appendix B</td>
<td>Green Valley Model Layer Elevations</td>
<td>1-93</td>
</tr>
<tr>
<td>Appendix C</td>
<td>Steady State Model Calibration</td>
<td>1-97</td>
</tr>
<tr>
<td>Appendix D</td>
<td>Green Valley Model Calibrated Parameters</td>
<td>1-101</td>
</tr>
<tr>
<td>Appendix E</td>
<td>Green Valley Model Predicted Drawdown and Recovery Hydrographs</td>
<td>1-105</td>
</tr>
<tr>
<td>Appendix F</td>
<td>Test Bore Geologic Logs</td>
<td>1-111</td>
</tr>
</tbody>
</table>

FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.1:</td>
<td>Sydney Basin Showing Location of Proposed Green Valley Sand Quarry</td>
<td>1-59</td>
</tr>
<tr>
<td>Figure 2.1:</td>
<td>Green Valley Sand Quarry Drill Hole Location Plan</td>
<td>1-60</td>
</tr>
<tr>
<td>Figure 3.1:</td>
<td>Green Valley Sand Quarry Limit of Sand Extraction</td>
<td>1-61</td>
</tr>
<tr>
<td>Figure 3.2:</td>
<td>Green Valley Sand Quarry Sandstone Groundwater Contours</td>
<td>1-62</td>
</tr>
<tr>
<td>Figure 3.3:</td>
<td>Groundwater Hydrographs for Continuously Logged Piezometers</td>
<td>1-63</td>
</tr>
<tr>
<td>Figure 3.4:</td>
<td>Piper Trilinear Diagram: Green Valley Bores</td>
<td>1-64</td>
</tr>
<tr>
<td>Figure 3.5:</td>
<td>Piper Diagram: Penrose Sand Project BHs 2 – 5</td>
<td>1-65</td>
</tr>
<tr>
<td>Figure 3.6:</td>
<td>Piper Diagram: Penrose Sand Project BHs 6, 7, 17 &amp; 21</td>
<td>1-66</td>
</tr>
<tr>
<td>Figure 3.7:</td>
<td>Piper Diagram: Penrose Sand Project Surface Waters</td>
<td>1-67</td>
</tr>
</tbody>
</table>
CONTENTS

Figure 5.1: Green Valley Sand Quarry Extraction Stages ................................................................. 1-68
Figure 5.2: Green Valley Conceptual Model ...................................................................................... 1-69
Figure 5.3: Model Domain and Boundary Conditions ................................................................. 1-70
Figure 5.4: Scatter Diagram for Green Valley Model Steady-State Calibration ............................... 1-71
Figure 5.5: Green Valley Model Annual Extraction Sequence ....................................................... 1-72
Figure 5.6: Total Groundwater Outflow (Flux) from the Base Case Model .................................... 1-73
Figure 5.7: Predicted Quarry Inflow and Hanging Swamps Baseflow Rates .................................. 1-74
Figure 5.8: Green Valley Model Predicted Drawdowns in Layer 2; Quarry Year 33 ...................... 1-75
Figure 5.9: Green Valley Model Predicted Drawdowns in Layer 3; Quarry Year 33 ...................... 1-76
Figure 5.10: Green Valley Model Predicted Drawdowns in Layer 1 at the End of 83 Years .......... 1-77
Figure 5.11: Green Valley Model Predicted Drawdowns in Layer 2 at the End of 83 Years .......... 1-78
Figure 5.12: Green Valley Model Predicted Drawdowns in Layer 3 at the End of 83 Years .......... 1-79

TABLES

Table 2.1 Penrose Quarry – Monitoring Bore Data ................................................................. 1-13
Table 2.2 Green Valley Piezometer Construction Details and Groundwater Levels (July 2010) ....... 1-14
Table 2.3 Test Bore Construction Details and Test Results ...................................................... 1-16
Table 3.1 Monthly average rainfall and evaporation figures (in mm) for Penrose 68051 (rainfall) and Goulburn 70263 (evaporation) ................................................................. 1-18
Table 3.2 Summary of Hydraulic Testing Program – Piezometers (July 2008) .......................... 1-22
Table 3.3 Laboratory Analysis of Groundwater Quality Parameters ....................................... 1-23
Table 3.4 Penrose Quarry – Water Quality Data ................................................................. 1-24
Table 5.1 Steady State Model Calibration Groundwater Level Targets ...................................... 1-35
Table 5.2 Steady-state Calibration Performance of the Model ...................................................... 1-36
Table 5.3 Parameters, Zones and the Multipliers Tested in the Sensitivity Analysis Process ........ 1-36
Table 5.4 Sensitivity Analysis of Horizontal Hydraulic Conductivity Values ................................ 1-37
Table 5.5 Sensitivity Analysis of Recharge ............................................................................... 1-37
Table 5.6 Predicted Quarry Groundwater Inflows and Discharges to Hanging Swamps ............ 1-39
Table 6.1 Recommended Laboratory Analysis Suite for Annual Groundwater Monitoring .......... 1-46
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EXECUTIVE SUMMARY

This groundwater assessment report to support the proposed Green Valley Sand Quarry has been prepared by Aquaterra Consulting Pty Limited (Aquaterra) for R W Corkery & Co Pty Limited (Corkery) to support an application on behalf of Rocla Pty Limited (Rocla) for the Green Valley Sand Quarry Project.

Rocla Pty Limited (the Proponent) proposes to undertake a sand extraction and processing operation (the Project) within the “Green Valley” property in a locality referred to as Paddys River, approximately 28km southwest of Berrima and 14km northeast of Marulan. The “Green Valley” property is located adjacent to the Hume Highway, approximately 800m north of the intersection of Hume Highway and Murrimba Road.

Groundwater investigations were undertaken between June 2008 and July 2010, and baseline monitoring is continuing. These investigations aimed to verify aquifer parameters by testing of existing boreholes, obtain additional hydraulic data through the installation and testing of new monitoring boreholes, and assess potential impacts by groundwater modelling. The monitoring network of 22 bores (ten of which have been completed as piezometers), plus a shallow ‘hanging swamp’1 monitoring point, was selectively sampled and tested for groundwater levels, aquifer characteristics and groundwater quality. This network continues to be monitored for the purposes of obtaining natural variations as a baseline for ongoing groundwater management during the operational phase of the project. General findings of the investigations are given below.

EXISTING HYDROGEOLOGICAL ENVIRONMENT

The Hawkesbury Sandstone, which underlies elevated parts of the Project Site, is typically a friable, fine to coarse-grained sandstone. It is essentially a large perched aquifer with flow directions being controlled by the gradients of the underlying aquitard. This groundwater flow within the “Green Valley” property is controlled by the presence of the less permeable shales of the Berry Formation, which lie beneath the predominant Hawkesbury Sandstone formation aquifer. The underlying Berry Formation constitutes a basal aquitard, which causes a perched aquifer to be maintained within the sandstones above.

Hydraulic testing of the sandstone aquifer indicated that hydraulic conductivities are relatively high for the Hawkesbury Sandstone, and are more typical of fine grained sand. This reflects the locally weathered and friable nature of the sandstone. Weathering of the sandstone has allowed a greater than normal proportion of intergranular groundwater flow within the formation, which has resulted in an increased permeability within the aquifer. Groundwater levels are generally close to (within a few metres of) the base of the sandstone, reflecting the perching behaviour of the underlying shale.

The Hawkesbury Sandstone has a limited presence at the Green Valley Project Site, which is situated on the margin of the Sydney Basin. The sandstone occurs only in elevated parts of the Project Site, having been eroded from the valleys and hillslopes. It is virtually an outlier, bounded by outcrop on the eastern, southern and western sides, with only a limited connection to the more extensive Hawkesbury Sandstone occurrence within the basin to the northwest.

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1 Hanging Swamps have been referred to throughout this report and refer to areas of groundwater discharge. The extent shown has been inferred and is based on mapping and direct observation.

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The groundwater sampling has revealed the following general water quality characteristics for the groundwater within the “Green Valley” property.

- The groundwater is moderately acidic, with pH generally in the range 4.5 to 5.5.
- The groundwater in the Hawkesbury Sandstone has low salinity, with EC levels generally in the range 75-200 µS/cm, and TDS less than 100 mg/L.
- Surface water in the hanging swamps has similar water quality and chemistry to the Hawkesbury Sandstone.
- The groundwater in the underlying Permian Berry Formation is generally more saline, with EC in excess of 1000 µS/cm, although the salinity of groundwater in the fractured shales beneath the Green Valley site was found during test pumping of test production bores to be lower (EC less than 500 µS/cm) suggesting that there is good local recharge to the fractured shales, probably where the fracture zones intersected in drilling outcrop in gullies near the Project Site.

The primary discharge mechanism for the local sandstone aquifer, apart from evapotranspiration due to the vegetative cover, is via seepage down dip at the contact of the Hawkesbury Sandstone and underlying Berry Formation to ‘hanging swamps’ that are found to the east and southeast of the sandstone outcrop. These are fed by groundwater that discharges through the weathered zone around the base of the sandstone outcrop. This water can emerge to surface some distance downstream of the outcrop, so the hanging swamps may be located some distance downslope from the edge of the sandstone outcrop.

PREDICTION OF IMPACTS

The two main potential impacts of proposed Green Valley Sand Quarry on the hydrogeological environment are considered to be:

- Localised lowering of groundwater levels within the Hawkesbury Sandstone, due to groundwater inflows to the extraction excavations; and
- Possible impacts on groundwater baseflow contributions to the hanging swamps and Paddys River.

Groundwater modelling has been undertaken to assess the potential impacts of the Project on the groundwater environment, specifically with regard to:

- Predicted groundwater extraction rates (including both inflows to excavations and any external dewatering);
- Regional and localised changes in groundwater levels due to sand extraction; and
- Changes in baseflow contributions to surface watercourses.

The modelling assumed that dewatering would occur by pumping out water that flows into the excavation, rather than by external dewatering, although some external pumping may be used if it proves to be beneficial or necessary. Total predicted inflows to the staged extraction areas of the Project range from 0.01 ML/d to 0.12 ML/d, resulting in annual inflows as high as 43.8 ML/annum. These inflows will need to be licensed under the 1912 Water Act, and it is noted that there is currently an embargo in place for the granting of new groundwater licences in this area. An equivalent licensed volume will therefore need to be purchased for these groundwater inflows.
Groundwater modelling has indicated that baseflows to the hanging swamps that are located to the east and southeast of the Project Site can be maintained and possibly enhanced throughout the project life due to the increased effective recharge that will occur as operational areas are exposed, provided a Hawkesbury Sandstone veneer overlaying the Berry Formation is maintained during the sand extraction from the Sand Quarry. It has therefore been decided to retain a basal layer of permeable sandstone beneath the quarry floor, by stopping extraction 2m from the base of the Hawkesbury Sandstone, to allow ongoing groundwater throughflow to continue through the project life.

The calibrated groundwater model has shown that pre-quarrying baseflow contributions to the hanging swamps are in the order of 0.4 ML/d. Modelling indicates that these baseflows will be only marginally affected by the Project. Effective recharge will tend to increase as areas are de-vegetated and conductive sandstone is exposed in advance of sand extraction. Conservative model predictions indicate that baseflows to the hanging swamps would only reduce, as a maximum, by around 0.05ML/d during quarry operations, and sensitivity analysis indicates that baseflows are actually likely to increase, due to reduced evapotranspiration after vegetation clearing. Baseflows to the hanging swamps near the end of extraction are predicted to be at, or higher than, the baseflows prior to the start of the Project.

The groundwater assessment also shows that extraction from the proposed quarry should not have any adverse impacts on water quality or other groundwater users in the area.

As part of the potential water supply for the site, two test production bores have been constructed and tested within the Berry Formation. Analysis indicates that these or similar bores could have a sustainable yield of 0.5 L/s each (16 ML/annum), which would also need to be licensed under the 1912 Water Act if they are to be used for water supply purposes. Analytical assessment has shown that the use of these bores will not affect other groundwater users in the area.

In summary, the impact assessment studies have demonstrated that:

- the Project will not affect the hanging swamps which are located downstream of the Project Site which are partially fed by groundwater originating within the site;
- the Project will not affect the hanging swamp located on the northern side of the Hume Highway near the proposed southern access road;
- the Project will not affect the baseflow to Paddys River and down-slope creeks; and
- a viable water supply is available for the Project.

Management and Monitoring of Impacts

A number of water management activities are recommended to prevent pollution of groundwater from site activities. These are detailed within the main report. As noted previously, it is also recommended that a 2 m ‘veneer’ is left at the base of the sandstone aquifer to allow through flow of groundwater recharge and prevent significant impacts on the rate of discharge to the hanging swamps to the east and southeast.

Although impacts from the proposed project are generally anticipated to be small, a monitoring programme will be required to validate predictions and mitigate any detrimental impacts that occur as a result of sand extraction.

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Recommendations for the monitoring and review programme are contained within this report, and include the following:

- Monitoring of inflows and operational water use.
- Ongoing automated monitoring of water levels from the network of monitoring bores.
- Water quality monitoring of inflows to extraction areas and groundwater in monitoring piezometers.
- Regular data review by a suitably experienced hydrogeologist.
- Review and validation of the groundwater model predictions and updating, if deemed necessary.
- Procedures for investigation and response actions if data indicate that impacts on groundwater level or quality are greater than assessed trigger values, or if complaints are received by other groundwater users.
- Annual review of the data being collected to ensure it is meaningful, and adjustment of the monitoring program, if deemed appropriate.
1. INTRODUCTION

Rocla Pty Limited (Rocla) is proposing a sand extraction and processing operation referred to as the Green Valley Sand Quarry (the Project), within the “Green Valley” property located approximately 28km south of Berrima (Figure 1.1). The Project Site lies to the west of the Penrose Sand Quarry, which is operated by Boral Construction Materials. It is bounded to the south and west by Paddys River, to the north by the Hume Highway and to the east by private land and the Penrose State Forest.

Up to 41 million tonnes of friable sandstone (of the Hawkesbury Sandstone formation) would be extracted over the life of the quarry and processed through an on-site washing plant to produce approximately 30 million tonnes of sand. The anticipated life of the quarry is approximately 30 years.

This report presents the results of an assessment of hydrogeological conditions and the potential impacts of the proposed Project on local and regional groundwater resources. The assessment was undertaken by Aquaterra Consulting Pty Ltd (Aquaterra) on behalf of Rocla. The assessment has addressed the following:

- Existing groundwater conditions within and surrounding the Project Site.
- Local groundwater - surface water interactions.
- Identification of all local groundwater users that may be potentially affected by the Project.
- Compilation of data from the on-site piezometer network, identifying groundwater levels and quality.
- Identification of potential constraints on the Project related to groundwater.
- Determination of criteria for impact assessment.
- The potential impact of the Project on groundwater baseflows to down gradient hanging swamps.
- Monitoring requirements.
- Design of impact management strategies and operational safeguards to protect groundwater resources.
2. GROUNDWATER INVESTIGATIONS

2.1 PREVIOUS INVESTIGATIONS – PENROSE SAND QUARRY

A number of previous investigations have been undertaken relating to geology, groundwater and surface water quality at the nearby Penrose Sand Quarry, which is owned and operated by Boral Construction Materials. Information relating to previous studies for the Penrose Quarry has been taken from reports provided by Penrose Quarry.

We understand that the Penrose Sand Quarry is currently placed in care and maintenance. When in operation, friable sandstone from the Hawkesbury Sandstone formation was ripped and excavated, and processed through an on-site washing plant. Water supply for Penrose Sand Quarry was sourced from a combination of surface runoff and groundwater seepage within quarry site. In addition, the quarry is licensed to extract up to 84 ML/annum from Hanging Rock Swamp.

Golder Associates undertook investigations for the Penrose Sand Quarry between 1992 and 1997. Reports on the most recent investigations (Golder, 1997a) and ongoing surface water and groundwater quality monitoring (Golder, 1997b) have been reviewed for information relevant to the Rocla Green Valley Sand Quarry Project. The Golder investigations comprised drilling and piezometer installation, water sampling and analysis, permeability testing and groundwater modelling. The 1997 program was carried out in support of an Environmental Impact Statement for a proposed extension of the quarry.

A series of 29 piezometers were installed on the Penrose site. Six piezometers were monitored annually (BH2, BH5, BH6, BH7, BH17 and BH22). Monitoring points were also established in the Hanging Rock Swamp, and these were sampled periodically. A summary of the construction details and hydraulic nature of each of the piezometers is provided in Table 2.1.

In 2004, Peter Dundon and Associates undertook an independent review of the Golder reports and other relevant information, on behalf of a potential purchaser of the Penrose Quarry project (Dundon, 2004). The results of that review have been used in the interpretation of site conditions for this report.
Table 2.1
Penrose Quarry – Monitoring Bore Data

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<th>Bore</th>
<th>Bore Depth (m)</th>
<th>Surface RL (mAHD)</th>
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NOTES:
HS  Hawkesbury Sandstone.    PS  Permian age sedimentary rock (Berry Formation).
R  Rising head permeability test   F  Falling head permeability test

2.2 RECENT INVESTIGATIONS – GREEN VALLEY SAND QUARRY PROJECT SITE

Aquaterra has undertaken hydrogeological investigations for the proposed Project, which have included the following:

- Drilling of test bores and piezometer installation.
- Measurement of water levels.
- Hydraulic testing.
- Water quality sampling and hydrogeochemical analysis.
- Search of the NOW2 groundwater database to confirm local groundwater usage.

The results of these studies are detailed in Section 3 of this report.

A number of other specialist studies have also been conducted for the Project. Some of these are relevant to the groundwater investigations, including:

- Geological investigations, comprising sandstone resource drilling and mapping (Koncek, 2008).
- Soils and surface water hydrology studies (SEEC, 2010).
- Ecological studies (Mills, 2010).

Relevant results from these investigations are also contained in Section 3 of this report.

---

2 NSW Office of Water, formerly Department of Water and Energy (DWE)
2.2.1 Piezometer Installation and Monitoring

Twenty-two boreholes have been drilled on the site during the 2006 and 2008 sand resource drilling programs, denoted GV01 to GV22 on Figure 2.1. The boreholes were core-drilled at 98 mm diameter (HQ) by Intertech Drilling Services. Ten of these boreholes were completed as piezometers (denoted by the prefix MW, as shown on Figure 2.1), which were cased with 50mm PVC, screened with slotted casing thorough the monitored horizon, and constructed with gravel packs and bentonite seals as appropriate. One of which (MW22) has been dry since installation.

In addition to the piezometers, a monitoring point (MW10B on Figure 2.1) was established within a groundwater discharge area downslope to the south-east of the proposed extraction area. This monitoring point was constructed by burying a concrete culvert section into the edge of the swamp to enable monitoring of groundwater levels within the swampy ground at this location.

Manual monitoring of groundwater levels in the piezometers was initially undertaken until August 2008. Automatic water level recorders were then installed in six of the piezometers (MW1, MW2, MW10A, MW10B, MW14 and MW18) in August 2008, and are recording water levels at 6-hourly intervals. The other piezometers are monitored manually at irregular intervals.

Bore construction details and groundwater levels recorded in July 2010 in each piezometer are presented in Table 2.2.

<table>
<thead>
<tr>
<th>Bore ID</th>
<th>MGA Coordinates</th>
<th>Depth (m)</th>
<th>Surface (mAH)</th>
<th>Depth to Base of Hawkesbury Sandstone (m)</th>
<th>Screen interval (m)</th>
<th>Water Level (mAH)</th>
<th>Depth to Water (m)</th>
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<td>MW01</td>
<td>237850 6163490</td>
<td>24</td>
<td>667</td>
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<td>41</td>
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<td>32.8</td>
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<td>MW10A</td>
<td>238711 6162692</td>
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<td>23 - 29</td>
<td>644.7</td>
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<td>0.8</td>
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<tr>
<td>MW11</td>
<td>238004 6163651</td>
<td>42</td>
<td>677</td>
<td>38.3</td>
<td>33 - 39</td>
<td>643.5</td>
<td>33.5</td>
</tr>
<tr>
<td>MW14</td>
<td>237508 6162918</td>
<td>14.5</td>
<td>672</td>
<td>10.2</td>
<td>5.5 – 11.5</td>
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</tr>
<tr>
<td>MW16</td>
<td>237742 6162620</td>
<td>29.6</td>
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<td>17 – 29.5</td>
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<td>24.6</td>
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<tr>
<td>MW17</td>
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<td>665</td>
<td>28.3</td>
<td>8 – 29.6</td>
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<tr>
<td>MW18</td>
<td>238263 6162897</td>
<td>23.7</td>
<td>657</td>
<td>22.5</td>
<td>8 – 23.7</td>
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<td>238155 6162379</td>
<td>5</td>
<td>652</td>
<td>NP</td>
<td>1 – 5</td>
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<td>Dry</td>
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</tbody>
</table>

NP = not present

* MW10B is a monitoring point located within a groundwater discharge area above Hanging Rock Swamp

** Review of the construction of bore MW14 shows that the ‘groundwater’ level relates to an extended sump that extends 3m below the screen interval. The monitored horizon is dry and the measured water level simply relates to water left within the sump following construction
2.2.2 Hydraulic Testing of Piezometers

Testing of aquifer characteristics in the piezometers was conducted by Aquaterra in October 2008 and January 2009. A summary of the testing program and results is provided in Section 3. Test data are presented in Appendix A.

Slug tests (falling head permeability tests) were undertaken on all piezometers except the dry bore MW22 to derive estimates of aquifer hydraulic conductivity (permeability). The slug test procedure involved adding a slug of water to each piezometer and then recording water-level recovery back to a static level using a downhole pressure transducer. The slug test data were analysed using the Hvorslev Method (Hvorslev, 1951) for tests on the hard rock units, which are suitable for providing ‘near well’ estimates of aquifer hydraulic conductivity (K).

Short term constant rate (CR) pumping and recovery tests were also undertaken on six piezometers which could sustain some low rate pumping (MW01, MW02, MW10A, MW16, MW17 and MW18) using a sampling pump. All bores tested intersected the Hawkesbury Sandstone.

2.2.3 Groundwater Supply Investigation

Full scale production at the Green Valley Project Site is understood to require a water supply of approximately 2.6 L/s (82 ML/a) during maximum production at 1,000,000 tpa. It is proposed that some of this would need to be obtained from local groundwater sources.

An investigation was undertaken to assess the potential for a local groundwater supply from the Berry Formation, the Permian aged sedimentary rock unit which underlies the Hawkesbury Sandstone, to meet part of the Project's water demand for processing purposes. The Berry Formation is considered to be a regional aquitard, but it is known to have limited water supply potential, due to the presence of jointing/fracturing associated with local/regional structures.

There are several licensed groundwater extraction bores within 2 km of the Project Site which are screened within the Berry Formation. Reported bore yields are as high as 3.5 L/s (eg GW108198).

A short term pumping test was conducted on an existing bore located adjacent to the Green Valley property homestead (House Bore), to test the yield of this bore as a potential process water supply source. The location of the bore is shown on Figure 2.1. The bore is known to be screened within the Berry Formation, but otherwise construction details are unknown. The bore depth is understood to be approximately 80 m.

Three additional bores (PB1, PB2, and PB3) were drilled during March 2009 as part of a water supply feasibility investigation. Locations of the test bores are shown in Figure 2.1. Bore details are included in Table 2.3. Two bores (PB1 and PB3) indicated potential for water supply and were completed as test production bores. The third bore (PB2) failed to intersect any water-bearing zones and was abandoned at 50 m and backfilled. PB1 and PB3 were drilled to depths of 102 m and 114 m respectively.

The bores were drilled by Highland Drilling at 200mm diameter using air rotary methods, and cased with 150mm class 18 PVC casing, with screens located adjacent to identified water inflow zones. The screens were manufactured by Highland Drilling from standard class 12, 150 mm PVC pipe. The casing-hole annulus was gravel packed to above the screens with 2 mm graded pea gravel, sealed by a bentonite seal and cement-groutied above.
On completion, the two installed bores (PB1 and PB3) were developed by airlift pumping (i.e., to establish hydraulic connection with the target aquifers). PB1 was airlifted for 205 minutes and PB3 for 120 minutes at rates of up to 1.5 and 1.8 L/s respectively. This enabled an initial assessment of likely sustainable yields.

As the Project Site is located within an embargoed area, test pumping was not permitted by the bore licence. It was, however, possible to monitor water level recovery after airlift development. Analysis of the recovery data indicated that individual sustainable bore yields of around 0.5 L/s are likely to be achieved for these or similar bores.

The test results for the testing undertaken on the house bore and the two test bores are included in Table 2.3. Test data are presented in Appendix A.

Airlifting during drilling suggested that the majority of groundwater inflow occurs from the upper 60 m of saturated shale, and therefore it is recommended that any additional bores be drilled to a maximum depth of 80 m within the Berry Formation.

### Table 2.3

<table>
<thead>
<tr>
<th>Bore</th>
<th>MGA Coordinates</th>
<th>Drilled Depth</th>
<th>Water Bearing Zones</th>
<th>Salinity (EC)</th>
<th>Screen Intervals</th>
<th>Airlift / Pump Yield</th>
<th>Standing Water Level</th>
<th>Recovery Test Results</th>
</tr>
</thead>
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<tr>
<td>PB1</td>
<td>E 238237    N 616339</td>
<td>102</td>
<td>47-48</td>
<td>180</td>
<td>36-48</td>
<td>0.5</td>
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<td>PB2</td>
<td>50</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>PB3</td>
<td>E 237259    N 6162986</td>
<td>114</td>
<td>35-36</td>
<td>300</td>
<td>30-42</td>
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<td>85-86</td>
<td>340</td>
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<td>1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>House Bore</td>
<td>E 239159   N 6162454</td>
<td>80</td>
<td>Unknown</td>
<td>327</td>
<td>Unknown</td>
<td>0.15</td>
<td>20</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### 2.2.4 Groundwater Quality

Water quality sampling of the piezometers and the surface water site (MW10A) was carried out in conjunction with the hydraulic testing program during 17 and 18 July 2008. Each bore was purged of at least four bore volumes prior to sampling, except for bores MW1, MW11, MW14, MW16 and MW18 which rapidly pumped dry due to a limited water make. Samples were collected from these bores following water level recovery after being purged dry. The sample from MW16 was very turbid, and may not be truly representative of the horizon screened. MW14 did not recover sufficiently after being pumped dry to allow a sample to be collected.

Field measurements of pH, EC and temperature were made during purging. Samples were then submitted to a NATA registered laboratory (ALS Environmental) for analysis of the following:

- Physio-chemical parameters – pH, EC, TDS, TSS and turbidity.
- Major cations/anions – Ca, Mg, Na, K; CO$_3$/$\text{HCO}_3$, alkalinity, SO$_4$ and Cl.
- Dissolved metals – As, Cd, Cr, Cu, Pb, Ni, Mn, Zn, Hg.

Results from this testing are summarised in Section 3 of this report.
2.3 SEARCH OF NOW GROUNDWATER DATABASE

A search of the NOW groundwater bore database was undertaken to assess groundwater usage in the vicinity of the Project Site. The search revealed thirteen (13) registered groundwater bores within a 2 km radius of the Project Site, including seven (7) monitoring bores located on the adjacent Penrose Sand Quarry site. Most of the other registered bores surrounding the area are used for private use. Locations are shown on Figure 2.1.

One registered bore (GW044851) lies within the Green Valley property, and is reported to have been drilled to a depth of 80 m. Water-bearing zones are reported from between 29 m and 45 m within jointed/fractured sandy shale, ironstone and conglomerate which is interpreted to be within the Berry Formation. No information on water quality is provided within the database.

Two further bores lie to the north of the Green Valley property, just across the Hume Highway (GW034230 and GW101829). GW101829 is screened within the Hawkesbury Sandstone is reported to yield good quality water with modest yields (less than 1 L/s). No standing water levels were recorded. GW034230 is very shallow and appears to be located in the weathered zone of the Shoalhaven Group. There is no information on yield or quality.
3. EXISTING ENVIRONMENT

3.1 TOPOGRAPHICAL SETTING

The “Green Valley” property covers an area of approximately 380 ha. The Project Site will occupy approximately 111 ha within the Green Valley property. The proposed limit of sand extraction is shown on Figure 3.1.

The extraction area has a medium to dense cover of eucalypt forest and radiata pine regrowth, and is located within elevated terrain ranging between approximately 685 mAH and 735 mAH. The central part of the property, where the sand extraction site will be located, is at relatively higher elevation and the terrain slopes steeply to the south and west from here towards Paddys River. The ground slopes less steeply to the east and southeast towards a hanging swamp terrain, which is part of the Hanging Rock Swamp that drains into Paddys River. Hanging swamp areas associated with the Project Site are shown on Figure 3.1. The Hanging Swamps have been delineated by soil landscape terrain mapping (SEEC, 2010). The elevated slopes above the Hanging Swamps represent groundwater discharge areas and provide groundwater seepage to the swamps and Paddys River.

Of particular relevance to local drainage is that the Hawkesbury Sandstone aquifer only occurs in the elevated areas above the hanging swamps and does not intersect the swamps. The subsurface drainage towards the swamps is controlled by the surface of the underlying less permeable Berry Formation.

3.2 CLIMATE

The climate of the region is cool to temperate with seasonal climatic conditions ranging from hot summers to cool winters. The average daily maximum temperature ranges from 19.6 ºC in January to 6.0 ºC in July.

3.2.1 Rainfall and Evaporation

Four rainfall stations were investigated, two closed stations close to the Site (Penrose 68051 and Wingello 68067), plus the two closest open, active stations (Moss Vale 68045 and Goulburn 70263). The Penrose rainfall station (68051) is the closest geographically to the Project Site with a reliable and relatively complete rainfall record exceeding 50 years. 75 years of data were available, from 1900 to 1975, giving an annual average rainfall of 1,016 mm/yr. The closest meteorological station collecting evaporation data is at Goulburn, approximately 30km to the west-south-west of the Project Site. Mean monthly data for these sites are shown in Table 3.1.

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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</thead>
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<tr>
<td>Rain</td>
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<td>110.5</td>
<td>99.1</td>
<td>81.9</td>
<td>85.5</td>
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<td>56.4</td>
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<td>74.6</td>
<td>96.8</td>
<td>1,016</td>
</tr>
<tr>
<td>Evap</td>
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<td>127.1</td>
<td>78</td>
<td>52.7</td>
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<td>37.2</td>
<td>58.9</td>
<td>84</td>
<td>120.9</td>
<td>147</td>
<td>189.1</td>
<td>1,277.5</td>
</tr>
</tbody>
</table>

Annual evaporation for the site potentially exceeds precipitation in all but five months in the year (April to August).
3.3 GEOLOGY

3.3.1 Regional Geology
The Project Site is located on the south-western edge of the Sydney Basin where the near-surface bedrock generally consists of Triassic age sedimentary rocks. The Geological Survey of NSW 1:250,000 Geological Series Wollongong map-sheet indicates that the area is located at the edge of the outcrop extent of the Triassic Hawkesbury Sandstone Formation, which unconformably overlies the Permian age Shoalhaven Group. The Hawkesbury Sandstone outcrops on ridges and hill tops, with the Permian sedimentary rocks outcropping in eroded valleys.

Isolated igneous rocks occur in the area, consisting mainly of weathered remnants of Tertiary basalts.

The Hawkesbury Sandstone is indicated on the map-sheet to be quartz sandstone with some shale lenses. The Permian sedimentary rocks of the Shoalhaven Group are reported to be typically siltstone, shale and sandstone.

3.3.2 Project Site Geology
The geology for the Green Valley Project site is based largely on the interpretation of exploratory drilling by geologist Len Koncek (Koncek, 2008). That report details descriptive logs of 22 diamond drill holes drilled during 2006 and 2008. These bores were drilled to a maximum depth of 48m below ground surface, generally penetrating the Hawkesbury Sandstone (where present) and a short distance into the underlying Berry Formation. Drillhole locations, including those that were converted to groundwater monitoring bores, have been shown previously on Figure 2.1.

The Hawkesbury Sandstone underlies elevated parts of the Project site (i.e. mostly in the central part of the "Green Valley" property). The Hawkesbury Sandstone on this site typically comprises friable, fine- to coarse-grained quartzose sandstone. The majority of the sandstone has been logged by Koncek (2008) as soft and friable, very weathered and porous sandstone, with the weathering profile extending fully to the base of the sandstone unit. Some horizons are finer in grain size and clayey, grading to a siltstone. Some coarse-grained sandstone and pebbly horizons have also been noted. Occasional iron-rich (ironstone) horizons have also been noted. The boundary of the area underlain by Hawkesbury Sandstone is shown on Figure 3.2.

The less-elevated parts of the property are underlain the Berry Formation, which comprises siltstone, sandstone and shale, as discussed previously. The Berry Formation is part of the Shoalhaven Group and comprises the Budgong Sandstone and an undifferentiated member comprising siltstone, sandstone and shale, which is the unit that is present beneath the Project Site.

The Golder investigations for the Penrose Sand Quarry revealed friable, relatively permeable Hawkesbury Sandstone up to at least 84m in thickness beneath the Penrose site to the west, unconformably overlying the less permeable Permian siltstones and shales. Weathering in the Hawkesbury Sandstone varied from extremely weathered to slightly weathered to fresh, and the sandstone contained zones of iron-staining and iron-induration.
3.4 HYDROGEOLOGY

3.4.1 Regional

The main stratigraphic units also form the major hydrogeological units, with the Hawkesbury Sandstone forming a regional aquifer, and the Shoalhaven Group forming a regional aquitard.

On a regional scale the aquifer potential in the Hawkesbury Sandstone formation is normally associated with fracture permeability. In places, leaching has resulted in locally occurring granular permeability and porosity, and this is present on the “Green Valley” property. The Shoalhaven Group shales and minor sandstones form a confining unit in many areas, and form a basal aquitard to the Hawkesbury Sandstone aquifer in this area.

3.4.2 Local Aquifers – Project Site

The main aquifer beneath the Project Site is the Hawkesbury Sandstone. The soft, friable nature of the weathered sandstone in this area means that it demonstrates significant inter-granular matrix flow and storage in addition to the larger-scale fracture flow that generally characterises the Hawkesbury Sandstone on a basin-wide scale. Weathering/leaching has also resulted in greater effective porosity than that generally seen within the broader Hawkesbury Sandstone. The Hawkesbury Sandstone has a limited presence at the Green Valley Project Site, due to its location on the southwestern margin of the Sydney Basin. The sandstone occurs only in elevated parts of the site, having been eroded from the valleys and hillslopes. It is virtually an outlier, bounded by outcrop on the eastern, southern and western sides, with only a limited connection to the more extensive Hawkesbury Sandstone occurrence within the basin to the north-west.

The underlying Berry Formation of the Shoalhaven Group constitutes a basal aquitard on the Green Valley Site, resulting in the development of a perched aquifer within the overlying sandstones. Groundwater levels within the sandstone are generally close to (within a few metres of) the base of the aquifer, and in places, the upper sections of the Berry Formation are dry beneath saturated sandstone. This was observed during drilling of the test bores PB1 and PB3 located just downslope of the outcrop line of the Hawkesbury Sandstone, where the upper part of the Berry Formation drilled dry. Groundwater levels following bore development were in the order of 20 m below natural ground surface.

There is a thin shale lens present within the sandstone near the northern part of the “Green Valley” property (intersected in boreholes GV10, GV11, GV21 and GV2), which probably causes localised ephemeral perching within the sandstone aquifer depending on the frequency and local effectiveness of rainfall recharge. The geological logs from exploration drilling indicate that there are thin horizons of ironstone and shale elsewhere, which may also result in minor localised perching.

3.4.3 Groundwater Levels and Flow

Water levels recorded at each of the site piezometers during July 2008 have already been presented within Table 2.2. Hydrographs of the water level data gathered from the continuous water level monitors in Project Site piezometers are presented in Figure 3.3. These hydrographs show very little variation in water levels through time, with no discernable seasonal variation, and only minor responses to rainfall events. The sharp rise and slower fall in water levels in MW14 in July 2008 was due to slug testing being carried out at the time.
Figure 3.2 includes the interpreted groundwater contours for the site, based on the water levels listed in Table 2.2. Because the underlying shales have low permeability and very limited hydraulic connectivity with the overlying sandstones, the topography of the contact between the Hawkesbury Sandstone Formation and underlying shales exerts a strong control on groundwater flow within and from the sandstone aquifer. Within the Project Site, groundwater in the sandstone generally flows to the south-east, controlled principally by the slope of the contact, but also by a muted reflection of the surface topography.

The water level data and field observations indicate that the sandstone aquifer discharges mainly to the east and southeast, following both surface topography and the sandstone/shale contact. Discharge mechanisms and the interactions between groundwater and the hanging swamps and other surface waters are discussed in Sections 3.4.6 and 3.4.7.

Groundwater level information from the nearby Penrose Quarry Site, as described in Section 2.1, is also included within Figure 3.2, and is consistent with the above interpretation. Like the Green Valley Site, there is evidence of springs with swampy vegetation downslope of the outcrop line of the unconformity between the sandstone and underlying shale on the slopes above Paddys River.

Piezometer MW22, drilled to the south of the sandstone outcrop line and into the underlying Berry Formation shale, was dry. The two test bores drilled to the north-west and west revealed groundwater levels in the Berry Formation about 20m below the base of the Hawkesbury Sandstone. There is insufficient information on groundwater distribution within the Berry Formation to determine if an extensive water table aquifer exists. If present, it is believed that a water table in the shale would show a subdued reflection of surface topography but probably with a much steeper hydraulic gradient than the sandstone.

### 3.4.4 Aquifer Hydraulic Properties

#### 3.4.4.1 Hawkesbury Sandstone

Results of hydraulic testing of piezometers at the Project Site are shown in Table 3.2.

Results of hydraulic testing on installed monitoring bores indicate that hydraulic conductivity of the Hawkesbury Sandstone within the Project Site is approximately in the range 0.1 to 0.5 m/day. These values are relatively high for the Hawkesbury Sandstone compared with elsewhere in the Sydney Basin, and are more typical of fine grained loosely cemented sand. This reflects the locally weathered and friable nature of the sandstone.

These values are consistent with those obtained from earlier testing of the Penrose Quarry bores as detailed in Section 2.1 (Golder, 1997a), which also indicated average hydraulic conductivities ranging from 0.01 m/d to 0.5 m/d (1×10\(^{-7}\) m/s to 5×10\(^{-6}\) m/s). The lower values in that range were generally obtained from bores screened in the shale or both sandstone and shale.
3.4.4.2 Berry Formation

Results of hydraulic testing on test production bores installed into the Berry Formation, as described in Section 2.2, indicate that hydraulic conductivity of the shales beneath the Project Site are in the order of 0.01 m/d to 0.02 m/d, i.e. an order of magnitude less permeable than the Hawkesbury Sandstone.

Airlift development of the bores following construction, provided some indication of the long term performance as potential production bores. Recovery of water levels following cessation of airlift development was monitored on PB1 and PB3, and the results analysed to assess groundwater supply potential of the Berry Formation. PB1 and PB3 were airlifted for 205 min and 120 min respectively, at rates of 1.5 L/s to 1.75 L/s.

While the airlifting was not carried out for a sufficient length of time to identify the presence of any hydraulic barrier boundaries, it was sufficient to assess with reasonable confidence that the bores have the potential to each yield up to 0.5 L/s on a sustained basis.

3.4.5 Groundwater Quality

The assessment of groundwater quality in the vicinity of the Project site was based on sampling of the Green Valley piezometers (MW01, MW02, MW10A, MW11, MW14, MW16, MW17 and MW18), and previous sampling carried out for the nearby Penrose Quarry. The laboratory analysis results from the Green Valley sampling are presented in Table 3.3. Water quality data from the Penrose Quarry are summarised in Table 3.4.

In most cases, the laboratory analysis results for pH and EC were broadly consistent with those measured in the field, with the exception of borehole MW16, as discussed later.

Aquaterra Consulting Pty Ltd
### Table 3.3
Laboratory Analysis of Groundwater Quality Parameters

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<th>Sample ID</th>
<th>Units</th>
<th>Freshwater Ecosystem Protection Guideline</th>
<th>Drinking Water Guideline</th>
<th>MW1</th>
<th>MW2</th>
<th>MW10A</th>
<th>MW10B</th>
<th>MW11</th>
<th>MW14</th>
<th>MW16</th>
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#### GENERAL PARAMETERS

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<th>MW10B</th>
<th>MW11</th>
<th>MW14</th>
<th>MW16</th>
<th>MW17</th>
<th>MW18</th>
<th>PB1</th>
<th>PB3</th>
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<td>80</td>
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<td>Bicarbonate Alkalinity as CaCO₃</td>
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<td>3</td>
<td>0.012</td>
<td>0.128</td>
<td>0.05</td>
<td>0.006</td>
<td>0.01</td>
<td>0.391</td>
<td>0.007</td>
<td>0.015</td>
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<td>0.149</td>
<td>0.238</td>
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<td>0.044</td>
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<td>Mercury</td>
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<td>&lt;0.0001</td>
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**Notes:**
1. ANZECC (2000)
2. Based on ANZECC (2000) trigger values for protection of 95% of fresh water species

Exceedances of the ANZECC (2000) guidelines are shown in **bold**
Table 3.4
Penrose Quarry – Water Quality Data

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<td>53</td>
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<td>pH</td>
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<td>7</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>SO₄</td>
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<td>5.0</td>
<td>5.0</td>
<td>3.0</td>
<td>2.0</td>
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<td>NO₃</td>
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<td>0.2</td>
<td>0.1</td>
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The water quality results for the study area show the following general water quality characteristics for groundwater:

- The groundwater is moderately acidic, with pH generally in the range 4.5 to 5.5.
- The groundwater in the Hawkesbury Sandstone has low salinity, with EC generally in the range 75-200 µS/cm, and TDS less than 100 mg/L.
- Groundwater in bore MW16, which is thought to be representative of confined Berry Formation groundwater (as described below) is more saline, with EC in excess of 1000 µS/cm. The two Berry Formation test production bores (PB1 & PB3) on the Green Valley site yielded lower salinity water (EC less than 500 µS/cm), and reasons for this are discussed below.
- Surface water in the swamps has similar water quality and chemistry to the Hawkesbury Sandstone groundwater.
- The dominant ions in solution are sodium and chloride, with other cations calcium and magnesium generally below detection limits, and other anions sulphate and bicarbonate present at very low concentrations.

Overall, the Hawkesbury Sandstone groundwater is of generally potable quality, with low to very low TDS, but slightly low pH and elevated levels of manganese. All measured constituents are also below ANZECC (2000) freshwater ecosystem protection guideline values, apart from zinc. Natural dissolved zinc concentrations in the Hawkesbury Sandstone groundwater samples were in the range 0.006 to 0.128 mg/L, compared with the ANZECC freshwater ecosystem protection guideline value of 0.008 mg/L.

The elevated salinity noted in the laboratory results from MW16 is considered to be anomalous. The measured EC during purging was 98 µS/cm, which is similar to the ECs reported for other bores on the Site. However, laboratory EC of the sample collected after the bore recovered was 1250 µS/cm, more than 12 times higher. This might be partly as a result of the high turbidity of the sample due to the slow seepage into the bore after it was pumped dry during purging, but it may also represent a contribution from the underlying Berry Formation.
Water quality from the Berry Formation, as measured during pumping of the test bores, indicated a relatively low concentration of total dissolved solids, with water quality generally very similar to that measured within the Hawkesbury Sandstone. Analysis at the Penrose Quarry site indicates that ionic characteristics of the two ground waters are normally markedly different, as discussed below. It is considered that the similarity between the two waters on the Green Valley Site is probably due to fact that the fractures intersected in these boreholes are readily recharged because they subcrop locally in contact with the stream system.

The major ion concentrations for the groundwater samples collected from the Project Site bores have been plotted on a Piper Trilinear Diagram in Figure 3.4. The relative concentrations of the major cations (calcium, magnesium, sodium and potassium) and major anions (chloride, sulphate and bicarbonate) provide a useful indicator when comparing water samples from different sources.

The Piper plot provides a means of visually comparing samples on the basis of the relative concentrations of the major ions. Differences in the relative ionic concentrations indicate different water types that may reflect different primary sources, differences in the rates of or proximity to recharge, and possible mixing of waters from different sources. All the Hawkesbury Sandstone samples and the swamp sample from the Project Site plot in a close grouping near the right hand apex of the diamond field on the Piper diagram, indicating that the samples from both the Hawkesbury Sandstone and the Green Valley swamp are derived from a common source. The low TDS and water quality signature indicate that the water is derived from recent/local rainfall recharge.

The water samples from the two Berry Formation test bores PB1 and PB3 plot in a different part of the diamond field on the Piper diagram (Figure 3.4), indicating that this water and the Hawkesbury Sandstone groundwater are separate water sources, even though both have low salinity.

Figures 3.5 to 3.7 show Piper Trilinear Diagrams for water samples collected previously from the Penrose Quarry (Golder, 1997). The Penrose data also show distinctively different water chemistry between the groundwater in the Hawkesbury Sandstone and that in the underlying Permian shale (Dundon, 2004). The surface water samples derived from Hanging Rock Swamp have similar ionic composition to the Hawkesbury Sandstone groundwater, providing strong evidence that the sandstone is the primary source of water in the swamps.

Hanging Rock Swamp water quality data taken from the adjacent Penrose Quarry site (Figure 3.7) is shown on Figure 3.4 by a highlighted ellipse. The Green Valley swamp water quality, represented by data from site MW10B, indicates that the water quality in hanging swamps within the “Green Valley” property is closer to the Hawkesbury Sandstone groundwater quality than that seen in the adjacent Penrose Quarry site.

3.4.6 Recharge and Discharge

The main recharge mechanism for the groundwater beneath the Project Site is considered to be local infiltration of rainfall. Rainfall runoff infiltrates the sandstone and percolates to the groundwater table within the Hawkesbury Sandstone.
The groundwater in the Hawkesbury Sandstone forms a perched aquifer above the Berry Formation aquitard, and discharge to the surface water system occurs around and downslope of the subcrop line of the sandstone/shale contact. The Hawkesbury Sandstone in this area forms an isolated outcrop, so the groundwater it contains has a totally localised flow system, and discharges locally to surface drainages. It does not form part of a regional flow system across the Sydney Basin.

The direction of flow and discharge from the Hawkesbury Sandstone in the Project area is controlled by the easterly dip on the top of the underlying Berry Formation. Groundwater therefore flows in an easterly/southeasterly direction. Discharge from the sandstone aquifer initially seeps into and flows within a shallow weathered zone at the top of the shale. It then emerges at the surface some distance downslope from the edge of the sandstone, leading to the formation of the upland hanging swamps. This flow regime means that the hanging swamps occur some way downslope from the edge of the sandstone, rather than directly at the unconformity. The swamps then overflow to the surface drainage system. Because the basal contact between the sandstone and the underlying shale dips to the east/southeast, the swamps only occur on that side of the sandstone outcrop, and no seepage areas have been observed on the western or northern sides of the Project Site.

The hanging swamps develop on areas of elevated topography which are subject to an ongoing supply of water, generally where there is a slow seepage of groundwater. This leads to an accumulation of grass and reeds, and over time a buildup of peaty soil, which may in turn lead to additional capture of surface runoff. The hanging swamps that occur down slope of both the Penrose Quarry and the proposed Green Valley Sand Quarry are part of an extensive zone of swamps that have formed downslope of the Hawkesbury Sandstone sub-crop line in this area, known as Hanging Rock Swamp.

Some ephemeral discharges to springs in elevated areas may occur in other places where the contact between the Berry Formation and the Hawkesbury Sandstone is exposed at the surface. These spring flows would cease when groundwater levels drop in periods of reduced rainfall.

As the site is heavily to moderately vegetated by eucalypts and remnant plantation pines, there would be significant evapotranspiration losses occurring, which would reduce when the vegetation is cleared in advance of sand extraction. It is expected that the net recharge rate could increase from 105 of rainfall pre-extraction to around 205 or rainfall after vegetation clearing. This would lead to increased downslope discharge, and increased baseflow to the Paddys River drainage system.

3.4.7 Interaction with Surface Water

The Project Site is located within the catchment of Paddys River, which in turn is part of the Wollondilly River catchment. The Wollondilly River has a catchment area of in excess of 10,000 km² and forms part of the Warragamba Dam catchment, which contributes to Sydney's drinking water supply. Paddys River is the principal surface water feature receiving water from the local area including groundwater discharging from the Project Site. Paddys River itself is located to the south and west of the Project Site.
The hanging swamps around the Project Site tend to form at elevated sites above the main regional surface drainage elevations. They are underlain by the Berry formation in areas below the contact between the Berry Formation and the Hawkesbury Sandstone and fed by the seepage outflow from sandstone at and just above the contact between these two entities.

These hanging swamps perform important hydrological functions within the landscape by regulating and sustaining flows, reducing turbidity, and maintaining and enhancing the water quality of discharge streams. The groundwater that feeds these swamps is believed to provide a significant contribution to the stream/river baseflow.
4. PROJECT OVERVIEW

4.1 PROJECT DESCRIPTION

Rocla Pty Limited is proposing a sand extraction and processing operation within the Project Site, and the staged development of a final rehabilitated landform. Friable sandstones of the Hawkesbury Sandstone formation would be excavated and processed through an on-site washing plant. Up to 41 Mt of friable sandstone would be extracted over the life of the quarry yielding approximately 30 Mt of sand. The anticipated life of the quarry is approximately 30 years.

The proposed quarry operations will require process water for the production of sand products, which includes washing and removal of fine particulate matter. Processing activities would involve the use of a sand washing plant to reduce the quantity of fines in the washed sand products. These fines would be managed largely through on-site settling ponds. The oversize generated by processing would be used in site rehabilitation.

Water used in the washing plant and for dust suppression would be sourced from captured surface runoff and groundwater. Water recovered from the washing plant will be recycled through settling ponds, with makeup water derived from a captured surface water component and/or a groundwater bore(s) as required.

The Project Site currently contains extensive areas of regenerated native vegetation, pine plantations, cleared land, various drainage lines and sandstone outcrops. It is anticipated that, following excavation, areas no longer required for extraction operations would be partially backfilled with dewatered fines and/or imported excavated natural material, and the disturbed areas would be progressively reshaped and rehabilitated for future agricultural land use and nature conservation purposes.

4.2 POTENTIAL GROUNDWATER- RELATED PROJECT CONSTRAINTS

The possible constraints that the groundwater environment may impose on the proposed extraction of sandstone from the Project Site were considered to include:

- potential impacts on other groundwater users;
- changes to baseflow discharges to hanging swamps and to Paddys River;
- potential impacts upon Groundwater Dependent Ecosystems (GDE’s);
- sourcing an adequate water supply for the project;
- licensing requirements and possible conditions attached to licences; and
- potential downstream water quality impacts.

4.2.1 Potential Impacts on Other Groundwater Users

Of the thirteen registered bores within a radius of 2 km, only one has have been assessed to be potentially impacted by the Project. GW044851 lies within the “Green Valley” property and appears on the basis of this initial assessment to be down gradient of the groundwater discharge area, and screened in the Berry Formation. Because the bore is located within the “Green Valley” property, its project related status would negate any adverse impact on the existing low flow rate.
Two registered bores located to the north of the Project Site on the northern side of the Hume Highway (GW034230 and GW101829). These draw water up-gradient from the site, and the closest bore (GW034230) is very shallow and located within the weathered zone of the Shoalhaven Group. This means there are effectively no hydrogeological mechanisms linking the Project Site with these bores, so there will be no project related impacts at either bore.

Other bores in the area within a 2 km radius include monitoring bores within the adjacent Penrose Quarry, and others which are listed as being used for private and or stock and domestic purposes. None of the stock and domestic bores is considered to pose a constraint due to the interpreted disconnection between the aquifers screened by those bores and the sandstone deposit to be extracted on the “Green Valley” property.

4.2.2 Potential Changes to Baseflow Discharges to Hanging Swamp and Paddys River

Sand extraction below the water table will require a groundwater management plan to minimise impacts upon the surrounding hydrological environment. Requirements for this are described in Section 6 of this report.

Progressive extraction of the sand resource will involve partial removal of the principal Hawkesbury Sandstone aquifer within the Project Site. Groundwater inflow and the associated removal of groundwater from the proposed extraction area has the potential to cause a lowering of the water table within the sandstone aquifer around the excavation. This drawdown may affect groundwater gradients and flow directions in the immediate vicinity of the Project Site, and potentially reduce the flow volumes that are available to support the hanging swamps. However, the removal of vegetation and stripping of topsoil to expose the sandstone will increase rainfall recharge, which would locally increase groundwater levels and offset part, or even all, of the groundwater that is lost through the dewatering of the excavated area. The net effect of the Project activities on groundwater levels and baseflow discharges can therefore only be evaluated through quantitative numerical modelling, as described in Section 5.

Because the Hawkesbury Sandstone outcrops above all other strata, changes to groundwater levels and flow directions will be limited to the area where Hawkesbury Sandstone is present.

4.2.3 Potential Impacts on Groundwater Dependent Ecosystems (GDEs)

The only GDEs that have been identified are the Hanging Swamps adjacent to Paddys River and some of its tributaries down gradient from the Project Site (SEEC, 2010). Discharge from the sandstone aquifer supports hanging swamps and as noted above is a contributing source of baseflow within Paddys River.

4.2.4 Project Water Supply

At full production, the project will require a water supply of up to 2.6 L/s for operational purposes. It is anticipated that the Project’s water supply will be derived from a number of sources, which would include groundwater and the harvesting of rainfall run-off over the Project Site. Both are limited in capacity.
Investigation of groundwater supply potential as part of this study indicated that the two test bores that were drilled in the Berry Formation are potentially capable of sustaining a combined total of 1 L/s, over the life of the project. Numerical modelling, as detailed in Section 5, indicates that groundwater inflows to the mine workings will be between 0.16 and 1.44 L/s, with timing as detailed in Table 5.6. The proportion of this total inflow that could be collected and used for water supply cannot be quantified at this stage, as the amount of evaporation and potential re-infiltration to the groundwater system will depend on the detailed drainage set up within the pit, and can be significantly affected by issues such as the accumulation of fines (which tend to soak up and then evaporate water). The overall water balance that is described in the surface water assessment (SEEC, 2010) contains the assumption that around 35% of the water entering the excavation could be usefully captured. This is a realistic lower estimate for an active quarry site that includes excavation of permeable material. However, it is noted that the installation of active interception methods (such as shallow drainage channels, sumps or small benches that prevent seepage to the wider quarry floor) on the downslope perimeter of the active extraction area could reduce losses and increase the amount of groundwater that is available for use. The additional water supply that could be obtained by using such methods needs to be considered against the operational difficulties that could be caused by including them within active excavation areas.

4.2.5 Licensing and Downstream Water Quality Impacts

Sand extraction is proposed to occur below the present water table and therefore a groundwater licence will be required under the 1912 Water Act. Any abstraction bores will also need to be licensed. Currently there is an embargo on new licences in this area, imposed for the NSW Southern Highlands and gazetted on the 16th December 2005. Existing licences will therefore need to be traded (purchased) in order to access and use groundwater from the excavation and from any abstraction bores.

It is noted that the site may be covered by the proposed Greater Metropolitan Region Water Sharing Plan (WSP), which will implement the 2000 Water Management Act in this area. However, the constraints that might be imposed by this will not be clear until the WSP is gazetted.

Because the Project Site is included within the catchment for the Greater Sydney water supply, the Sydney Catchment Authority places a Neutral Beneficial Effects test on new developments, which requires no net impact on downstream water quality. As described in Section 5, there are no impacts that would result in changes to the water quality of groundwater discharges to hanging swamps and hence to Paddys River, so there is no groundwater-related reason why the site would not satisfy the Neutral Beneficial Effects test.
5. **GROUNDWATER IMPACT ASSESSMENT**

5.1 **BACKGROUND**

The potential local and regional impacts of the “Green Valley” Sand Quarry Project on the groundwater environment have been assessed largely with the aid of numerical groundwater flow modelling, and an appropriate groundwater model was developed to simulate the groundwater system of the Project Site.

The model simulates the staged extraction plan and schedule as outlined in the EA. The extraction plan and schedule included seven extraction stages over a 30 year period. Figure 5.1 shows the indicative staged extraction sequence for the overall project. Extraction within the initial stage of the quarry area would commence at an annual rate of approximately 200 000 tpa in the first year, increasing to 800 000 tpa within 5 years.

Some analytical and qualitative assessment methods were used to evaluate potential impacts on other groundwater users from potential pumping from water supply bores, and to assess potential impacts on groundwater quality. These are described at the end of this Section.

5.2 **CONCEPTUAL GROUNDWATER MODEL DESIGN**

The conceptual model is a simplified representation of the real system, identifying the most important geological units and hydrogeological processes, while acknowledging that the real system may be hydrogeologically and geologically more complex. The conceptual model forms the basis for the numerical groundwater flow model.

The key conceptual model features of the Green Valley model are graphically illustrated in Figure 5.2 and can be summarized as follows:

- An unconfined, perched aquifer in the Hawkesbury Sandstone, underlain by an aquiclude (Berry Formation shale). The shale forms a no-flow barrier, which is relatively flat-lying with a gentle dip to the east and south-east. The dominant groundwater flow within the local hydrogeological system occurs within the sandstone aquifer.
- The unconfined sandstone aquifer is recharged solely by rainfall infiltration and there is no groundwater inflow from the west or north.
- Groundwater flows to the east and southeast, where it discharges to the surface at the edge of the sandstone occurrence (where the upper surface of the underlying shale aquitard outcrops) and into the drainage pathways to the east of the “Green Valley” Property and then into the hanging swamp system, which in turn discharges into Paddys River.

5.3 **GROUNDWATER MODEL SET-UP**

5.3.1 **Modelling Software**

A 3-Dimensional finite difference model was used to simulate extraction operations and is based on the MODFLOW code in conjunction with SURFACT (Version 3, HydroGeoLogic, Inc., 2006), operating under the Groundwater Vistas (Version 5.16) graphic interface software package (ESI, 2006).

The use of MODFLOW - SURFACT allows for both saturated and unsaturated flow conditions and provides for more stable drying and re-wetting of cells in thin model layers.
5.3.2 Model Set-up

5.3.2.1 Model Domain and Boundary Conditions
The model domain covers a 9 km² area, as shown in Figure 5.3. It includes the proposed Green Valley extraction area and extends to the Hume Highway to the north, and to the east, west and south as far as the outcrop line of the Hawkesbury Sandstone. The active areas in the model domain encompass the full extent of the Hawkesbury Sandstone across the “Green Valley” property.

The model comprises a grid of 120 rows and 120 columns (total of 14400 cells) with uniform cell size (25m x 25m).

The model boundary conditions in the Green Valley model have been assigned to represent the regional groundwater flow system in a realistic manner, taking into account stratigraphic and topographic controls. The western and northern (upslope) margins of the Hawkesbury Sandstone outcrop are set as a no-flow boundary. The south-eastern margins of the sandstone have been assigned as drain cells to simulate the predominant groundwater discharge process (seepage). The drain stage elevations were set to 1m above the bottom elevation of the aquifer, which ensured that all near surface flow to this boundary was simulated and quantified by the use of the drain cells.

5.3.2.2 Aquifer Representation
The sandstone aquifer was represented numerically using three model layers. Layer surface elevation data is presented in Appendix B.

The top elevation of Layer 1 was specified from the surface topography Digital Elevation Model. The bottom elevation of Layer 3 was defined by sandstone floor elevations. This surface also represents the contact with the underlying Berry Formation. The Berry Formation itself was not included as part of the model as it is believed to be dry immediately beneath the Hawkesbury Sandstone in this location and forms a regional aquitard, with little groundwater exchange with the overlying sandstones, and it will not be affected by the quarry extraction.

Three layers were used to represent the sandstone aquifer to allow for simulation of progressive sand extraction and changes to aquifer properties over time during extraction and partial backfilling. This layer set up also allowed for the 2m veneer of Hawkesbury Sandstone that will be left beneath the extraction in order to maintain groundwater flow beneath extraction areas.

Prior to sand extraction, all three layers were representative of the in-situ sandstone, and had the same hydraulic properties. During progressive extraction, the properties of Layers 1 and 2 were changed as the sandstone was removed and the void was partially backfilled by fines and capped with oversize material and VENM/ENM. Layer 3 maintained the in-situ sandstone hydraulic characteristics. Post extraction model parameters were modified over time to represent void and fill characteristics following excavation and backfilling.
5.3.2.3 Recharge

Long term recharge varies across the area according to land use. Based on the results of previous studies in the area and of quarry projects elsewhere, recharge rates of between 3% and 10% of rainfall were adopted across the site for pre-extraction conditions. The highly permeable nature of the land surface in areas where the Hawkesbury Sandstone outcrops means that a high proportion of incident rainfall will infiltrate to the subsurface and only a small percentage will run off. The vegetative cover of eucalypts and plantation pines would cause a large proportion of infiltrated rainfall to be lost to evapotranspiration. In this environment, the recharge rates of 3% to 10% represent the net difference between infiltration and evapotranspiration.

The range of recharge values was empirically checked against a simple chloride mass balance assessment. Chloride mass balance can be used to estimate the upper potential limit of recharge rates for the “Green Valley” property. The chloride mass balance method is based on the conservation of mass below the root zone. Chloride is a relatively inert ion, and normally the only significant concentrating factor for chloride is evapotranspiration.

The chloride mass balance is a widely accepted method (US Salinity Laboratory (1954)) and has been successfully used to determine drainage under irrigated sites. The method assumes that the chloride concentration in the groundwater relative to the chloride concentration in rainfall provides an indication of the percentage of rainfall that reaches the water table as recharge. This approach assumes that chloride is entirely conservative – i.e. there is no gain or loss of chloride from the system during recharge and evapotranspiration, and that evapotranspirative concentration is the only mechanism that alters the chloride concentration, so the assessment will provide an upper limit on possible recharge rates.

Within the “Green Valley” property, groundwater samples from monitoring bores screened solely within the Hawkesbury Sandstone contained very low chloride concentrations (mean of 32 mg/L in July 2008), compared with the estimated concentration of chloride in rainfall for this area of 4 mg/L (Hutton, 1976).

Measurements of chloride concentrations in sampled groundwater and assumed concentrations in rainfall were used to estimate recharge using the following equation:

\[ R = \frac{(P \times C_p)}{(C_a \times 100)} \]

where

- \( R \) = recharge as a percentage of precipitation
- \( P \) = precipitation (mm/y)
- \( C_p \) = average chloride concentration of precipitation (in this case it was estimated to be around 4 mg/L, based on the calculations described in Hutton (1976))
- \( C_a \) = the chloride concentration of groundwater (mean of 32 mg/L).

This resulted in an upper limit of around 12% recharge as an average figure. The model calibration referred to in Section 5.4.1 indicates that this value is probably higher than the actual average recharge value across the site. However, the above analysis does indicate that the upper value of 10% recharge used in the calibrated model is realistic.

The range of chloride values shown in Table 3.3 indicates that recharge could be as high as 20% in some areas, and this appears to represent the upper limit for recharge to exposed, highly weathered, poorly vegetated areas of the sandstone outcrop.
Under pre-project conditions, evapotranspiration in the model was accounted for in the adopted recharge rates, which represented the difference between rainfall infiltration and evapotranspiration loss. Once the vegetation is cleared during the sand extraction process, evapotranspiration will be very much reduced over the cleared areas. There will still be some evaporative loss from any surface water that ponds within the excavation before it infiltrates into the ground, but this loss is still inherently allowed for within the higher recharge values that were used for the cleared areas.

Evapotranspiration was not therefore included in the model simulations as a specific, separate process.

5.3.2.4 Discharge to Hanging Swamps

Discharge to the hanging swamps down gradient from the extraction area was simulated in the model by drain cells around the southern and eastern margins of the sandstone aquifer, as described in Section 5.3.2.1. These drain cells are aligned along the southeastern outcrop margin of the sandstone occurrence and do not coincide with the mapped margins of the hanging swamps which are located some distance down slope from the edge of the Hawkesbury Sandstone /Berry Formation interface and beyond the Project Site.

5.4 MODEL CALIBRATION

Calibration is the process by which the independent variables of a model (parameters and boundary conditions) are adjusted, within realistic limits, to produce the best match between simulated and measured data. The parameter values assigned were constrained by the range of measured values from pumping tests and other hydrogeological investigations.

Steady state calibration was carried out, but transient model calibration was not appropriate because the piezometer water level hydrographs (Figure 3.3) showed negligible variation over the two years of baseline monitoring, indicating negligible response to varying rainfall conditions or other stresses.

5.4.1 Steady State Calibration

Steady state calibration is based on matching predicted versus observed long term average groundwater levels for long term average inputs (i.e. hydraulic conductivity and rainfall recharge distribution). The model was calibrated against groundwater levels measured during the investigations, which showed negligible variation over time and hence were considered to be representative of long term average (i.e. steady state) conditions. Assumed hydraulic parameters were adjusted to achieve an acceptable match between predicted and observed groundwater levels.

The calibrated model parameters (for the key steady-state calibration parameters):

- Rainfall recharge ranges from 3% to 10% of average rainfall, applied to four distinct zones.
- Hydraulic conductivity ranges from 0.1 m/d to 1 m/d, applied to three distinct zones.
The ratio of horizontal to vertical hydraulic conductivity (Kh to Kv) was 100:1. It is extremely difficult to measure this parameter directly, and factors of between 10:1 and 100:1 are often used for laminar sedimentary deposits of this type. In this case, because the sandstone is friable and very permeable, any silty layers will represent a significant impediment to vertical flow in comparison to the horizontal sandstone permeability, so a ratio at the higher end of the normal range was adopted in this case.

Plans (maps) of the distribution of these key calibration parameters within the model are presented in Appendix D.

Steady state model calibration performance can be demonstrated in quantitative terms by the model water balance and by visual comparison and statistical analysis of predicted versus observed head values.

Contour plots of predicted versus observed groundwater levels for the calibrated model are presented in Appendix C. These show a good match between predicted and observed groundwater levels.

The water balance for the steady-state calibration model was very good, with a total imbalance of less than 0.01%.

The 'scaled root mean square' (SRMS) error, based on the differences between measured and predicted heads, is commonly used as the major quantitative indicator for model calibration performance. This value is calculated as the root mean squared (RMS) value of head differences divided by the range of measured heads across the site. It was considered that a 10% SRMS value on aquifer water levels would be an appropriate target for this project, consistent with the Australian best practice modelling guidelines (MDBC, 2001). The calibration met this target, as discussed below.

Table 5.1 lists the predicted and measured water levels at the eight piezometers used for calibration. A scatter diagram of measured versus modelled heads is plotted in Figure 5.4. Table 5.2 shows the results of statistical analysis of the data plotted on Figure 5.4. The SRMS error of 8.71%, and the coefficient of determination of 1 confirm that the steady state calibration was sufficiently reliable for this investigation.

### Table 5.1
Steady State Model Calibration Groundwater Level Targets

<table>
<thead>
<tr>
<th>Bore</th>
<th>Easting (MGA)</th>
<th>Northing (MGA)</th>
<th>Observed Head (mAHD)</th>
<th>Simulated Head (mAHD)</th>
<th>Head Difference (m)</th>
<th>Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW01</td>
<td>238342.0</td>
<td>6163538</td>
<td>648.36</td>
<td>648.14</td>
<td>0.22</td>
<td>3</td>
</tr>
<tr>
<td>MW02</td>
<td>238706.3</td>
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<td>643.57</td>
<td>644.11</td>
<td>-0.54</td>
<td>3</td>
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<td>MW11</td>
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<td>MW14</td>
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<td>660.00</td>
<td>670.75</td>
<td>-10.75</td>
<td>3</td>
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<td>654.56</td>
<td>-1.10</td>
<td>3</td>
</tr>
<tr>
<td>MW17</td>
<td>238720.9</td>
<td>6163000</td>
<td>644.06</td>
<td>642.53</td>
<td>1.53</td>
<td>3</td>
</tr>
<tr>
<td>MW18</td>
<td>238891.2</td>
<td>6163002</td>
<td>640.83</td>
<td>637.63</td>
<td>3.20</td>
<td>3</td>
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<td>MW10A</td>
<td>238618.4</td>
<td>6163781</td>
<td>654.49</td>
<td>644.75</td>
<td>9.74</td>
<td>3</td>
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<tr>
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<td></td>
<td></td>
<td>648.66</td>
<td>648.50</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td>640.83</td>
<td>637.63</td>
<td>-10.75</td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
<td></td>
<td>660.00</td>
<td>670.75</td>
<td>9.74</td>
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</tr>
<tr>
<td>Range</td>
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<td></td>
<td>19.17</td>
<td>33.12</td>
<td>-</td>
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Aquaterra Consulting Pty Limited
<table>
<thead>
<tr>
<th>Calibration Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>N</td>
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<tr>
<td>Scaled Mean Sum of Residuals</td>
<td>SMSR</td>
</tr>
<tr>
<td>Root Mean Square</td>
<td>RMS</td>
</tr>
<tr>
<td>Scaled RMS</td>
<td>SRMS</td>
</tr>
<tr>
<td>Root Mean Fraction Square</td>
<td>RMFS</td>
</tr>
<tr>
<td>Scaled RMFS</td>
<td>SRMFS</td>
</tr>
<tr>
<td>Coefficient of Determination</td>
<td>CD</td>
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</tbody>
</table>

Table 5.2
Steady-state Calibration Performance of the Model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
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<tr>
<td>Scaled Mean Sum of Residuals</td>
<td>SMSR</td>
</tr>
<tr>
<td>Root Mean Square</td>
<td>RMS</td>
</tr>
<tr>
<td>Scaled RMS</td>
<td>SRMS</td>
</tr>
<tr>
<td>Root Mean Fraction Square</td>
<td>RMFS</td>
</tr>
<tr>
<td>Scaled RMFS</td>
<td>SRMFS</td>
</tr>
<tr>
<td>Coefficient of Determination</td>
<td>CD</td>
</tr>
</tbody>
</table>

5.4.2 Sensitivity Analysis

Model sensitivity analysis was carried out to assess the sensitivity of model predictions to the values adopted for the key model parameters. Sensitivity analysis was undertaken by first decreasing and then increasing one input parameter or boundary condition at a time, and evaluating the impacts of the changes on the calibration statistics. The base SRMS value for these runs was 8.71%.

Based on the understanding of the Site (conceptual hydrogeological model) and model calibration exercise, the key parameters were clearly:

- Hydraulic conductivity (horizontal and vertical); and
- Recharge.

The sensitivity analysis undertaken is summarised in Table 5.3. The results of the sensitivity analysis are listed in Tables 5.4 and 5.5.

Table 5.3
Parameters, Zones and the Multipliers Tested in the Sensitivity Analysis Process

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Zone</th>
<th>Calibrated Value</th>
<th>Layer</th>
<th>Model</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Hydraulic Conductivity</td>
<td>1</td>
<td>0.88 m/d</td>
<td>1,2,3</td>
<td>Steady-state</td>
<td>0.5, 2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.77 m/d</td>
<td>1,2,3</td>
<td>Steady-state</td>
<td>0.5, 2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1 m/d</td>
<td>1,2,3</td>
<td>Steady-state</td>
<td>0.5, 2</td>
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<tr>
<td>Vertical Hydraulic Conductivity</td>
<td>1</td>
<td>0.0088 m/d</td>
<td>1,2,3</td>
<td>Steady-state</td>
<td>0.1, 10</td>
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<tr>
<td></td>
<td>2</td>
<td>0.0077 m/d</td>
<td>1,2,3</td>
<td>Steady-state</td>
<td>0.1, 10</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.01 m/d</td>
<td>1,2,3</td>
<td>Steady-state</td>
<td>0.1, 10</td>
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<tr>
<td>Recharge</td>
<td>1</td>
<td>4.3%</td>
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<td>Applied to Highest Active Layer</td>
<td>Steady-state</td>
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<tr>
<td></td>
<td>2</td>
<td>6.5%</td>
<td></td>
<td>Applied to Highest Active Layer</td>
<td>Steady-state</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>10%</td>
<td></td>
<td>Applied to Highest Active Layer</td>
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<tr>
<td></td>
<td>4</td>
<td>3%</td>
<td></td>
<td>Applied to Highest Active Layer</td>
<td>Steady-state</td>
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### Table 5.4
Sensitivity Analysis of Horizontal Hydraulic Conductivity Values

<table>
<thead>
<tr>
<th>Zone</th>
<th>Calibrated Value</th>
<th>Layer</th>
<th>Multiplier</th>
<th>SRMS (%)</th>
<th>Zone</th>
<th>Calibrated Value</th>
<th>Layer</th>
<th>Multiplier</th>
<th>SRMS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.88</td>
<td>1,2,3</td>
<td>0.5</td>
<td>11.9</td>
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<td>1,2,3</td>
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<td>8.7</td>
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<td>2</td>
<td>0.77</td>
<td>1,2,3</td>
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<td>9.35</td>
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<td></td>
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<td>10</td>
<td>8.7</td>
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<tr>
<td>3</td>
<td>1</td>
<td>1,2,3</td>
<td>0.5</td>
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<td></td>
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<td>10</td>
<td>8.67</td>
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### Table 5.5
Sensitivity Analysis of Recharge

<table>
<thead>
<tr>
<th>Zone</th>
<th>Calibrated Value</th>
<th>Layer</th>
<th>Multiplier</th>
<th>SRMS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.3%</td>
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<td>0.5</td>
<td>8.93</td>
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<td>2</td>
<td>10.78</td>
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<td>2</td>
<td>6.5%</td>
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<td>8.76</td>
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<td>3%</td>
<td>Applied to Highest Active Layer</td>
<td>0.5</td>
<td>8.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>8.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>10.45</td>
</tr>
</tbody>
</table>

Overall, results show that the model is moderately sensitive to recharge and horizontal hydraulic conductivity, but is generally insensitive to vertical hydraulic conductivity (SRMS values remain well below the 10% target value when Kv is increased or decreased tenfold). Doubling or halving the recharge or horizontal conductivity parameters may lead to SRMS values slightly above the 10% target value. However, increasing or decreasing the vertical hydraulic conductivity values by tenfold has only minor impact on the SRMS % values.
5.5 MODEL PREDICTED GROUNDWATER IMPACTS

5.5.1 Approach
The groundwater modelling was used to assess the potential impacts of the Green Valley Sand Quarry Project on the groundwater environment, specifically with regard to:

- Predicted total groundwater abstraction rates (inflows to excavations plus any dewatering by pumping from bores);
- Regional and localised changes in groundwater levels as a result of sand extraction; and
- Changes in baseflow contributions to surface watercourses.

The model was used to estimate total groundwater inflows into the quarry, and to predict the effects on the hydrogeological regime that result from the progressive sand extraction, disposal of fine silts within the quarry and capping with overburden and over size material. The predictive simulation was run for a 33 year sand extraction period and for a 50 year post-extraction recovery period.

Impacts were predicted in terms of changes to groundwater levels and groundwater-surface water interactions. The model used for the predictions, based on the steady-state calibrated set of hydraulic properties and boundary conditions, is referred to as the ‘Base Case’ simulation.

In order to represent the progressive back filling of the extraction areas, it was necessary to use the ‘time slicing’ approach. This approach allows modelled values of hydraulic conductivity to be changed over time, which effectively allows the model to represent the changes in hydraulic conductivity caused by the change from in-situ sandstone, to extracted void and then backfilled areas. Because MODFLOW cannot allow changes in hydraulic conductivity with time during a model run, a series of consecutive models were run representing various “time slices”. The model was run for 16 time slices with the final groundwater heads from one time slice used as input heads for the next time slice. Hydraulic parameters and recharge rates were varied for each time slice as required to simulate void areas and backfill material.

5.5.2 Simulation of Sand Extraction and Void Backfilling
Sand extraction was represented in the model by specifying drain cells at the base of the layer wherever active extraction areas occur. The drain cell configurations and elevations were progressed in annual increments, in line with the progressive advancement of the pit, as shown in the extraction plan detailed on Figure 5.5. Drain cells were progressively deactivated as the relevant parts of the pit were backfilled with fines/oversize material.

In order to simulate the changes in hydraulic properties that occur during sand extraction (with the material inside the extraction area starting as friable sandstone, then being progressively replaced first by a temporary void and finally by backfill material), it was necessary to change the hydraulic properties of the in-pit cells with time in accordance with the proposed extraction/backfilling schedule. The ‘time slice’ approach, as described previously, was used to achieve this, with hydraulic properties being changed as relevant model cells changed from sandstone to void and finally to partially backfilled final landform.
The following assumptions were made during each time slice:

- The hydraulic conductivity (Kh and Kv) values of the cells representing the backfilled open cut areas were Kh = 1m/d and Kv = 0.1m/d for the top layer (representing the capping layer comprising coarse washery rejects or VENM), and Kh = 0.0001m/d and Kv = 0.00001m/d for Layer 2 (representing fine washery rejects or VENM).

- The recharge values of the cells representing open excavation parts of the quarry were increased to 20% of average rainfall. This range was based on the maximum calculated recharge rates described in Section 5.3.2, and reflect the level of recharge that would be expected for exposed, de-vegetated areas of the friable sandstone.

- The recharge values were changed to 10% of average rainfall for backfilled areas. This reflects a higher presence of fines and re-growth of vegetation in those areas. This value is uncertain, so the analysis of inflows and baseflow impacts has been described as a range, with 10% as the ‘Base Case’ recharge, but allowing for up to 20% recharge to backfilled areas as a sensitivity analysis in the predictions.

### 5.5.3 Predicted Inflow Rates and Swamp Baseflow

Table 5.6 provides a summary of the predicted inflows to active extraction areas and outflow discharge rates to the swamp areas for the ‘Base Case’ time slice model.

**Table 5.6**

Predicted Quarry Groundwater Inflows and Discharges to Hanging Swamps

<table>
<thead>
<tr>
<th>Project Year</th>
<th>Extraction Area Inflow (m³/d)</th>
<th>Baseflow to Swamps (m³/d)</th>
<th>Total Groundwater Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(m³/d)</td>
<td>(ML/d)</td>
<td>(m³/d)</td>
</tr>
<tr>
<td>1</td>
<td>52.6</td>
<td>0.05</td>
<td>377.5</td>
</tr>
<tr>
<td>2</td>
<td>55.0</td>
<td>0.05</td>
<td>373.8</td>
</tr>
<tr>
<td>3</td>
<td>62.6</td>
<td>0.06</td>
<td>367.5</td>
</tr>
<tr>
<td>4</td>
<td>41.7</td>
<td>0.04</td>
<td>369.0</td>
</tr>
<tr>
<td>5</td>
<td>54.4</td>
<td>0.05</td>
<td>367.8</td>
</tr>
<tr>
<td>6</td>
<td>28.6</td>
<td>0.03</td>
<td>366.0</td>
</tr>
<tr>
<td>7</td>
<td>46.4</td>
<td>0.05</td>
<td>373.2</td>
</tr>
<tr>
<td>8</td>
<td>21.5</td>
<td>0.02</td>
<td>382.0</td>
</tr>
<tr>
<td>9</td>
<td>42.5</td>
<td>0.04</td>
<td>388.9</td>
</tr>
<tr>
<td>10</td>
<td>14.3</td>
<td>0.01</td>
<td>395.2</td>
</tr>
<tr>
<td>11</td>
<td>78.3</td>
<td>0.08</td>
<td>394.8</td>
</tr>
<tr>
<td>12</td>
<td>57.8</td>
<td>0.06</td>
<td>387.1</td>
</tr>
<tr>
<td>13</td>
<td>68.3</td>
<td>0.07</td>
<td>374.2</td>
</tr>
<tr>
<td>14</td>
<td>96.9</td>
<td>0.10</td>
<td>352.3</td>
</tr>
<tr>
<td>15</td>
<td>124.7</td>
<td>0.12</td>
<td>343.4</td>
</tr>
<tr>
<td>16</td>
<td>97.2</td>
<td>0.10</td>
<td>363.4</td>
</tr>
</tbody>
</table>
Table 5.6 (Cont’d)
Predicted Quarry Groundwater Inflows and Discharges to Hanging Swamps

<table>
<thead>
<tr>
<th>Project Year</th>
<th>Extraction Area Inflow</th>
<th>Baseflow to Swamps</th>
<th>Total Groundwater Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(m³/d)</td>
<td>(ML/d)</td>
<td>(m³/d)</td>
</tr>
<tr>
<td>17</td>
<td>108.5</td>
<td>0.11</td>
<td>376.0</td>
</tr>
<tr>
<td>18</td>
<td>76.8</td>
<td>0.08</td>
<td>358.2</td>
</tr>
<tr>
<td>19</td>
<td>108.3</td>
<td>0.11</td>
<td>348.1</td>
</tr>
<tr>
<td>20</td>
<td>84.4</td>
<td>0.08</td>
<td>355.7</td>
</tr>
<tr>
<td>21</td>
<td>112.7</td>
<td>0.11</td>
<td>357.5</td>
</tr>
<tr>
<td>22</td>
<td>69.7</td>
<td>0.07</td>
<td>362.5</td>
</tr>
<tr>
<td>23</td>
<td>95.1</td>
<td>0.10</td>
<td>372.0</td>
</tr>
<tr>
<td>24</td>
<td>77.4</td>
<td>0.08</td>
<td>377.2</td>
</tr>
<tr>
<td>25</td>
<td>71.0</td>
<td>0.07</td>
<td>381.2</td>
</tr>
<tr>
<td>26</td>
<td>77.9</td>
<td>0.08</td>
<td>374.1</td>
</tr>
<tr>
<td>27</td>
<td>115.0</td>
<td>0.12</td>
<td>379.4</td>
</tr>
<tr>
<td>28</td>
<td>66.8</td>
<td>0.07</td>
<td>387.5</td>
</tr>
<tr>
<td>29</td>
<td>90.7</td>
<td>0.09</td>
<td>393.3</td>
</tr>
<tr>
<td>30</td>
<td>79.2</td>
<td>0.08</td>
<td>395.8</td>
</tr>
<tr>
<td>31</td>
<td>89.7</td>
<td>0.09</td>
<td>400.6</td>
</tr>
<tr>
<td>32</td>
<td>107.3</td>
<td>0.11</td>
<td>395.9</td>
</tr>
<tr>
<td>33</td>
<td>113.7</td>
<td>0.11</td>
<td>389.3</td>
</tr>
</tbody>
</table>

**Figure 5.6** shows the ‘total groundwater flux’ that is predicted for the ‘Base Case’ predictive model. The ‘total groundwater flux’ represents the total amount of water that is ‘lost’ from the model via drain cells, and is equal to the total inflows to the excavation plus the outflows to the drain/discharge areas on the model boundaries. This shows that the increase in recharge that is caused by the vegetation stripping in the ‘Base Case’ model increases the total predicted flux from 0.43 ML/d (430 m³/d) at the start to 0.50 ML/d (503 m³/d) at the end of sand extraction period. This compares with a total pre-quarry flux rate of 0.40 ML/d (400 m³/d).

**Figure 5.7** shows predicted inflows to the extraction area and discharge rates to the boundary drains (which represent discharge to the hanging swamps) separately year by year throughout the life of the project. As described in Section 5.5.1, two scenarios are shown, one assuming 10% rainfall recharge to backfilled areas, and the other 20% rainfall recharge:

- Total predicted inflows to the extraction area range from 0.05 ML/d (50 m³/d) at the start, to 0.11 ML/d (110 m³/d) at the end of sand extraction. Generally higher inflow rates predicted from Year 10 are due to the extraction area progressing to the north-east, where the extraction will penetrate deeper below the groundwater table. Higher rates of groundwater inflow are predicted if a recharge rate of 20% of rainfall is assumed for the backfilled areas, ranging up to 0.20 ML/d (195 m³/d) by the end of the project.
For the 10% recharge scenario, model-predicted discharges through the downgradient drain cells (i.e. to the hanging swamps) are moderately reduced during the early stages of the quarry operation, but this reduction represents only a small proportion (10% or less) of the pre-project discharge rate. There is no net impact by the end of the excavation schedule. In the case of a 20% recharge rate, the discharge to the hanging swamps (drain cells) actually increases during the life of the quarry.

The above analysis shows that the increases in recharge that occur as a result of de-vegetation and sand exposure during project excavation and backfill activities result in a total groundwater flux (i.e. inflow to the excavation plus discharge to the hanging swamps) that increases steadily through the project, from an initial 0.40 ML/d to 0.50 ML/d at the end. Because of this increase in total flux, the analysis indicates that it will be possible to use the groundwater inflows that occur to the excavation area for water supply purposes, without significantly affecting the rate of discharge of groundwater to the down gradient hanging swamp areas.

The quarry will not adversely affect the inflow to the hanging swamps or baseflow contribution to the downstream creeks.

5.5.4 Predicted Water Level Drawdowns

In order to assess the overall impact that the extraction may have on water levels, the ‘Base Case’ model was compared against a pseudo steady state model that was run over the same 33 year extraction period, but without the hydraulic property changes, drain cell alterations or changes in recharge rates accommodated in the 16 time-slice model.

The difference in groundwater level predictions between the two models can be entirely attributable to the effects of the Green Valley Sand Quarry Project. Figure 5.8 and Figure 5.9 show the impact of quarrying at the end of the project (Year 33), assuming that all inflows to the excavation area are used for water supply purposes. This shows a maximum drawdown of 5 m in the central part of the proposed extraction area. The extent of the drawdown is localised and generally limited to the area being actively extracted. Impacts on groundwater levels within the Hawkesbury Sandstone have been shown to be limited to areas inside the “Green Valley” property boundary, due to the restricted extent of the sandstone outcrop.

5.5.5 Recovery Simulation

The post-project recovery run was conducted as a 50-year transient model run, using the predicted water levels at the end of the Green Valley project (i.e. groundwater levels at the end of Year 33) as the initial head conditions. Aquifer parameters representing backfill were applied in the extraction area.

Figures 5.10 to 5.12 show predicted residual drawdowns in each model layer at the end of the recovery period (Year 83). They are generally less than 0.5 m, apart from small localised areas where up to 1m residual drawdown is predicted. Hydrographs of predicted water level drawdown and recovery at the monitoring bore sites are included in Appendix E.
In summary, the drawdown plots and hydrographs show the following:

- The maximum model predicted drawdown in the water table (Layer 1) is only 1m. Residual drawdowns in Layers 2 and 3 at the end of the recovery period are also predicted to be no more than 1 m.
- Changes to recharge rates caused by the presence of backfill affects water levels in the post extraction period. In some areas, this results in predicted water levels that are higher than the levels that applied before extraction started.

5.6 POTENTIAL DOWNSTREAM WATER QUALITY IMPACTS

The sandstone aquifer intercepted by the excavation has very good water quality, although it does demonstrate moderately low pH and elevated levels of zinc in comparison to the ANZECC (2000) freshwater ecosystem protection guideline value. This is naturally occurring, and groundwater from the site already drains to the hanging swamps to the east and southeast of the site, which have very similar ionic characteristics to the Hawkesbury Sandstone aquifer (as detailed in Section 3.4.5). The surface water impact assessment (SEEC, 2010) indicates that surface water tributaries leading from this area to Paddys River also have low natural pH. The groundwater in the sandstone is already heavily affected by recent recharge, so there is no reason to conclude that water quality in this aquifer will change as a result of excavation/exposure. Based on this, and the existing connectivity between ground and surface waters, it is concluded that there will be no effects on downstream water quality as a result of groundwater related impacts from the excavation.

The risk of groundwater contamination due to other, general project operations will be mitigated through the use of appropriate mitigation measures, as described in Section 6.

5.7 IMPACTS ON EXISTING GROUNDWATER USERS

Because the quarrying activities themselves will only affect groundwater within the Hawkesbury Sandstone, which is perched above the Berry Formation aquitard, impacts on groundwater levels from sand extraction and the use of groundwater that enters the extraction area will be limited to the Hawkesbury Sandstone within the confines of the “Green Valley" property. They will not therefore affect other groundwater users.

The use of water supply bores within the Berry Formation does have the potential to affect other users outside of the Green Valley property. The pumping of proposed water supply bores PB1 and PB3 was not included within the model simulation as there are no feasible hydraulic mechanisms that would cause this pumping to significantly affect flows or levels in the Hawkesbury Sandstone. Groundwater levels and quality are distinctly different between the Hawkesbury Sandstone and the underlying Berry Formation shale within the Project Site, and the Hawkesbury Sandstone aquifer is considered to be perched above the upper surface of the Berry Formation. A separate, analytical approach was therefore used to evaluate the potential impacts if those bores are used for water supply purposes.
For long term abstraction from low yield boreholes, the most suitable analytical approach for estimating the potential zone of impact that might occur as a result of the abstraction is to evaluate the ‘equivalent recharge area’ that would be needed to supply the borehole. This method is based on a simple mass balance approach, whereby the volume of water that is required to supply the borehole in the long term is divided by the annual recharge rate (in mm) to determine the equivalent ‘catchment area’ that is required to provide the necessary recharge. Because this ‘catchment area’ can provide the required water supply in the long term, groundwater outside of this area will not be significantly affected by the extraction. This approach is particularly applicable to the two water supply bores, as water quality analysis indicates that much of the water that was being pumped from the bores is being sourced from local, recent groundwater recharge.

Testing of aquifer conditions within the Berry Formation was conducted on 2 test bores and an existing stock and domestic bore on the property for the purpose of assessing the potential for groundwater to augment processing water demand. Test pumping revealed low transmissivity in the order of 1m/day with a sustainable yield in the order of 0.5 L/s (16 ML/a) for each of the two bores. An average recharge rate of 5% of the long term average rainfall would result in an equivalent ‘recharge area’ of approximately 300 m radius for each bore. The two bores are located well apart from each other, so they are not expected to mutually interfere during pumping.

Impacts from long-term production pumping of 0.5 L/s from each of the proposed water supply bores will therefore be confined to a local area within 300 m of each bore, which is well within the boundary of the “Green Valley” property. Other users of groundwater from the Berry Formation at greater distance will not therefore be affected.
6. RECOMMENDED CONTROLS AND MITIGATION MEASURES

6.1 SITE WATER MANAGEMENT

Surface water management, including management of any water contaminated during the processing operations, off-site water supply and the overall site water balance, will be addressed in a Site Water Management Plan (SWMP). Any groundwater generated during the operation will enter the site water management system.

Interaction between surface water and groundwater will also be addressed in the SWMP.

6.2 GROUNDWATER MANAGEMENT

Maintenance of baseflows to hanging swamps discharging to Paddys River is the most important environmental factor potentially impacted by extraction operations. Groundwater modelling has shown that baseflows to the hanging swamps immediately downslope of the quarry can be maintained and potentially enhanced during quarrying operations, provided that groundwater flow beneath the excavations is not interrupted by the quarry operations.

Retention of a continuous layer of permeable sandstone beneath the quarry will ensure continuing groundwater flow from the quarry area can occur to the downslope discharge areas throughout the operations and thereafter. It is therefore recommended that a ‘veneer’ of sandstone (around 2 m thick) is maintained across the floor of the extraction area to ensure that impact on baseflows to the swamp areas is minimised. The thickness of this veneer does not need to be exact; rather it needs to allow recharge to travel beneath the quarry floor without significant evaporation, which will maintain water levels and hence baseflows to the hanging swamps on the eastern and southeastern side of the Hawkesbury Sandstone outcrop. Given the nature of the sandstone material, a depth of 2m will be well beyond the capillary fringe (Dingman 1994), and hence prevent evaporative loss of the recharge that occurs.

In the event that a reduction in groundwater flow is recorded flowing to the hanging swamps, it is recommended that some of the groundwater inflow to the excavation be pumped into infiltration ponds constructed on the down-gradient side of excavated areas to maintain outflow to downstream areas. Dimensions of these ponds would be designed to specification based on required infiltration rates, which will be determined from monitoring, and will only be required if flows beneath the quarry are not maintained as anticipated and as predicted by the modelling.

6.3 MITIGATION MEASURES

Mitigation measures to minimise the groundwater impacts of the extraction operation should include the following:

- Maximise operational use of the groundwater inflows to the extraction in preference to water from outside sources such as licensed pumped water;
- Permit no off site discharges of water from the disturbed areas;
- Make use of sumps within the quarry void for storage of excess water where possible during the quarrying operation;
• Maintenance of a 2m sandstone veneer in the base of extraction areas, as described in the previous section; and
• Construct infiltration ponds if loss of baseflow to hanging swamps is detected.

Mitigation measures to minimise the risk of groundwater contamination should include:

• Lined and bunded workshop and wash down areas;
• Waste water recycling from wash down areas;
• Treatment of wash down water and water from workshop areas before disposal;
• Sediment ponds to reduce stormwater sediment loads prior to discharge;
• Monitoring operational area water quality and removing potentially contaminated water from these areas before it can recharge the groundwater system;
• Lined and bunded areas for all chemical and fuel storages; and
• Removal of sewage waste from site via pump out septic systems.

During operation, it is anticipated there will be ground disturbance from earthworks including:

• Drilling;
• Stockpiling of excavated topsoil;
• Ground disturbance from the positioning of equipment, sediment controls and vehicle movements around the site; and
• Possible ground disturbance from the clearing of vegetation.

It is not anticipated that any of these activities will adversely affect groundwater, and the potential hydro-geological effects have been included within the impact assessment. No specific mitigation is therefore required for these activities. There is a theoretical risk of soil erosion at groundwater discharge locations. However, the discharge structures will be on rock, and the risk can be mitigated provided any drainage pathways within the site are suitably designed and lined where appropriate.

6.4 GROUNDWATER MONITORING

A monitoring program has been instigated to build baseline knowledge of conditions for the Project. It is recommended that groundwater continues to be monitored closely throughout the project life. This would include both groundwater levels and groundwater quality, and also the levels and quality of water in the downslope hanging swamps.

Future monitoring will be designed to provide a reliable database for comparing the actual performance with predicted impacts of the project. It specifically deals with:

• the performance of the site water management system, including the process water circuit;
• impacts on natural surface waters;
• impacts on groundwater levels on neighbouring properties and on any users of groundwater;

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• impacts on groundwater dependent ecosystems associated with the sandstone aquifer; and
• impacts of the development on groundwater quality such as around storage areas.

More intensive monitoring, particularly of water quality, is recommended during construction and during the first 2 years of operation. Background groundwater level monitoring should continue on a monthly basis until the commencement of the construction phase. The last samples to be collected prior to the construction phase should include a comprehensive analytical suite assessed to cover all possible contamination sources.

The groundwater monitoring program will also be coordinated with surface water monitoring.

During the first two years of operation of the quarry, the monitoring program should include the following:

• groundwater extraction volumes – weekly totals from all pumping bores and sumps, and weekly totals from extraction areas and water storage facilities;
• groundwater and surface water discharge quality – monthly measurements on site of the EC and pH of each groundwater extraction area;
• annual sampling from all pumping bores for laboratory analysis (as outlined in Table 6.1);
• monthly manual monitoring, or continuous automated monitoring, of water levels from the network of monitoring bores; and
• annual sampling of representative monitoring bores for laboratory analysis (as outlined in Table 6.1).

### Table 6.1
Recommended Laboratory Analysis Suite for Annual Groundwater Monitoring

<table>
<thead>
<tr>
<th>Class</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical parameters</td>
<td>EC, TDS, TSS and pH</td>
</tr>
<tr>
<td>Major cations</td>
<td>calcium, magnesium, sodium and potassium</td>
</tr>
<tr>
<td>Major anions</td>
<td>carbonate, bicarbonate, sulphate and chloride</td>
</tr>
<tr>
<td>Dissolved metals</td>
<td>aluminium, arsenic, boron, cobalt, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, silver, selenium, zinc</td>
</tr>
<tr>
<td>Nutrients</td>
<td>ammonia, nitrate, phosphorus, reactive phosphorus</td>
</tr>
</tbody>
</table>

Thereafter, water level measurements and sampling could be reduced to less frequent intervals based on the performance of the system during the first two years of operation. Groundwater levels should be compared to daily rainfall data and abstraction data for any bores pumping groundwater on site.

Data collected will enable the Project to establish, and continually assess, the impacts that extraction activities might have on other groundwater users and the groundwater environment. Collection of these data will also enable continual periodic review of any observed impacts against those predicted by the numerical modelling, and will allow further refinement of the groundwater model as the quarry develops.
The monitoring piezometers that have already been constructed around the perimeter of the Project Site are considered sufficient to monitor groundwater impacts from the quarry operations. Additional bores may be required outside of the proposed extraction area as any existing bores are lost due to the extraction.

An annual review of the monitoring data should be conducted to:

- review the monitoring results;
- identify any impacts resulting from the operation of the quarry;
- assess the need for mitigation measures; and
- assess whether changes to the monitoring program are required.

An annual monitoring report should be produced presenting the findings and recommendations, and included in the Annual Environmental Management Report for the quarry.
7. SUMMARY AND CONCLUSIONS

The Hawkesbury Sandstone, which underlies elevated parts of the Project Site, typically comprises a friable, fine to coarse-grained sandstone. Groundwater levels and flow within the Hawkesbury Sandstone in the “Green Valley” property are controlled by the presence of the underlying, poorly permeable shales of the Berry Formation, which form a basal aquitard, and result in perched groundwater within the overlying Hawkesbury Sandstone aquifer.

Recharge to the sandstone aquifer occurs through infiltration of rainfall, and discharge occurs by either evapotranspiration or by surface/sub-surface seepage to the east and south-east at the sub-crop line of the Hawkesbury Sandstone above the Berry Formation. The downslope groundwater discharge areas occur above hanging swamps, which are supported by the continuing groundwater seepage. Onward seepage from these swamps then enters the surface streams and eventually flows into Paddys River. Maintenance of the groundwater discharge from the sandstone aquifer during and after the sand extraction project is therefore seen as an important environmental measure to limit the potential impact of the proposed project on either the hanging swamps or baseflows to Paddys River.

Hydraulic testing of the sandstone aquifer indicated that hydraulic conductivities are relatively high for the Hawkesbury Sandstone, and are more typical of fine grained sand than indurated sandstone. This reflects the locally weathered and friable nature of the sandstone. This weathering of the sandstone has resulted in relatively high permeability, allowing a greater than normal proportion of intergranular groundwater flow within the formation. Groundwater levels are generally close to (within a few metres of) the base of the sandstone, reflecting the perching behaviour caused by the underlying shale.

The groundwater sampling has revealed that the groundwater is moderately acidic, with pH generally in the range 4.5 to 5.5. Groundwater found in the Hawkesbury Sandstone aquifer within the Project Site has low salinity, with EC generally in the range 75 - 200 µS/cm, and TDS generally less than 100 mg/L. The surface water in the swamps has similar water quality and chemistry to the Hawkesbury Sandstone groundwater, indicating that the sandstone aquifer plays an important role as the major water source for the swamps.

The underlying Berry Shale is believed to be dry immediately beneath the base of the Hawkesbury Sandstone. Groundwater in the Berry Formation occurs primarily in association with fracturing, and is marginally more saline than the Hawkesbury Sandstone groundwater, with EC locally up to 500 µS/cm, and even higher on a regional basis.

Groundwater modelling has been undertaken to assess the potential impacts of the Green Valley Sand Quarry on the groundwater environment, specifically with regard to:

- predicted groundwater inflow rates to excavated areas;
- regional and localised changes in groundwater levels as a result of the sand extraction project; and
- changes in baseflow contributions to the swamps and Paddys River downstream.

Total predicted inflows to the excavation range from 0.01 ML/d to 0.12 ML/d.
The steady state calibration for the groundwater model showed that pre-quarrying baseflow contributions to the hanging swamps are in the order of 0.4 ML/d. Predictive modelling indicates that outflows to the hanging swamp discharge areas may decrease slightly as the project proceeds, but that, at worst, discharge will only reduce by 0.05 ML/d before recovering to at least pre-project levels by the end of sand extraction. However, this does depend on the level of recharge that occurs to backfilled quarry areas, and it is feasible that discharge rates to the swamp could actually increase slightly as a result of the proposed project activities. It is recommended that sandstone ‘veneer’ of around 1 – 2m is left at the base of the active excavation area to ensure that groundwater recharge reaches the sandstone aquifer areas downslope of the quarry and hence maintains the baseflow to the hanging swamps.

Water demand for the Project is understood to be up to 82 ML/a, or up to 3.3 L/s, for full scale sand production. The prediction of minimal impact on downslope discharges shows that there is potential for groundwater inflows to provide part of the Project’s water requirement for processing purposes. Not all of this water could be collected, as some will be lost to re-infiltration to the groundwater system, or evaporation, particularly water runs into fines or mud on the quarry floor. The water balance contained in the surface water specialist report assumes a 35% use figure, which is considered to be a reasonable lower bound figure for the site. This percentage could be increased through the use of appropriate drainage/interception measures, but the use of such measures needs to be offset against the potential operational difficulties that might be caused by including them in the active extraction area.

Investigation was also undertaken in the underlying Berry Formation as a potential water supply source for the Project. Two test bores were installed into the Berry Formation, with screens set against inflow zones associated with fracturing. Recovery monitoring after airlift development showed that the Berry Formation has limited ability to meet the water supply needs on its own, but it could provide a useful component of the water supply in conjunction with other options such as harvesting of surface water runoff and/or a licensed allocation from Paddys River.

The limited extent of the Hawkesbury Sandstone within the “Green Valley” property limits drawdown from the excavation, and prevents any potential impact to other groundwater users from development of the proposed sand extraction project. Analytical assessment of the potential impact from possible abstraction bores within the Berry Formation indicates that significant impacts from those bores would not extend outside of the “Green Valley” property boundary.

Water quality impacts from the Project are not anticipated, provided suitable operational water management and mitigation measures are put in place to prevent contamination from sediment, fuel storage, chemicals, etc.

Although impacts from the proposed Project are generally anticipated to be small, a monitoring programme and contingency response plan will be required to validate predictions and mitigate any detrimental impacts that occur during sand extraction. Proposed recommendations for these programmes are contained within this report, and include:

- Monitoring of groundwater inflows and water use.
- Monthly manual monitoring or continuous automated monitoring of water levels from the network of monitoring bores.
• Water quality monitoring of inflows to operational areas and groundwater sampled from monitoring piezometers.
• Data review by a suitable, experienced hydrogeologist.
• Review and validation of the groundwater model predictions and updating if deemed necessary.
• Procedures for investigation and action if data indicate that impacts on groundwater level or quality are greater than assessed trigger values, or if complaints are received from other groundwater users.
• Annual review of the data being collected to ensure it is meaningful, and adjustment of the monitoring program if deemed appropriate.
8. REFERENCES


Hutton, J. T., 1976, Chloride in rainfall in relation to distance from ocean, Search, 7(5), pp. 207–208.

Hvorslev, M. J., 1951, Time lag and soil permeability in ground-water observations, U.S. Army Corps of Engineers Waterways Experimental Station Bulletin, no.36. 50 pp.


National Health and Medical Research Council (NHMRC) / Natural Resource Management Ministerial Council (NRMMC), 2004. Australian Drinking Water Guidelines.


US Salinity Laboratory, 1954. Diagnosis and improvement of saline and alkali soils. USDA Handbook No 60.
9. GLOSSARY OF TECHNICAL TERMS

AHD. Australia Height Datum. This refers to the height of a given point above the standard specified datum level, and allows all points or objects to be compared using a standardised system.

AQUICLUDE. A low-permeability unit that forms either the upper or lower boundary of a groundwater flow system. Aquicludes are almost entirely impermeable and prevent the movement of groundwater.

AQUIFER. Rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit significant quantities of water to wells and springs. Aquifers generally occur in formations which can also store large volumes of water such as sands, gravels, limestone, sandstone, or highly fractured rocks.

AQUIFER, CONFINED. An aquifer that is overlain by a confining bed. The hydraulic conductivity of the confining bed is significantly lower than that of the aquifer.

AQUIFER, PERCHED. A region in the unsaturated zone where the aquifer material may be locally saturated because it overlies a low-permeability unit.

AQUIFER, UNCONFINED. Also known as water-table and phreatic aquifer. An aquifer in which there are no confining beds between the zone of saturation and the surface. The water table is the upper boundary of unconfined aquifers.

AQUITARD. A low-permeability unit that can store groundwater and also transmit it slowly from one aquifer to another.

BORE (WELL). A structure drilled (bore) or dug (well) below the surface to obtain water from an aquifer system.

BOUNDARY CONDITIONS. A boundary condition for a groundwater model where the head is known and specified at the boundary of the flow field, and the model computes the associated groundwater flow.

CONCEPTUAL MODEL. A simplified and idealised representation (usually graphical) of the physical hydrogeologic setting and our hydrogeological understanding of the essential flow processes of the system. This includes the identification and description of the geologic and hydrologic framework, media type, hydraulic properties, sources and sinks, and important aquifer flow and surface-groundwater interaction processes.

CONFINING LAYER. A body of relatively impermeable material that is stratigraphically adjacent to one or more aquifers. It may lie above or below the aquifer.

DISCHARGE. The volume of water flowing in a stream or through an aquifer past a specific point in a given period of time.

DISCHARGE AREA. An area in which there are upward components of hydraulic head in the aquifer.
DRAWDOWN. A lowering of the water table of an unconfined aquifer, or of the potentiometric surface of a confined aquifer. Drawdown is the result of pumping of groundwater from wells or other hydrogeological disturbances (such as excavation activities).

EC. An acronym for Electrical Conductivity unit. 1 EC = 1 micro-Siemens per centimetre, measured at 25°C. It is used as a measure of water salinity (see salinity below).

EVAPOTRANSPIRATION. The sum of evaporation and transpiration (from plants).

GROUNDWATER. The water contained in interconnected pores located below the water table.

GROUNDWATER FLOW MODEL. An application of a mathematical model to represent a site-specific groundwater flow system.

HYDRAULIC CONDUCTIVITY. The rate at which water of a specified density and kinematic viscosity can move through a permeable medium (notionally equivalent to the permeability of an aquifer to fresh water).

HYDRAULIC GRADIENT. The change in total head with a change in distance in a given direction which yields a maximum rate of decrease in head.

HYDROGRAPH. A graph that shows some property of groundwater or surface water (usually head or flow) as a function of time.

INfiltration. The flow of water downward from the land surface into and through the upper soil layers.

MEGALITRE (ML). One million litres.

MGA. Metric triangular grid system, its unit of measure is the metre and identifies unique locations in Australia. A co-ordinate system used for mapping purposes.

MODEL CALIBRATION. The process by which the independent variables (parameters) of a numerical model are adjusted, within realistic limits, to produce the best match between simulated and observed data (usually water-level values). This process involves refining the model representation of the hydrogeologic framework, hydraulic properties, and boundary conditions to achieve the desired degree of correspondence between the model simulations and observations of the groundwater flow system.

NUMERICAL MODEL. A model of groundwater flow in which the aquifer is described by numerical equations, with specified values for boundary conditions, that are usually solved on a digital computer. In this approach, the continuous differential terms in the governing hydraulic flow equation are replaced by finite quantities. The computational power of the computer is used to solve the resulting algebraic equations by matrix arithmetic. In this way, problems with complex geometry, dynamic response effects and spatial and temporal variability may be solved accurately. This approach must be used in cases where the essential aquifer features form a complex system, and where surface-groundwater interaction is an important component (ie. high complexity models).
OBSERVATION WELL. A non-pumping well used to observe the elevation of the water table or the potentiometric surface. An observation well is generally of larger diameter than a piezometer and typically is screened or slotted throughout the thickness of the aquifer.

PERMEABLE STRATA. Layers of rock through which water can pass.

PIEZOMETER. A non-pumping well, generally of small diameter, that is used to measure the elevation of the water table or potentiometric surface. A piezometer generally has a short well screen through which water can enter.

POROSITY. The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment.

POROSITY, EFFECTIVE. The volume of the inter-connected void spaces through which water or other fluids can travel in a rock or sediment divided by the total volume of the rock or sediment.

PUMPING TEST. Also known as an aquifer test. A test made by pumping a well for a period of time at a measured rate and observing the change in hydraulic head in the aquifer. A pumping test may be used to determine the capacity of the well and the hydraulic characteristics of the aquifer.

RECOVERY. The period following extraction where groundwater levels trend towards initial conditions through natural recharge processes.

RECHARGE. The process which replenishes groundwater, usually by rainfall infiltrating from the ground surface to the watertable and by river water entering the watertable or exposed aquifers. The addition of water to an aquifer.

RECHARGE BOUNDARY. An aquifer system boundary that adds water to the aquifer. Streams and lakes are typically recharge boundaries.

SALINITY. The concentration of sodium chloride or dissolved salts in water, usually expressed in EC units or milligrams of total dissolved solids per litre (mg/L TDS). The conversion factor of 0.6 mg/L TDS = 1 EC unit is commonly used as an approximation.

SENSITIVITY ANALYSIS. The measurement of the uncertainty in a calibrated model as a function of uncertainty in estimates of aquifer parameters and boundary conditions.

SIMULATION. One complete execution of a groundwater modelling program, including input and output.

TOTAL DISSOLVED SOLIDS (TDS). A measure of the salinity of water, usually expressed in milligrams per litre (mg/L). Sometimes TDS is referred to as total dissolved salts, or as TSS, total soluble salts. See also EC.

TRANSMISSIVITY. The rate at which water is transmitted through a unit width of aquifer of confining bed under a unit hydraulic gradient. The product of saturated thickness and hydraulic conductivity.
UNCERTAINTY ANALYSIS. The quantification of uncertainty in model results due to incomplete knowledge of model aquifer parameters, boundary conditions or stresses.

UNCONFINED AQUIFER. An aquifer that contains the watertable and is normally exposed to the surface. Occasionally there may be a layer overlying this type of aquifer protecting it from the surface.

UNSATURATED ZONE. Also known as the zone of aeration and the vadose zone. The zone between the land surface and the water table. It includes the root zone, intermediate zone, and capillary fringe. The pore spaces contain water at less than atmospheric pressure, as well as air and other gases. Saturated bodies, such as perched groundwater, may exist in the unsaturated zone.

WATER TABLE. The upper level of the unconfined groundwater, where the water pressure is equal to that of the atmosphere and below which the soils or rocks are saturated. It is the location where the sub-surface becomes fully saturated with groundwater, the level at which water stands in wells that penetrate the water body. Above the water table, the sub-surface is only partially saturated (often called the unsaturated zone). The water table can be measured by installing shallow wells extending just into the zone of saturation and then measuring the water level in those wells.

WELL SCREEN. A tubular device with either slots, holes, gauze, or continuous-wire wrap; used at the end of a well casing to complete a well. The water enters the well through the well screen.
Figures
SYDNEY BASIN

Proposed Green Valley Sand Quarry

Aquterra Consulting Pty Limited
Hanging Rock Swamp
Green Valley Swamp
Figure 5.3

Model Domain
and Boundary Conditions
### Incremental Advance

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FIGURE 5.6: TOTAL GROUNDWATER OUTFLOW (FLUX) FROM THE BASE CASE MODEL

FIGURE 5.7: PREDICTED QUARRY INFLOW AND HANGING SWAMPS BASEFLOW RATES
APPENDICES

(No. of pages excluding this page = 34)

Appendix A    HYDRAULIC TEST DATA
Appendix B    GREEN VALLEY MODEL LAYER ELEVATIONS
Appendix C    STEADY STATE MODEL CALIBRATION
Appendix D    GREEN VALLEY MODEL CALIBRATED PARAMETERS
Appendix E    GREEN VALLEY MODEL PREDICTED DRAWDOWN AND RECOVERY HYDROGRAPHS
Appendix F    TEST BORE GEOLOGIC LOGS
Appendix A

Hydraulic Test Data

Number of pages including blank pages = (12)
MW10a CONSTANT RATE PUMP TEST - Recovery

Time (min)

Depth (m)

\( q_0 = 1.4 \, \text{m} \)

\( T_1 = 2.3 \, \text{m} \)

\( T_2 = 2.3 \times 0.2 \, \text{m} \)

\( T_3 = 2.3 \times 0.1 \, \text{m} \)

\( K_{avg} = 0.03 \, \text{m}^2/\text{d} (\approx 10.5 \, \text{m/d}) \)

MW11 CONSTANT RATE PUMPING TEST - Recovery

Time (min)

Pumping Rate (L/min)

\( q_0 = 2.5 \, \text{m} \)

\( T_1 = 2.3 \, \text{m} \)

\( T_2 = 2.3 \times 0.2 \, \text{m} \)

\( T_3 = 2.3 \times 0.1 \, \text{m} \)

\( K_{avg} = 0.17 \, \text{m}^2/\text{d} (\approx 10.4 \, \text{m/d}) \)

Constant Rate Pumping Test
Bore MW11 (15 July 2008)

\( Q = 0.14 \, \text{L/min} = 12 \, \text{KL/d} \)
**ROCLA PTY LIMITED**

Green Valley Sand Quarry
Report No. 765/03

**SPECIALIST CONSULTANT STUDIES**

Part 1 - Groundwater Assessment

---

**SLUG TEST: MW1**

Date: 18 July 2005

\[ K_s = \frac{r_e^2 \cdot \ln \left( R_e / r_i \right)}{2 \cdot b \cdot T_0} \]

- \( r_e = 0.225 \) in
- \( R_e = 200 \) ft
- \( R_i = 3.35 \) ft
- \( b = 180 \) ft

**Initial Transmissivity:**

- \( K_{trans} = 2.7 \times 10^{-2} \text{ ft/min (0.24 m/d)} \)

---

**SLUG TEST: MW10a**

Date: 18 July 2009

\[ K_s = \frac{r_e^2 \cdot \ln \left( R_e / r_i \right)}{2 \cdot b \cdot T_0} \]

- \( r_e = 0.0225 \) in
- \( R_e = 6.5 \) ft
- \( R_i = 120 \) ft

**Initial Transmissivity:**

- \( K_{trans} = 2.3 \times 10^{-2} \text{ ft/min (0.02 m/d)} \)

---

Date: 22 April 2009
Scale: As Shown

**ROCLA PTY LIMITED**

**HYDRAULIC TESTING**

**SLUG TEST MW1 AND MW10a**

Aquaterra Consulting Pty Ltd
Slug Test MW11

StartTime: 16/07/2003

Slug Test - MW11

K_r = \frac{n}{m} \ln \left( \frac{R_1}{R_2} \right) \frac{1}{2 \cdot \pi \cdot T_m}

= 0.0252 \ln \left( \frac{200}{2.63 \cdot 10^3} \right)

K_t = 2.3 \times 10^{-3} \text{ m/s} (0.02 \text{ m/s})

Slug Test MW14

K_r = \frac{n}{m} \ln \left( \frac{R_1}{R_2} \right) \frac{1}{2 \cdot \pi \cdot T_m}

= 0.0258 \ln \left( \frac{200}{2 \times 3 \times 5380} \right)

K_{saturation} = 1 \times 10^{-3} \text{ m/s} (0.01 \text{ m/s})

Aquterra Consulting Pty Limited
CONSTANT RATE TEST
PB1 - Recovery

T = 2.3 x Q / 4n x Δs

s = 15m
Q = 101m³/day
T = 1.3m/day, K = 0.013m/day

Recovery on PB1 1/4/2009

CONSTANT RATE TEST
PB3 - Recovery

T = 2.3 x Q / 4n x Δs

s = 23m
Q = 101m³/day
T = 0.8m/day, K = 0.606m/day

Recovery on PB3 1/4/2009
Drawdown / Distance Relationship
PB1 and PB3

Distance from pumped bore (m)

Q = 0.5 l/s
S = 0.0001
K = 1 - 2 m/day
Pumping Time = 1820 days (5 years)

K (m/d)
1
2

Aquaterra Consulting Pty Limited
Appendix B

Green Valley Model Layer Elevations

Number of pages including blank pages = (4)
Appendix C

Steady State Model Calibration

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Appendix D

Green Valley Model
Calibrated Parameters

Number of pages including blank pages = (4)
APPENDIX D GREEN VALLEY MODEL CALIBRATED PARAMETERS

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Appendix E

Green Valley Model Predicted Drawdown and Recovery Hydrographs

Number of pages including blank pages = (6)
APPENDIX E - PREDICTED DRAWDOWN AND RECOVERY HYDROGRAPHS
MW10a (Layer 3)

MW11 (Layer 3)

APPENDIX E-PREDICTED DRAWDOWN AND RECOVERY HYDROGRAPHS
APPENDIX E-PREDICTED DRAWDOWN AND RECOVERY HYDROGRAPHS
MW17 (Layer 3)

MW18 (Layer 3)

APPENDIX E - PREDICTED DRAWDOWN AND RECOVERY HYDROGRAPHS
Appendix F

Test Bore Geologic Logs

Number of pages including blank pages = (4)
## COMPOSITE WELL LOG

**Well No:** PB1

**Client:** ROCLA  
**Project:** Green Valley Project

- **Commenced:** 31/03/09
- **Completed:** 31/03/09
- **Drilled:** Hyland Drilling
- **Logged By:** SD
- **Method:** Rotary Air Hammer
- **Fluid:** Water
- **Bit Record:** 200mm Hammer
- **Area:**
  - East: 2382237.6
  - North: 6163339.4
- **Collar (RL):**
- **Date:** 31/03/09

### Static Water Level
- **Level:** 20.40mbgl

### Composite Well Log

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<th>Lithological Description</th>
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<tr>
<td>0</td>
<td>Clay: dark brown clay, fine sand, gravel angular to 20mm</td>
</tr>
<tr>
<td>10</td>
<td>Gravel: fine to coarse sand, minor gravel to 1cm</td>
</tr>
<tr>
<td>20</td>
<td>Clay: light brown, minor fine sand</td>
</tr>
<tr>
<td>30</td>
<td>Shale/Claystone: light grey Shale, minor fine sand</td>
</tr>
<tr>
<td>40</td>
<td>Shale: some light brown clay bands at 13-13.5m and 16.5-16m</td>
</tr>
<tr>
<td>50</td>
<td>Light grey shale, some coarse Sand to 3mm</td>
</tr>
<tr>
<td>60</td>
<td>Red brown claystone band at 21-22.5m</td>
</tr>
<tr>
<td>70</td>
<td>Red Claystone band at 33-34.5m</td>
</tr>
<tr>
<td>80</td>
<td>Angular sandstone fragments</td>
</tr>
<tr>
<td>90</td>
<td>White sandstone streaks at 64.5-66m</td>
</tr>
<tr>
<td>100</td>
<td>Fine grained sandstone band at 67.5-68m</td>
</tr>
<tr>
<td></td>
<td>Pale grey fine grained sandstone at 82.5-84, angular to 2cm</td>
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</tbody>
</table>

### Field Notes

- Standing Water Level 20.40mbgl
- Water from 34.5m

### Well Completion

- EOH = 102m

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