GROUNDWATER ASSESSMENT

Abel Upgrade Modification

Environmental Assessment

APPENDIX B

Resource Strategies

DONALDSONCOAL

Part of the Yancoal Australia Group

ABEL UPGRADE MODIFICATION GROUNDWATER ASSESSMENT

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Disclaimer

EXECUTIVE SUMMARY

Background

The Abel Underground Mine is an underground coal mining operation located approximately 23 kilometres (km) north-west of the Port of Newcastle, New South Wales (NSW) in the Newcastle Coalfield. The Abel Underground Mine is owned and operated by Donaldson Coal Pty Ltd, a wholly owned subsidiary of Yancoal Australia Limited.

Project Approval (05_0136) for the Abel Underground Mine was granted on 7 June 2007 by the then NSW Minister for Planning pursuant to section 79J of the NSW *Environmental Planning and Assessment Act 1979.* The potential environmental impacts of the existing Abel Underground Mine were assessed in the *Abel Underground Mine Part 3A Environmental Assessment*.

The proposed Abel Upgrade Modification (the Modification) provides for an increase in resource recovery within the area and the seams currently approved to be mined by the Abel Underground Mine, while maintaining prior commitments regarding the management and mitigation of potential impacts to the environment and other stakeholders.

The Existing Environment

The study area is located within the Newcastle Coalfield of the Sydney Basin. The Permian aged coal reserves within the Abel Upgrade Modification (the Modification) area are mostly within the Shortland Formation of the Hexham Sub-Group within the Newcastle Coal Measures.

The topography of the Abel Underground Mine area is dominated by Black Hill, an east-west trending ridge located near the centre of the Abel Underground Mine area. Black Hill is the highest topographic point at 210 metres (m) Australian Height Datum. The Abel Underground Mine area is characterised by undulating ridge-affected terrain and shallow, slope-wash filled gullies and foot slopes.

The majority of the Abel Underground Mine area either drains towards Hexham Swamp to the east, via Long Gully and Blue Gum Creek, or Woodberry Swamp to the north-east via Weakleys Flat Creek and Viney Creek. Other portions of the Abel Underground Mine area are located in the ephemeral headwaters of Four Mile Creek and Buttai Creek.

Two distinct aquifer systems are known to occur within the Abel Underground Mine area:

- A fractured rock aquifer system in the coal measures, with groundwater flow occurring mainly in the coal seams; and
- A surficial granular aquifer system in the alluvium associated with swamp, floodplain and estuarine sediments along the Wallis Creek and Hunter River systems and their tributaries.

Groundwater levels in the alluvium are closely related to topography, with flow patterns broadly similar to the surface flow patterns. Recharge occurs by rainfall infiltration, and flow down gradient towards the local surface drainages. In the most elevated areas, alluvium is absent, and the regolith is unsaturated. Occasional localised perched groundwater is found in the colluvium and weathered bedrock zone in lower-lying areas along creek lines.

Groundwater levels in the strata of the deeper Permian coal measures have a more regional pattern, and are controlled by the topographic elevations in areas where specific coal seams outcrop or subcrop and receive recharge, and the discharge zones to the east beneath the Hunter River estuary. Groundwater flows down gradient from the recharge zones towards the discharge areas, with a generally south-easterly flow direction. There is very little or no vertical flow across the bedding from shallow to deeper strata under natural conditions; flow is predominantly parallel to the bedding, and occurs mostly within the more permeable coal seams.

Groundwater quality has been monitored at the Donaldson Open Cut Mine and the Abel and Tasman Underground Mines, and elevated salinity is found within much of the Permian coal measures aquifer system, with groundwater salinity ranging from less than around 600 microSiemens per centimetre (μS/cm) electrical conductivity (EC) in the more permeable coal seams to more than 16,000µS/cm EC within some of the less permeable overburden/interburden units.

Approach to Impact Assessment

In order to assess the impacts that the Modification may have on the hydrogeological environment, the MODFLOW-SURFACT Donaldson Regional Groundwater Model was used.

Project Approval (05_0136) for the Abel Underground Mine included a requirement for the further development of the groundwater model prepared for the Abel Underground Mine Environmental Assessment. In accordance with this requirement, the Donaldson Regional Groundwater Model was developed. This model was further improved for the Tasman Extension Project and for this study.

For this study, the model was first calibrated against quasi 'steady state' pre-mining conditions, and was then subject to a transient calibration to groundwater levels, baseflows and mine inflows from 2006 to 2012. As coal mining has been undertaken in this area for over 170 years, it is not possible to represent true pre-mining conditions, so a quasi-steady state condition was adopted which is believed to represent relatively stable conditions before the start of large scale mining at the Donaldson Open Cut Mine and the Abel and Tasman Underground Mines, which has occurred since 2000.

The groundwater modelling included a number of specific approaches that were used to simulate potential impacts from the proposed mining activities, including:

- Simulation of groundwater dewatering caused by both open cut and underground mining; and
- Changes to the hydraulic properties of overburden material caused by the caving and subsidence above underground mine panels.

Groundwater Inflows

Groundwater inflows have been predicted using the groundwater model. Inflows are predicted to increase during the Modification, reaching a maximum of 6.3 megalitres per day in mid-2015. These inflow volumes would be licensed in accordance with the requirements of the *Water Act 1912.*

Potential Impacts

The groundwater model has been used to predict the incremental impacts of the Modification compared to the approved impacts associated with approved mine plan for the Abel Underground Mine. To enable this, the model was run separately for the Approved mine plan and the Modification mine plan. By subtraction, the predicted impacts associated with the Modification in isolation have been identified.

Groundwater Level Impacts – Mining

At the end of mining, the Modification is predicted to result in very limited drawdown in alluvium in the Abel Underground Mine area compared to the minor drawdown predicted for the Approved mine plan. The maximum predicted increase in drawdown in the alluvium associated with the Modification is predicted to be approximately 1m. The alluvium is predicted to remain partially saturated.

In general, less drawdown in the Lower and Upper Donaldson Seams is predicted for the Modification mine plan compared to the drawdown predicted for the Approved mine plan.

Groundwater Level Impacts – Post-Mining

Recovery of groundwater levels has been assessed for 100 years following the completion of mining at the Abel Underground Mine. For the recovery run, it was assumed that all mining operations had ceased.

In general, less residual drawdown in the Lower and Upper Donaldson Seams is predicted for the Modification mine plan compared to the residual drawdown predicted for the Approved mine plan.

This residual drawdown in the Lower and Upper Donaldson Seams is not predicted to significantly affect the alluvium.

Stream Baseflows

Overall, the Modification is predicted to result in very limited (i.e. less than 1 m^3/day) incremental changes in baseflow to/from streams in the Abel Underground Mine area compared to the baseflow changes predicted for the Approved mine plan.

As there is negligible impact on the surface watercourses associated with the Modification during mining, and given residual drawdown in the Lower and Upper Donaldson Seams is not predicted to significantly affect the alluvium, no residual impacts are anticipated post-mining.

Groundwater Dependent Ecosystems

There are a number of locations within or adjacent to the Abel Underground Mine area that could support Groundwater Dependent Ecosystems (GDEs). These include: the Rainforest Protection Zones located along watercourses; swamps located within alluvium associated with Long Gully and Blue Gum Creek; Pambalong Nature Reserve; and Hexham Swamp.

Impacts on flows and groundwater levels in the alluvium within the Abel Underground Mine area are predicted to be insignificant, both during mining and post-mining. Therefore, it is considered very unlikely that there would be any impact on GDEs. Notwithstanding, a monitoring regime is recommended for the drainage lines in the areas which may support GDEs above and downstream of the mine.

Other Groundwater Users

All non-mine owned registered groundwater bores are located outside the extent of predicted drawdown effects from mining at the Abel Underground Mine. Therefore, no impacts to groundwater users are predicted.

Licensing Requirements

Donaldson Coal Pty Ltd would require a water licence under Part 5 of the *Water Act 1912* to account for groundwater inflows from the fractured rock aquifer system in the coal measures. Unregulated river access licences within the Wallis Creek and Newcastle Water Sources may also be required to account for take from surface water sources in accordance with the *Water Management Act 2000*. If licensed entitlements already held are insufficient, excess entitlements would be obtained.

Monitoring and Management of Impacts

A comprehensive monitoring program is already in place for the Abel Underground Mine and will be expanded for the Modification. Additional monitoring, using vibrating wire piezometers is recommended (e.g. adjacent to Pambalong Nature Reserve). It is also recommended that the existing Groundwater Management Plan is updated for the Modification, and is used to determine appropriate management strategies and response measures for any unforeseen impacts.

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APPENDICES

1. INTRODUCTION

This report presents the results of a groundwater assessment for the proposed Abel Upgrade Modification (the Modification) undertaken by RPS Aquaterra for Donaldson Coal Pty Ltd (Donaldson Coal).

1.1 Existing Approved Abel Underground Mine

The Abel Underground Mine is an underground coal mining operation located approximately 23 kilometres (km) north-west of the Port of Newcastle, New South Wales (NSW) in the Newcastle Coalfield. The Abel Underground Mine is owned and operated by Donaldson Coal, a wholly owned subsidiary of Yancoal Australia Limited.

Project Approval (05_0136) for the Abel Underground Mine was granted on 7 June 2007 by the then NSW Minister for Planning pursuant to section 79J of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act). The potential environmental impacts of the existing Abel Underground Mine were assessed in the *Abel Underground Mine Part 3A Environmental Assessment* (Donaldson Coal, 2006).

Underground mining operations at the Abel Underground Mine occur within Mining Lease (ML) 1618, located immediately to the south and west of John Renshaw Drive and the F3 Freeway, respectively (Figure 1.1).

In accordance with Project Approval 05_0136, the Abel Underground Mine is approved to extract up to 4.5 million tonnes per annum (Mtpa) run-of-mine (ROM) coal from the Upper and Lower Donaldson Coal Seams within ML 1618, using the bord and pillar mining method, over a mine life of approximately 21 years (i.e. until 31 December 2028).

Donaldson Coal also owns and operates two other mining operations west of Newcastle, these being the Tasman Underground Mine, located south of George Booth Drive, and the Donaldson Open Cut Mine, located on the northern side of John Renshaw Drive (Figure 1.1).

The coal from all three existing Donaldson Coal operations is processed at the Bloomfield Coal Handling and Preparation Plant (CHPP), situated on the outskirts of Maitland to the north-west of the Donaldson Open Cut Mine.

A detailed description of the existing Abel Underground Mine and the Modification is provided in the Main Report of the Environmental Assessment (EA).

1.2 Previous Groundwater Assessments and Predictive Models

Potential impacts associated with the Abel Underground Mine were assessed in the Abel Coal Project Groundwater Assessment (Peter Dundon and Associates Pty Ltd [PDA], 2006). The Abel Underground Mine model (PDA, 2006) was developed as part of the 2006 assessment.

Schedule 4, Condition 15(a) of Project Approval 05_0136 for the Abel Underground Mine required "*further development of the regional and local groundwater model*".

In accordance with Schedule 4, Condition 15(a) of Project Approval 05_0136, Aquaterra developed the Donaldson Regional Groundwater Model (DRGM). Comparative to the Abel Underground Mine model, the DGRM incorporated deeper layers and a larger regional extent, and included the Bloomfield Colliery operations.

In June 2012, Donaldson Coal lodged a development application (SSD-4962) with the NSW Department of Planning and Infrastructure for the Tasman Extension Project, which involved the continuation and extension of mining at the Tasman Underground Mine.

To assess potential impacts to groundwater associated with the Tasman Extension Project, RPS Aquaterra (2012) developed the Tasman Extension Project groundwater model, which refined and extended the DRGM.

1.3 Abel Upgrade Modification

The Modification provides for an increase in resource recovery within the area and the seams currently approved to be mined by the Abel Underground Mine, while maintaining prior commitments regarding the management and mitigation of potential impacts to the environment and other stakeholders.

The main activities associated with the development of the Modification relevant to potential groundwater impacts include the:

- Introduction of longwall mining in a section of the Lower Donaldson Seam (Figure 1.2);
- Introduction of shortwall mining in a section of the Upper Donaldson Seam, and in a section of the Lower Donaldson Seam (Figures 1.2 and 1.3);
- Extension of mining, using bord and pillar extraction, in a southern section of the Upper Donaldson Seam that overlies the Lower Donaldson Seam within ML1618 (Figure 1.3);
- Development of the modified mine layout to meet the existing approved subsidence management commitments; and
- Increased annual ROM coal production of up to 6.1Mtpa.

1.4 Groundwater Assessment Scope

The overall objective of this report is to describe the state of the groundwater environment in the Abel Underground Mine area (ML 1618) and immediate surrounds, and to assess the potential impacts on groundwater levels and quality from the Modification. This has been done to address any potential impacts on the groundwater and surface water resources, groundwater dependent ecosystems and existing groundwater users, to the satisfaction of the Minister for Planning.

The key tasks for this assessment are:

- Characterisation of the existing groundwater environment including identification of potential groundwater dependent ecosystems (GDEs) in consultation with other relevant specialists;
- Collation and review of baseline groundwater data including:
  - Existing groundwater monitoring program piezometer data;
  - Existing mine water management records; and
  - Additional data – e.g. NSW Office of Water records.
- Development of a conceptual groundwater model and refinement through analysis of data collated to develop and calibrate a numerical groundwater model to predict potential impacts of the proposal on the groundwater regime; and
- Preparation of a Groundwater Assessment report for inclusion in the EA, that includes the following:
  - Qualitative and quantitative assessment of groundwater impacts of the Modification, cumulative impacts with other existing and approved mines in the area and assessment of post-mining groundwater impacts (recovery of groundwater levels and stream baseflows); and
  - Development of measures to avoid, mitigate and/or remediate potential impacts on groundwater resources and to provide recommendations on groundwater monitoring to measure potential impacts on groundwater resources and other users.

1.5 Structure of this Report

This report is structured as follows:

- Section 2 addresses the statutory requirements, policies and guidelines relevant to the Modification;
- Section 3 contains a summary of previous groundwater investigations undertaken within the Abel Underground Mine area and surrounds;

- Section 4 reports on the existing State of the Environment within the Abel Underground Mine area, and includes available information on climate, topography and drainage, land use (including existing mining activities), and an evaluation of the current groundwater environment based on available groundwater levels and groundwater quality, and groundwater-surface water interactions;
- Section 5 outlines the conceptual model used to inform the numerical groundwater model;
- Section 6 outlines the mining proposal and provides a brief summary of implementation in the model;
- Section 7 details the groundwater modelling work undertaken to assess the potential impacts of the proposal;
- Section 8 contains details of the potential groundwater impacts of the Modification on groundwater and surface water resources, stream baseflows, GDEs, and other groundwater users;
- Section 9 details groundwater accounting, licensing and water sharing plans;
- Section 10 details proposed monitoring, mitigation and management strategies in relation to potential impacts on the groundwater resources, as well as recommendations for contingency response plans to address any unforeseen adverse impacts on groundwater and/or surface water;
- Section 11 provides a summary and conclusions; and
- Section 12 provides a list of references.

2. Statutory requirements

2.1 Director General's Requirements

In accordance with the *Environmental Planning and Assessment Act 1979*, the Director-General (DG) of the Department of Planning has issued requirements for the preparation of an Environmental Assessment for the Modification. Specific requirements have been provided by the DG and comments to the DG's requirements have been provided by relevant consulted public authorities. The requirements and comments relating to groundwater have been addressed within this report as detailed in Table 2.1.

Table 2.1: Director General's Requirements and Agency Comments

Director General's Requirements	**Relevant section of this report**
General Requirements	
A description of the existing environment, using sufficient baseline data.	Section 4
An assessment of the potential impacts of all stages of the development, including any cumulative impacts, taking into consideration relevant guidelines, policies, plans and statutes.	Section 8
A description of the measures that would be implemented to avoid, minimise and if necessary, offset the potential impacts of the development, including proposal for adaptive management and/or contingency plans to manage any significant risks to the environment.	Section 10
Key Issues (water resources)	
Detailed assessment of potential impacts on the quality and quantity of existing surface and groundwater resources, including: • Detailed modelling of potential groundwater impacts • Impacts on affected licensed water users and basic landholder rights • Impacts on riparian, ecological, geo-morphological and hydrological values of watercourses, including environmental flows	Sections 7 & 8 and refer to Evans and Peck (2012) (Appendix C of the EA)
A detailed site water balance, including a description of site water demands, water disposal methods (inclusive of volume and frequency of any water discharges), water supply infrastructure and water storage structures.	Refer to Evans and Peck (2012) (Appendix C of the EA)
Identification of any licensing requirements or other approvals under the *Water Act 1912* and/or *Water Management Act 2000.*	Section 9.1
Demonstration that water for the construction and operation of the proposed modification can be obtained from an appropriately authorised and reliable supply in accordance with the operating rules of any relevant Water Sharing Plan (WSP).	Section 9
A description of the measures proposed to ensure the development can operate in accordance with the requirements of any relevant WSP or water source embargo.	Section 9.3
A detailed description of the proposed water management system (including sewage), water monitoring program and other measures to mitigate surface and groundwater impacts.	Section 10 and refer to Evans and Peck (2012) (Appendix C of the EA)
Key Issues (biodiversity)	
A detailed assessment of potential impacts of the development on any: • groundwater dependent ecosystems	Section 8.3
Agency Comments	
NSW Office of Water comments	
• Identification of water requirements for the life of the proposed project in terms of both volume and timing, identification of the water sources that water will be taken from and identification of which water sources are the subject of a water sharing plan.	Section 9 and refer to Evans and Peck (2012) (Appendix C of the EA)
• Identification of any requirements (including potential requirements) to intercept groundwater, identification of the groundwater sources that will be intercepted, identification of which water sources are the subject of a water sharing plan and details of dewatering volumes.	Section 9.3
• Identify all proposed groundwater extraction.	Sections 7 & 9

Director General's Requirements	Relevant section of this report
• Provide details of the purpose, location and expected annual extraction volumes of all proposed groundwater extraction.	Sections 7 & 9
• Detail the extent to which all proposed groundwater extraction is consistent with *NSW Water Extraction Monitoring Policy* (2007).	Section 2.2
• Water supply works to take groundwater related comments.	N/A
• For all proposed aquifer interference activities which may intercept groundwater, provide details regarding purpose, location, construction and expected annual extraction volumes.	Sections 7 & 9.2
• Detail the extent to which the proposed project is consistent with the water management principles for aquifer interference activities prescribed in section 5(8) of the *Water Management Act 2000*.	Sections 2 & 9
• Include an assessment of the impact of the proposed project on groundwater sources.	Section 8.4
• Detailed description of any measures to be incorporated into the proposed project to avoid or minimise long-term actual and potential environmental impacts.	Section 10
• Details of ongoing monitoring programs for groundwater quality and quantity (minimum monthly data).	Section 10
• Contingency strategies to remediate, reduce or manage potential impacts.	Section 10
• Details of the predicted impacts of any final landform on the groundwater regime.	Section 8.1
• Details of the extent to which the proposed project is consistent with *The NSW State Groundwater Policy Framework Document* (1997), *The NSW Groundwater Quality Protection Policy* (1998) and the *Guidelines for Groundwater Protection in Australia* (1995).	Section 2.2
• Identification of potential GDEs within and adjacent to the proposed Abel Underground Mine area.	Section 4.10
• Details of groundwater quality and quantity requirements for all GDEs based on minimum fortnightly data collected over a minimum time period of two years.	Section 10
• Detailed assessment of any potential impacts on GDEs.	Section 8.3
• Detailed description of any measures to be incorporated into the proposed project to avoid or minimise adverse impacts on GDEs, including measures to: - Maintain natural patterns of groundwater flow, - Avoid disrupting groundwater levels that are critical for ecosystems, - Avoid pollution or causing adverse changes in groundwater quality, and - Rehabilitate degraded groundwater systems where practical.	Section 10
• Details of the extent to which the proposed project is consistent with *The NSW State Groundwater Dependent Ecosystems Policy* (2002).	Section 2.2
• Details of proposed rehabilitation measures to restore any land, water sources and dependent ecosystems which are degraded by the proposal.	Refer to Section 4 of the EA
• Justification of the proposed final landform with regard to minimizing impacts on local and regional surface and groundwater sources, basic landholder rights to water, adjacent/downstream licensed water users and groundwater dependent ecosystems.	Section 8
NSW Department of Resources and Energy	
• State the interaction between the proposed mining activities and the existing environment and so include a comprehensive description of water management.	Sections 4, 6 and refer to Evans and Peck (2012) (Appendix C of the EA)
NSW Environment Protection Authority	
• Describe existing groundwater quality. An assessment needs to be undertaken for any water resource likely to be affected by the proposal.	Section 4.8
• An outline of baseline groundwater information, including, depth to water table, flow direction and gradient, groundwater quality, reliance on groundwater by surrounding users and by the environment.	Section 4
• Assess impacts on groundwater and groundwater dependent ecosystems.	Section 8.3
The City of Newcastle	
• Assessment of the impact upon sensitive receivers such as Pambalong Nature Reserve and Hexham Swamp Nature Reserve. Council recommends that additional groundwater investigation be conducted as part of the proposed modification.	Section 8.3

2.2 Relevant State Policies and Guidelines

There are a number of guidance documents for groundwater protection and assessment in NSW. The key policy document is the *NSW State Groundwater Policy Framework Document* released by the then Department of Land and Water Conservation (DLWC) (currently NSW Office of Water) (DLWC, 1997). This document outlines the policy objectives relating to groundwater management and implementation strategies. The *NSW State Groundwater Policy Framework Document* refers to three component policies:

- The *NSW Groundwater Quality Protection Policy* (DLWC, 1998) outlines the beneficial use classification system applicable to all aquifer systems in NSW. The policy states that all groundwater systems should be managed to maintain the most sensitive identified beneficial use. The beneficial uses adopted in this policy include ecosystem protection, recreation and aesthetics, raw water for drinking water supplies, agricultural water and industrial water. For new developments, the policy also outlines the scale and scope of work required to demonstrate adequate groundwater protection which shall be commensurate with the risk the development poses to a groundwater system and the value of the groundwater resource;
- The *NSW State Groundwater Dependent Ecosystem Policy* (DLWC, 2002) provides guidance on how to protect and manage ecosystems that rely on groundwater for their survival for the benefit of present and future generations. GDEs may include terrestrial vegetation supported by shallow groundwater such as red gum forests, wetlands, ecosystems in streams fed by groundwater discharge and aquifer and cave ecosystems; and
- The policy on Groundwater Quantity Management has not been released but the principles and objectives are outlined in the *NSW State Groundwater Quality Protection Policy* and include the efficient, equitable and sustainable use of the State's groundwater resources. Groundwater access must be managed such that it does not cause unacceptable local impacts.

The draft guideline *Management of Stream/Aquifer Systems in Coal Mining Developments (Hunter Region)* (NSW Department of Infrastructure, Planning and Natural Resources [DIPNR], 2005) was developed to address potential impact on groundwater and rivers in the Hunter region. The objectives of the draft guideline incorporate protection of river systems which includes channels, stream beds and banks, connected alluvial groundwater and perched groundwater.

The *NSW Water Extraction Monitoring Policy (2007)* (DWE, 2007) was developed to ensure accurate monitoring of water extraction from NSW rivers and groundwater sources, essential for the fair and equitable sharing of the State's water. The Policy applies to extraction from water sources under both the *Water Management Act 2000* and the *Water Act 1912*. According to the policy, water extractions will need to be metered in stressed water sources and high conservation value water sources. In addition, licence holders who extract sufficient volumes of water to impact adversely on the environment or other licence holders should be monitored.

This report has also been prepared with due consideration of additional relevant state policies and guidelines including:

- Murray-Darling Basin Groundwater Quality Sampling Guidelines. Technical Report No. 3 (Murray-Darling Basin Commission [MDBC], 1997);
- Australian Groundwater Modelling Guidelines (Barnett *et al.* 2012); and
- Groundwater Flow Modelling Guidelines (MDBC, 2001).

2.3 Water Sharing Plans

Water sharing plans (WSPs) are being progressively developed for rivers and groundwater systems across NSW following the introduction of the *Water Management Act 2000* (WM Act 2000). The Modification lies within an area designated under the *Hunter Unregulated and Alluvial Water Sources WSP* (HUAWSWSP). The WSP commenced on 1 August 2009 and includes "*the highly connected alluvial groundwater (which are above the tidal limit)"*. Non-alluvial groundwater systems are not included within the Plan, and are still governed by the *Water Act 1912*.

These WSPs are designed to provide long-term environmental protection and sustainability of the groundwater resources as well as directing how water will be allocated and shared among the various water users. WSPs apply the goals and principles of the State Groundwater Policy at a local and regional level.

The WSPs identify the recharge component to each groundwater source or zone and direct how the recharge component will be allocated and shared among different water users. They also outline the management of local impacts, including groundwater interference, and list beneficial uses of the groundwater to be protected and occurrence of any GDEs within the groundwater source or zone.

The WSPs refer to the National Health and Medical Research Council (NHMRC) 1996 *Drinking Water Guidelines for drinking water beneficial use*. Other beneficial uses are defined by the Australian and New Zealand Environment and Conservation Council (ANZECC) *2000 Water Quality Guidelines* (ANZECC, 2000).

Compliance with the requirements of the HUAWSWSP is addressed in Section 9.3.

2.4 Water Licensing

The Modification will require the following approvals under legislation administered by the NSW Office of Water:

- A licence under Part 5 of the *Water Act 1912* will be required for any proposed use or interception of porous rock groundwater (including mine water make); and
- An access licence under the WM Act will be required for any incidental take of alluvial groundwater, or indirect take of surface water due to baseflow impacts.

Groundwater licences under Part 5 of the *Water Act 1912* will be required for any of the following activities relating to the Modification within the porous rock groundwater, including:

- Extraction of water from underground mining;
- Production bores; and
- Monitoring piezometers (for the purposes of water level and quality monitoring and test pumping).

Donaldson Coal currently holds the following Bore Licence Certificates under the Part 5 of the *Water Act 1912*:

- Bore Licence Number 20BL171935 issued on 5 August 2008 located on DP109/1100314 for a mining bore authorising groundwater extraction not to exceed 500 ML in any 12 month period; and
- Bore Licence Number 20BL172530 issued on 3 August 2010 for a groundwater monitoring bore located on DP1131/1057179.

The extraction of any groundwater from alluvial systems or impacts to surface water baseflow will be subject to conditions and management in accordance with rules set out the HUAWSWSP. In areas governed by a WSP, Water Access Licences (WALs) may be granted to access available water. These licences are held and traded independently from land and are issued separately to approvals.

Any discharge of surplus water volumes to the environment will be managed in accordance with the site's Environmental Protection Licence, under the *Protection of the Environment Operations Act 1997*.

2.4.1 Aquifer Interference Approvals

In September 2012, the NSW Office of Water released the Aquifer Interference Policy, which incorporates the regulation of activities such as mining in regards to groundwater. The purpose of the policy is to ensure that water taken by certain activities that may interfere with aquifers is properly licensed and accounted for in the water budget and water sharing arrangements.

According to the WM Act 2000, an aquifer interference activity is any of the following:

- The penetration of an aquifer;
- The interference with water in an aquifer;
- The obstruction of the flow of water in an aquifer;
- The taking of water from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations; or
- The disposal of water taken from an aquifer in the course of carrying out mining, or any other activity prescribed by the regulations.

As such, the proposed activity within the Abel Underground Mine area would require an aquifer interference approval (Part 3, Division 1 (s19), WM Act 2000). However at the time of writing, the aquifer interference approval application process is yet to be implemented by the State.

Further discussions on groundwater accounting and licensing for the Modification are provided in Chapter 9.

3. GROUNDWATER INVESTIGATIONS

3.1 Previous Work

A number of groundwater studies have previously been undertaken by Donaldson Coal, and for other surrounding mining projects, the main studies being:

- Groundwater investigations undertaken for the Donaldson Open Cut Coal Mine in 1998 (PPK Environmental and Infrastructure, 1998; Mackie Environmental Research, 1998);
- Hydrogeological studies undertaken for the existing Tasman Underground Mine in 2002 (PDA, 2002);
- Groundwater investigations undertaken for the Abel Underground Mine in 2006 (PDA, 2006);
- Groundwater investigations undertaken for the Bloomfield Colliery in 2008 (Aquaterra, 2008); and
- Hydrogeological studies undertaken for the Tasman Extension Project in 2012 (RPS Aquaterra, 2012).

As part of these studies, numerous groundwater monitoring bores were installed and core samples were collected. Many of these groundwater monitoring bores were maintained and form part of an ongoing monitoring network in the Abel Underground Mine region (Section 3.2).

Previous studies also included hydraulic conductivity testing of core samples from the Abel Underground Mine region (refer to Section 3.3).

RPS Aquaterra (2012) analysed data from the previous studies as part of the groundwater investigation program for the Groundwater Assessment prepared for the Tasman Extension Project Environmental Impact Statement (EIS), and this data was used in the ongoing development of the numerical groundwater model to assess the potential impact of the Modification.

3.2 Piezometer Monitoring Network

A broad network of 54 groundwater monitoring piezometers has been installed through the above investigation programs. Pertinent construction details of the piezometers (where available) are summarised in Appendix A. Many of the piezometers continue to form part of an ongoing baseline and impact assessment monitoring network.

Details of the piezometers and other monitoring bores are provided in Table 3.1. Bore locations are shown on Figure 3.1 and available bore logs are presented in Appendix A.

Table 3.1: Groundwater Piezometers and Other Monitoring Bores

Piezometer	MGA Coordinates		Surface RL (mAHD)	Depth (m)	Screen/Vibrating Wire Piezometer (mBGL)	Initial Water Level			Aquifer Formation
	Easting	Northing				Date	mBGL	mAHD	
Donaldson Open Cut Mine Piezometers									
DPZ1	370827	6369903	23.1	30	16.5-26.9	11/07/01	10.8	+12.2	Lower Donaldson and Big Ben Seams
DPZ2	371846	6370119	22.3	30	15.8-27.8	16/12/04	15.1	+7.2	Beresfield Seam
DPZ3	368773	6368608	49.1	30	6.8-18.8	17/08/05	12.4	+36.7	Undifferentiated coal measures below Lower Donaldson Seam
DPZ4A	370541	6368779	35.0	23	18.7-22.7	17/03/04	14.15	+20.86	Beresfield Seam
DPZ4B	370541	6368779	35.0	49	24.9-49.2	26/02/04	41.92	-6.91	Upper and Lower Donaldson and Big Ben Seams
DPZ5	371366	6368779	12.8	24	6-18	17/08/05	6.83	+5.97	Undifferentiated coal measures above Donaldson Seams
DPZ6	368614	6367357	57.7	43	26.7-42.5	14/08/02	13.64	+31.02	Upper and Lower Donaldson Seams
DPZ7A	368847	6367640	55.4	18	12.9-16.9	11/07/01	16.9	+38.5	Overburden above Upper Donaldson
DPZ7B	368847	6367640	55.4	41	22.9-34.9	17/08/05	23.5	+31.9	Lower Donaldson and Big Ben Seams
DPZ8	369374	6368073	51.8	33	22.2-32.2	17/08/05	25.3	+26.5	Lower Donaldson and Big Ben Seams
DPZ9	369847	6368016	36.4	40	12.5-36.5	17/08/05	32.1	+4.2	Upper and Lower Donaldson and Big Ben Seams
DPZ10	371001	6368463	19.8	30	11.8-29.8	17/08/05	13.8	+6.0	Beresfield Seam
DPZ12	369114	6366414	59.5	24	6-18	17/08/05	16.8	+42.7	Overburden above Upper Donaldson
DPZ13	371249	6367557	21.5	30	18-30	17/08/05	7.3	+14.2	Overburden above Upper Donaldson
DPZ15	370412	6369562	43.4		40.5-47.3	18/4/01	27.82	+15.58	Buchanan and Ashtonfield Seams
DPZ16	370244	6369815	26.83		21.1-24.0	18/4/01	14.42	+12.41	Ashtonfield Seam
DPZ17 (24m)	371339	6370036	15.25		~24	12/09/01	3.74	+11.51	
DPZ17 (38m)	371339	6370036	15.25		~38	12/09/01	3.67	+11.58	
DPZ17 (62m)	371339	6370036	15.25		~62	12/09/01	2.58	+12.67	
DPZ18 (72m)	371272	6369590	30.45		~72	12/09/01	18.5	+11.95	
DPZ18 (90m)	371272	6369590	30.45		~90	12/09/01	18.5	+11.95	

Piezometer	MGA Coordinates		Surface RL (mAHD)	Depth (m)	Screen/Vibrating Wire Piezometer (mBGL)	Initial Water Level			Aquifer Formation
	Easting	Northing				Date	mBGL	mAHD	
DPZ19 (56m)	370958	6369197	22.17		~56	12/09/01	9.58	+12.59	
DPZ19 (73m)	370958	6369197	22.17		~73	12/09/01	9.06	+13.11	
DPZ20A	370541	6368439	20.1	51	44	23/05/06	32.2	-12.0	Big Ben Seam
DPZ20B	370540	6368439	20.1	51	11.5-17.5	23/05/06	11.1	+9.0	Surficial aquifer – creek bed level
Tasman Underground Mine Piezometers									
TA23	360603	6357701	380.4	220		27/03/06		+238.8	Fassifern Overburden
TA24	364952	6359786	196.2	146.15	120	28/03/06		+90.8	Fassifern Seam
TA28	364163	6361235	158.9	303.25	290	27/11/06		+13.6	Donaldson Seam
TA41A	361231	6354126	315.7	663.5	382	30/04/09		+56.0	Sandgate Seam
TA41B	361231	6354126	315.7	663.5	303	30/04/09		+32.9	Fassifern - West Borehole Interburden
TA41C	361231	6354126	315.7	663.5	240	30/04/09		+74.5	Fassifern - West Borehole Interburden
Abel Underground Mine Piezometers									
C062A	370144	6366249	31.0	157	124-118	27/03/06	11.4	+24.6	Donaldson Seam
C062B	370144	6366249	31.0	157	87-81	27/03/06	4.2	+31.8	Overburden
C063A	372109	6366193	19.4	255	197	27/03/06	27.0	-8.0	Lower Donaldson Seam
C063B	372109	6366193	19.4	255	130	27/03/06	24.9	-5.9	Overburden
C072	369915	6362569	63.5	318	264	27/03/06	44.3	+18.7	Donaldson Seam
C072A	369915	6362569	63.5	318	168	23/03/06	41.3	+21.7	Overburden
C072B	369915	6362569	63.5	318	45-42	27/03/06	13.0	+50.0	Alluvium/weathered Permian
C078A	367188	6367077	73.5	101	99-96 and 90-87	26/04/06	48.6	+28.4	Donaldson Seam
C078B	367188	6367077	73.5	24	24-18	28/03/06	9.5	+67.5	Alluvium/weathered Permian
C080	368017	6365168	175.3	300	280	27/03/06	148.4	+28.6	Donaldson Seam
C081A	370011	6364017	1.9	225	149.7	27/03/06	-23.9	+26.0	Donaldson Seam
C081B	370011	6364017	1.9	20	20-14	27/03/06	0.3	+2.0	Alluvium/weathered Permian

Piezometer	MGA Coordinates		Surface RL (mAHD)	Depth (m)	Screen/Vibrating Wire Piezometer (mBGL)	Initial Water Level			Aquifer Formation
	Easting	Northing				Date	mBGL	mAHD	
C082	370319	6364647	34.0	20	20-14	27/03/06	15.3	+18.7	Alluvium/weathered Permian
C087	367419	6366587	85.9	18.3	18.3-12.3	26/04/06	10.5	+63.5	Alluvium/weathered Permian
C123A	366288	6364703	56.1	267.4	229	28/04/08		-8.1	Lower Donaldson Seam
C123B	366288	6364703	56.1	267.4	207	28/04/08		-2.5	Upper Donaldson Seam
C123C	366288	6364703	56.1	267.4	162	28/04/08		+31.4	Beresfield Seam
C123D	366288	6364703	56.1	267.4	148	28/04/08		+21.9	Upper Buttai Seam
C123E	366288	6364703	56.1	267.4	78	26/05/08		+36.0	Sandgate - Donaldson Interburden
C123F	366288	6364703	56.1	267.4	29	28/04/08		+47.4	Fassifern - West Borehole Interburden
C138A	364964	6367034	29.2	332	136	30/10/08		-10.3	Ashtonfield Seam
C138B	364964	6367034	29.2	332	142	30/10/08		-12.5	Big Ben - Ashtonfield Interburden
C138C	364964	6367034	29.2	332	163	30/10/08		-11.5	Big Ben Seam
C138D	364964	6367034	29.2	332	113	30/10/08		-7.7	Donaldson Seam
C138E	364964	6367034	29.2	332	75	30/10/08		+7.8	Sandgate - Donaldson Interburden
C141A	363873	6364370	30.3	303	282	24/11/08		+9.9	Ashtonfield Seam
C141B	363873	6364370	30.3	303	267	29/10/08		+9.9	Big Ben Seam
C141C	363873	6364370	30.3	303	150	29/10/08		+13.5	Donaldson Seam
C141D	363873	6364370	30.3	303	100	29/10/08		+19.7	Sandgate - Donaldson Interburden
C141E	363873	6364370	30.3	303	30	29/10/08		+19.7	Sandgate Seam
C148A	362443	6364501	22.2	243.3	237	25/02/09		+18.5	Big Ben - Ashtonfield Interburden
C148B	362443	6364501	22.2	243.3	200	25/02/09		+19.1	Big Ben Seam
C148C	362443	6364501	22.2	243.3	125	25/02/09		+19.6	Sandgate - Donaldson Interburden
C148D	362443	6364501	22.2	243.3	50	25/02/09		+20.5	West Borehole Seam
C223A	365530	6364594	164.8	294.81	350	26/02/10		+9.2	Lower Donaldson Seam
C223B	365530	6364594	164.8	294.81	325	26/02/10		+5.2	Upper Donaldson Seam
C223C	365530	6364594	164.8	394.81	242	26/02/10		+16.2	Buttai Seam

Piezometer	MGA Coordinates		Surface RL (mAHD)	Depth (m)	Screen/Vibrating Wire Piezometer (mBGL)	Initial Water Level			Aquifer Formation
	Easting	Northing				Date	mBGL	mAHD	
C223D	365530	6364594	164.8	394.81	160	26/02/10		+30.4	Sandgate Seam
C223E	365530	6364594	164.8	394.81	125	26/02/10		+40.7	West Borehole Seam
C257(75m)	370030	6366642	41.6	122	75	17/08/10		+12.0	Sandgate - Donaldson Interburden
C257(55m)	370030	6366642	41.6	122	55	17/08/10		+19.1	Sandgate - Donaldson Interburden
C257(35m)	370030	6366642	41.6	122	35	17/08/10		+22.0	Donaldson Seam
C262A	370208	6367201	33.4	100	70	17/08/10		-1.0	Donaldson Seam
C262B	370208	6367201	33.4	100	50	17/08/10		+12.5	Sandgate - Donaldson Interburden
C262C	370208	6367201	33.4	100	30	17/08/10		+24.1	Sandgate - Donaldson Interburden
Tasman Extension Project Piezometers									
B002AA	361942	6360971	51.3	383.5	363	30/04/09		+43.5	Big Ben Seam
B002AB	361942	6360971	51.3	383.5	128	30/04/09		+35.7	Sandgate Seam
B002AC	361942	6360971	51.3	383.5	98	30/05/09		+27.5	West Borehole Seam
B002AD	361942	6360971	51.3	383.5	50	30/04/09		+2.04	Fassifern - West Borehole Interburden
B004	363050	6362107	60.5	402.3	140	30/08/06		+17.2	West Borehole Seam
B005	363765	6361992	125.7	476.1	182	30/08/06		-31.8	West Borehole Seam
B017A	360800	6359938	58.6	315.3	87	30/01/08		+44.0	Sandgate Seam
B017B	360800	6359938	58.6	315.3	50	30/04/07		+52.7	West Borehole Seam
B29A	361362	6360639	47.0	326.22	280	23/12/08		+50.9	Lower Donaldson Seam
B29B	361362	6360639	47.0	326.22	250	23/12/08		+30.9	Upper Donaldson Seam
B29C	361362	6360639	47.0	326.22	150	23/12/08		+41.0	Sandgate - Donaldson Interburden
B29D	361362	6360639	47.0	326.22	92	23/12/08		+40.9	Sandgate Seam
B29E	361362	6360639	47.0	326.22	66	23/12/08		+39.2	West Borehole Seam
B30A	361400	6359400	60.7	360.8	300	25/02/10		-4.1	Donaldson – Big Ben Interburden
B30B	361400	6359400	60.7	360.8	230	25/02/10		+49.3	Upper Donaldson Seam
B30C	361400	6359400	60.7	360.8	150	25/02/10		+56.8	Sandgate Seam

Piezometer	MGA Coordinates		Surface RL (mAHD)	Depth (m)	Screen/Vibrating Wire Piezometer (mBGL)	Initial Water Level			Aquifer Formation
	Easting	Northing				Date	mBGL	mAHD	
B30D	361400	6359400	60.7	360.8	97	25/02/10		+49.6	Fassifern - West Borehole Interburden
B30E	361400	6359400	60.7	360.8	50	25/02/10		+48.2	Fassifern - West Borehole Interburden
B031A	360186	6358946	180.9	294.8	230	31/08/10		+10.1	Upper Donaldson Seam
B031B	360186	6358946	180.9	294.8	180	31/08/10		+59.2	Sandgate - Donaldson Interburden
B031C	360186	6358946	180.9	294.8	100	31/08/10		+82.1	West Borehole Seam
B031D	360186	6358946	180.9	294.8	54	31/08/10		+133.0	Fassifern - West Borehole Interburden
Bloomfield Colliery Piezometers									
VW1(35m)	363804	6370113	24.61	171	35	18/04/07	24.23	-7.23	Donaldson Seam
VW1(46m)	363804	6370113	17.4	171	46	18/04/07	24.12	-7.12	Big Ben Seam
VW5(62m)	366534	6368071	60.7	92	62	11/05/07	46.26	+9.44	White Creek Seam
VW5(71m)	366534	6368071	60.7	92	71	11/05/07	51.19	+4.51	Donaldson Seam
VW5(89.5m)	366534	6368071	60.7	92	89.5	11/05/07	54.39	+1.31	Big Ben Seam
VW6(96m)	365299	6368267	53.6	130	96	11/05/07	82.31	-29.81	White Creek Seam
VW6(114m)	365299	6368267	53.6	130	114	11/05/07	88.46	-35.96	Donaldson Seam
VW6(128m)	365299	6368267	53.6	130	128	11/05/07	95.11	-42.61	Big Ben Seam
VW7(70m)	364595	6368658	26.8	110	70	26/05/07	29.79	-4.89	White Creek Seam
VW7(95m)	364595	6368658	26.8	110	95	26/05/07	31.21	-6.31	Donaldson Seam
VW7(107m)	364595	6368658	26.8	110	107	26/05/07	31.11	-6.21	Big Ben Seam
VW8(83m)	363020	6369039	23.9	240	83	11/05/07	28.46	-5.96	Donaldson Seam
VW8(97m)	363020	6369039	23.9	240	97	11/05/07	28.37	-5.87	Big Ben Seam
SP2-1	365285	6371010	78.6	65	55.2 – 61.4	25/02/08	54.2	+9.8	Donaldson Seam
SP2-2	365295	6371007	79.2	85	79.0 – 94.0	25/02/08	61.4	+3.3	Big Ben Seam
SP3-1	366819	6372115	30.4	14	11 – 14	25/02/08	5.7	+33.1	Alluvium/weathered Permian
SP4-2	367685	6371033	26.7	9.4	6.4 – 9.4	25/02/08	3.1	+24.7	Alluvium/weathered Permian
SP7-1	364594	6368654	26.8	11.2	9.2 – 12.2	25/02/08	Dry	Dry	Alluvium/weathered Permian

Piezometer	MGA Coordinates		Surface RL (mAHD)	Depth (m)	Screen/Vibrating Wire Piezometer (mBGL)	Initial Water Level			Aquifer Formation
	Easting	Northing				Date	mBGL	mAHD	
FMCPZ1	368832	6368129	22.17			16/5/01	7.8	+14.37	
FMCPZ2	368776	6367607	51.53			16/5/01	16.26	+35.27	
REGDPZ1	371178	6371241	40			9/11/00	19.5	+20.5	
Big Ben Bore	365353	6369248				30/1/01		-5.57	Ashtonfield Seam
West Wallsend Piezometers									
WWA1	364299	6353855							Alluvium/colluvium
WWA2	364199	6353895							Alluvium/colluvium
WWA3	364299	6354055							Alluvium/colluvium
WWA4	364299	6353955							Alluvium/colluvium
WWA5	364199	6354255							Alluvium/colluvium
WWA6	364299	6354355							Alluvium/colluvium
WWA7	364370	6354420							Alluvium/colluvium

mAHD = metres Australian Height Datum

m = metres

BGL = below ground level.

3.3 Hydraulic Testing

Previous studies and investigations have included hydraulic conductivity testing results for the coal seams and interburden in the regional area. For the purposes of this report it should be noted that the terms "hydraulic conductivity" and "permeability" are used synonymously. Table 3.2 provides a summary of the typical range of values recorded to date.

Table 3.2: Summary of Historical Hydraulic Testing in the Study Area

Strata Layer Tested	Type of Testing Involved	Recorded Hydraulic Conductivity Range (m/d)	Notes
Alluvium/Weathered Permian	Slug & CRT (4 Tests)	0.07 – 0.6	-
'Overburden' – Abel Underground Mine Area	CRT (1 Test)	0.01 – 0.06	General result for reasonably deep overburden
'Overburden' – Tasman Underground Mine Area	Slug Test	0.09	Just above roof of Fassifern Seam
Bloomfield Colliery Rehabilitated Areas	Slug Test (3 tests)	0.02 – 2.3	-
Mudstone Interburden	Lab K Tests (Kh) (3 Tests)	0.0003 – 0.0037	Generally shallow samples
	Lab K Tests (Kv) (3 Tests)	0.0001 – 0.0002	
Mixed Mudstone/Sandstone Interburden	Lab K Tests (Kh) (2 Tests)	0.0014 – 0.0015	Generally shallow samples
	Lab K Tests (Kv) (2 Tests)	0.0001 – 0.0005	
Sandstone	Lab K Tests (Kh) (2 Tests)	0.0015 – 1.3	Generally shallow samples (high value only for very coarse/weathered sample)
	Lab K Tests (Kv) (2 Tests)	0.0009 – 0.19	
Fassifern Seam	Slug Tests (3 Tests)	0.01 – 0.12	-
Above West Borehole Seam	Packer Test	2.07E-05	-
	Lab K Tests (Kh)	5.11E-07 – 7.95E-07	
	Lab K Tests (Kv)	5.41E-07 – 5.8E-07	
West Borehole Seam	Lab K Tests (Kh) (2 Tests)	1.59E-05	-
	Lab K Tests (Kv) (2 Tests)	2.04E-06	
Sandgate Seam	Packer Test	1.21E-05	-
	Lab K Tests (Kh)	4.57E-07 – 6.75E-03	
	Lab K Tests (Kv)	1.35E-07 – 1.69E-06	
Sandgate-Donaldson Interburden	Packer Test	8.12E-06	-
	Lab K Tests (Kh)	4.27E-07 – 8.03E-05	
	Lab K Tests (Kv)	2.68E-07 – 5.74E-07	
Above Donaldson Seam	Lab K Tests (Kh) (2 Tests)	1.35E-07 – 1.10E-05	-
	Lab K Tests (Kv) (2 Tests)	8.39E-08 – 1.23E-06	
Donaldson/Big Ben Seams	Slug & CRT (9 Tests)	0.002 – 2	The high value was a single, isolated record in a disturbed area at sub-crop. The next highest was 0.17. All deeper samples were at the lower end of the range (0.002 – 0.07). No samples below 100m.
Donaldson Seams	Packer Test	1.30E-04	
	Lab K Tests (Kh)	1.08E-07 – 8.55E-03	
	Lab K Tests (Kv)	1.27E-07 – 3.79E-07	

Strata Layer Tested	Type of Testing Involved	Recorded Hydraulic Conductivity Range (m/d)	Notes
Thornton Claystone	Lab K Tests (Kh)	1.73E-07 – 7.51E-06	-
	Lab K Tests (Kv)	1.73E-07 – 1.78E-04	
Big Ben Seam	Packer Test	1.30E-04	-
	Lab K Tests (Kh)	7.36E-07 – 3.35E-06	
	Lab K Tests (Kv)	2.67E-07 – 8.64E-07	
Just below Big Ben Seam	Lab K Tests (Kh)	1.85E-06	-
	Lab K Tests (Kv)	5.13E-07	
Ashtonfield Seam	Slug Tests (3 Tests)	0.009 – 0.04	No samples below 100m, deepest sample at the lower end of the range.
	Lab K Tests (Kh)	6.94E-08 – 6.03E-06	
	Lab K Tests (Kv)	8.88E-08 – 1.55E-06	

m/d – metres per day.

These results show a noticeable decrease in permeability with depth for the coal seams, with permeability decreasing from the Fassifern Seam (0.01 to 0.12m/d) through to the Ashtonfield Seam (0.009 to 0.04m/d). This exhibited decrease is probably due to greater cover depth and/or remoteness from outcrop, as well as the near-surface effects of weathering.

The results also show that laboratory tests for interburden materials demonstrate very low permeabilities in comparison to field slug tests, and vertical permeability is typically less than horizontal permeability. Discrepancies between laboratory tests and field scale tests are expected, as the laboratory scale tests do not contain fractures or fissures. Mackie (2009) identified three ‘types’ of bulk rock mass permeability in the Hunter Coalfields:

- Areas where there are very few fissures, or where fissures are so deeply compressed by hydrostatic loading that they are effectively closed, and bulk rock mass permeability is similar to laboratory values;
- Areas where there are ‘limited’ active joints. The impact this has on permeability depends on the rock type, with hydraulic conductivity for coarse grained or weathered sandstones/conglomerates only increasing by a factor of 5, whereas mudstones could increase by up to 100 times the laboratory value; and
- Areas that are unloaded and heavily jointed. Most rock types in this category have similar hydraulic properties, in the range 0.01 to 0.001m/d.

Differences between vertical and horizontal permeability are also well documented, with vertical (or across bedding) permeabilities typically several orders of magnitude less than horizontal (or parallel to bedding) permeability. This is because fractures and fissures tend to be oriented with bedding planes, and layers of mudstone or other low permeability strata tend to cause coherent barriers to flow across the bedding.

The coal seams tend to be the most permeable parts of the coal measures, and the permeability of coal seam layers also varies, generally dependent on the degree of cleating within the coal (which dominates permeability) and the depth of cover (and hence compressive stress on the cleats) (Mackie, 2009). Both empirical analysis (Laubach *et al*., 1998) and modelling of cleat fracture permeability (Mackie, 2009) suggest that the permeability of coal seams tends to reduce by around an order of magnitude with each 200 m of additional overburden.

3.4 Groundwater Level Monitoring

There are over 40 active monitoring bores in the regional study area. These cover the majority of the model domain, as shown in Figure 3.1, and monitor most of the coal seams and interburden layers described above. Hydrographs and hydrostatic head profiles for standpipes and multi-level vibrating wire piezometers are provided in Appendix B.

The hydrostatic head profile is used to gauge the quality of data sets, assess the degree of vertical connectivity and to explore the vertical hydraulic gradients which may be present. Generally, under pre-mining conditions, and assuming no perching of groundwater (i.e. there is vertical hydraulic continuity through the sequence), pressures can be expected to plot close to the 45° "hydrostatic line", indicating that the various horizons are in hydraulic equilibrium, while a slight shift away from the line indicates the presence of a potential vertical head gradient. Deviations from the 45° line may occur in areas already affected by mining or other stresses, where different aquifers are subject to different recharge/discharge processes, or where perched aquifers are present.

4. HYDROGEOLOGICAL SETTING

4.1 Rainfall and Evaporation

The climate of the region is temperate with hot summers and cool winters. The average daily maximum temperature ranges from 30.7º Celsius (C) in January to 16.6ºC in July.

Table 4.1 summarises rainfall data from the East Maitland Bowling Club (Station 61034, 1902 to 1994) and the Maitland Visitor Centre (Station 61388, 1997 to present) meteorological stations, both situated approximately 10km to the north of the Modification. Rainfall data from the Cessnock (Nulkaba) meteorological station (Station 61242, 1966 to present), situated approximately 12km west of the Modification has also been included in Table 4.1.

Table 4.1: Rainfall Data for East Maitland Bowling Club (Station 61034), Maitland Visitor Centre (Station 61388) and Cessnock (Nulkaba) (Station 61242).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Station 61034 Mean Rainfall (mm)	89.0	94.1	96.5	87.4	70.3	84.2	58.1	52.2	54.8	65.5	61.6	81.3	895.0
Station 61034 Mean Rain days	7.8	7.6	7.6	7.7	7.0	7.7	6.8	6.3	6.2	7.4	6.6	6.4	85.1
Station 61388 Mean Rainfall (mm)	46.5	111.9	90.5	84.0	67.3	86.6	48.7	33.5	54.4	65.1	86.3	61.1	835.9
Station 61388 Mean Rain days	10.7	11.5	11.6	11.9	10.9	12.4	10.6	8.9	8.9	9.8	12.4	10.4	130.0
Station 61242 Mean Rainfall (mm)	87.9	105.1	85.3	58.2	54.2	60.2	32.6	37.1	43.8	59.3	72.7	70.7	767.1
Station 61242 Mean Rain days	10.7	10.6	10.6	8.7	8.8	9.0	7.7	7.7	7.6	9.6	10.8	9.7	111.5

mm = millimetres.

Rainfall at all three sites exhibits a moderate seasonal pattern, with the highest mean rainfall generally occurring during the December to June period and the lowest rainfall observed between July and November.

Regionally, rainfall is the primary source of groundwater recharge. Therefore, fluctuations in the groundwater table under natural conditions typically display a close relationship to variations in rainfall. Periods of above average rainfall generally lead to rising groundwater levels, and below average rainfalls lead to declining groundwater levels. Typically, under natural conditions, trends in the groundwater elevation reflect the cumulative deviation between the long-term monthly (or yearly) average rainfall, and the actual monthly (or yearly) rainfall, which is presented graphically as the Residual Mass Curve (RMC).

The groundwater levels recorded during periods of rising RMC are expected to rise in proximity to recharge areas while those recorded during periods of declining RMC are expected to decline. A plot of the RMC at Cessnock since 1991 is shown in Figure 4.1. Below average rainfall has occurred from 2002 to 2007 and again in 2010. Above average rainfall is observed to have occurred in 2008, 2009 and again in 2011.

No evaporation data is available from the Maitland meteorological stations. Average Class A pan evaporation data for Cessnock (Station 61242) and Paterson (Station 61250), located approximately 20km to the north of the Modification, are provided in Table 4.2.

Table 4.2: Pan Evaporation Data for Cessnock (Nulkaba) Station 61242 (opened 1966) and Paterson (Tocal AWS) Station 61250.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Station 61242 Mean Evaporation (mm)	177	140	121	84	59	45	53	78	105	136	153	177	1328
Station 61250 Mean Evaporation (mm)	192	148	130	99	74	63	74	105	132	161	174	208	1560

Although actual evapotranspiration is generally only around 85% of the pan data, Tables 4.1 and 4.2 show that there is a clear annual rainfall deficit, as potential evaporation generally exceeds rainfall for most months of the year (except during the period April to July).

4.2 Topography and Drainage

An overview map of the regional topography is shown in Figure 4.2. The Abel Underground Mine area is located within the lower section of the Hunter River catchment and comprises undulating ridge-affected terrain and shallow, slope wash filled gullies and foot slopes (Strata Engineering, 2006). The main topographic feature is Black Hill, which is an east-west trending ridge located near the centre of the Abel Underground Mine area. Topographic relief varies from approximately 210mAHD at the top of Black Hill to approximately 0mAHD within the wetlands associated with the Pambalong Nature Reserve to the east of the Abel Underground Mine area.

The following surface drainage features are present within and nearby the Abel Underground Mine area, and are shown in Figure 4.3:

- Buttai Creek sub-catchment area drains north-westward into Wallis Creek;
- Weakleys Flat Creek and Viney Creek areas drain northward into Woodberry Swamp;
- Four Mile Creek sub-catchment area drains northward into more significant reaches of Four Mile Creek prior to entering the Hunter River;
- Blue Gum Creek and its tributary Long Gully drain the southern side of the ridgeline eastwards towards Pambalong Nature Reserve and Hexham Swamp (both located outside the Abel Underground Mine area); and
- Minmi Creek sub-catchment area drains eastward into Hexham Swamp.

The surface water features which drain the southern side of the Black Hill ridgeline are generally ephemeral; however Blue Gum Creek is expected to have at least a small baseflow for the majority of the year, including some minor seepage from near surface alluvium (shown in Figure 4.3).

The model area for the Modification (Figure 4.2) runs from Wallis Creek on the western boundary through to the low-lying Hexham Swamp, saline parts of the Hunter River and Lake Macquarie on the eastern side of the model. The Sugarloaf Range dominates the south-eastern part of the model area, and rises to a height of over 450mAHD (outside the Abel Underground Mine area). The Sugarloaf Range is drained by a number of ephemeral creeks that run to either Wallis Creek on the western side, or Hexham Swamp and Lake Macquarie on the eastern side of the range. The northern part of the model area is dominated by low lying (up to 150mAHD) hills that are bounded by Wallis Creek to the west and north, and low lying land associated with Hexham Swamp to the east.

4.3 Land Use

The majority of the Abel Underground Mine area comprises rural residential and areas of vegetated land. The majority of cleared land is used for grazing, commercial orchards and lifestyle properties.

Existing and proposed development within the Abel Underground Mine Area includes:

- The localities of Black Hill and Stockrington;
- Agricultural infrastructure including farm dams and irrigation systems;

- Black Hill Public School;
- Black Hill Church and cemetery;
- Transmission lines owned by TransGrid and Ausgrid;
- Hunter Water pipeline;
- Jemena natural gas pipeline;
- Telecommunications infrastructure owned by Telstra and Optus;
- The Black Hill Quarry and Stockrington Quarry;
- John Renshaw Drive, Black Hill Road, Seahampton Road, Lings Road, Dog Hole Road, Browns Road and other minor roads; and
- The proposed Black Hill Employment Lands.

The operational mines in the vicinity of the Abel Underground Mine area include:

- The existing approved Abel Underground Mine;
- Donaldson Open Cut Mine, to the immediate north;
- Bloomfield Colliery, approximately 1km north-west;
- The Tasman Underground Mine, approximately 8km south-west;
- West Wallsend Colliery, approximately 10km south; and
- Westside Colliery, approximately 11km south.

4.4 Stratigraphy and Lithology

A regional surface geological map of the model area for the Modification is shown in Figure 4.4 (Hawley and Brunton, 1995).

The majority of the Abel Underground Mine area is underlain by the Permian Tomago and Newcastle Coal Measures, the latter of which tops the higher parts of the Black Hill ridge. These lithological units include a number of coal seams, described further below.

Figure 4.5 shows a schematic stratigraphic column of the Permian coal measures, with depths to the main coal seams indicated based on exploration drill hole C233 (refer to Figure 3.1 for locality). Sediments above and below the coal seams comprise predominantly interbedded claystone, siltstone, sandstone and tuff.

The Tomago and Newcastle Coal Measures contain a number of named, significant coal seams that occur within the Model Area. These are (from youngest to oldest):

- Great Northern Seam;
- Fassifern Seam;
- West Borehole Seam;
- Sandgate Seam;
- Donaldson Seam: Upper, Lower*;
- Big Ben Seam*; and
- Ashtonfield Seam.

**N.B: There is some splitting of these seams, and Big Ben is currently only mined within the Bloomfield Colliery. The Upper and Lower Donaldson tend to split downdip to the south of the model area.*

The West Borehole Seam is present only in the southern part of the Abel mining lease (Figure 4.4), and was the subject of previous mining. It is stratigraphically about 200m above the Upper Donaldson Seam, on average 7.7m thick, and crops out in the south-west of the Abel Underground Mine area (PDA, 2006).

Other coal seams of lesser importance between the West Borehole and Donaldson seams include the Sandgate, Buttai and Beresfield seams.

The target coal seam of the proposed Abel mine is the Donaldson Seam, which divides into separate Upper and Lower units in the southern half of the lease (PDA, 2006). The Upper and Lower Donaldson seams are on average 2.0 and 2.5m thick, respectively. The seams are present throughout the Abel Underground Mine area and outcrop at about 800m north of the site. Due to the southerly dip, the seams reach depths of about -360mAHD in the south of the study area.

It should be noted that some nomenclature at the adjacent Bloomfield operation differs from that used elsewhere in the region. At Bloomfield Colliery, the Donaldson Seam is called the 'Whites Creek' Seam; the Big Ben Seam is known as the 'Donaldson' Seam, and the Ashtonfield Seam is known as the 'Big Ben' Seam.

Through most of the model area, fresh rock is overlain by regolith materials that are formed by *in situ* weathering of the Permian strata. Some Quaternary alluvial deposits are present, and are generally associated with the floodplains of Wallis Creek, the lower parts of the Hexham Swamp tributaries and the permanent river reaches of Cockle Creek. Minor alluvial development associated with Hexham Swamp/Pambalong Nature Reserve extends upstream from Pambalong for some distance along the lower reaches of Blue Gum Creek and Long Gully.

4.5 Structural Geology

Structurally, the area is dominated by the Maitland Syncline, which plunges to the south, as shown on Figure 4.4. There is a steep monocline on the western side of the Maitland Syncline, which causes sequential outcropping of Permian strata within the higher terrain associated with the Sugarloaf Range. The eastern flank of the syncline is bounded by either a shallow anticline or monocline structure.

There are several faults within the area, which run sub-parallel to the syncline, as shown on Figure 4.4. These occur in the southern part of the model area, near Lake Macquarie and Cockle Creek. The major structures shown in Figure 4.4 were sourced from Geoscience Australia. Additional structures shown in Figure 4.4 were provided by Donaldson Coal and include fault structures and dykes mapped within the area. These include shallow reverse fault structures in the Donaldson Open Cut Mine and Abel Underground Mine areas. Of these, a number of smaller faults do not extend to the Donaldson Seam.

The Krecji Fault however, is a significant reverse fault which has displaced and disconnected strata through to the Donaldson Seams, preventing mine development east of this structure. It is evident that the Krecji Fault in particular does have enhanced hydraulic conductivity associated with the disturbed fault zone, as elevated mine inflows are experienced during coal excavation in near proximity to the Abel Underground Mine. However, the fault also appears to act as a regional barrier to groundwater flow. The effect of the Krecji Fault on water levels and hydraulic conductivity is discussed further in Sections 4.7.2 and 5.2, respectively.

A number of igneous dykes are also known to occur, which also tend to run sub-parallel to the axis of the syncline. They tend to have a basic (taschenite) petrology, and are thought to be of Cretaceous age (Hawley and Brunton, 1995).

According to MSEC (2012), zones of geological disturbance (i.e. faults and dykes) have been identified within the Abel Underground Mine area, coinciding with the alignments of Buttai Creek and Long Gully. A zone of geological disturbance was also identified in the southern part of the lease, roughly aligned with, but offset from, the alignment of Blue Gum Creek.

Contours of the base of the Upper and Lower Donaldson coal seams are shown in Figures 4.6 and 4.7, respectively. The structural contours clearly show the plunging synclinal structure within the Abel Underground Mine area and the steep, monoclinal structure on the western flank of the basin. These regional structures are less obvious higher in the stratigraphic sequence. In the Abel Underground Mine area, the Donaldson seams can be observed to slope downwards towards the south-southeast.

The inferred sub-crops and geometry of the West Borehole and Donaldson Seams are also shown in Figure 4.4. These are based on the resource models provided by Ellemby Resources, modified on the western boundary to enable the formation sub-crop to be shown on the geological map. There is a slight discrepancy between the Geoscience Australia-sourced geological map and the resource model sub-crop lines which can be seen towards the west in Figure 4.4.

The West Borehole, Sandgate, Donaldson, Big Ben and Ashtonfield Seams all vary in thickness and the thickness of the interburden also varies according to the location on the synclinal structure. Details of seam and interburden thicknesses are given as part of the model description contained in Section 7.5. In general there is around 200m of interburden between the West Borehole and Donaldson seams. The Ashtonfield Seam is generally 30 to 60m below the Upper Donaldson Seam, except close to sub-crop.

4.6 Hydrogeological Units

Within the Abel Underground Mine area, aquifers are limited to alluvial aquifers associated with swamp, floodplain and estuarine sediments along the Wallis Creek and Hunter River systems and their tributaries, and the Permian coal measure aquifers (PDA, 2006). In the immediate Abel Underground Mine area, neither the alluvial nor the hard rock aquifer systems are significant aquifer systems.

The main hydrogeological units relevant to the coal mining operations and proposed developments in the area are as follows:

- Alluvium;
- Colluvium/weathered bedrock;
- Triassic Narrabeen Group;
- Coal measures overburden/interburden, comprising mudstones, siltstones, sandstones, with occasional minor coal seams;
- Main coal seams of interest to mining, including in stratigraphic order:
  - Great Northern Seam;
  - Fassifern Seam;
  - West Borehole Seam;
  - Sandgate Seam;
  - Buttai Seam: Upper and Lower;
  - Beresfield Seam;
  - Donaldson Seam: Upper and Lower;
  - Big Ben Seam;
  - Ashtonfield Seam; and
- Basal units which include coal measures and interburden of the Tomago Coal Measures, as well as underlying Wallis Creek Formation.

4.7 Groundwater Levels

Groundwater levels in the undisturbed alluvium, regolith and near surface weathered zones in the hard rock units in the study area tend to closely reflect local topographic elevation, as they are recharged and discharge locally. Groundwater levels at depth (within the hard rock Permian sequence) represent more regionally driven characteristics and are controlled principally by the surface elevations in areas of outcrop, often located some distance away up dip.

4.7.1 Groundwater Level Contours

According to PDA (2006), groundwater levels observed in the Donaldson Seam exhibit an overall pattern of flow to the east, south and west from a central ridge which extends southward from Donaldson Open Cut (Figure 4.8). The flow pattern is largely independent of the local topography. The contours also show the influence of dewatering in the Donaldson Open Cut area, with a prominent cone of depression located to the north of John Renshaw Drive, and a similar depression around the active Abel underground mining area to the south of John Renshaw Drive.

In general, a similar flow pattern is apparent within the other coal measures (PDA 2006). Recharge to the coal measures is represented in groundwater levels observed in the north of the area, and flows down dip to the south and east, except in areas where local hydraulic gradients are affected by ongoing, long-term mining activities.

4.7.2 Groundwater Level Hydrographs

The locations of all monitoring bores are shown in Figure 3.1 and detailed as follows:

- The C series bores were installed during investigations for the Abel Underground Mine;
- The DPZ monitoring bores are predominantly standpipes installed as part of the Donaldson Open Cut Mine and generally monitor groundwater levels in the Donaldson Seam and overburden;
- The FMC bores are located in the Donaldson Open Cut Mine area adjacent to Four Mile Creek, and REGDPZ1 is a regional control bore to the north of the Donaldson Open Cut Mine;
- TA bores are those installed for the Tasman Underground Mine;
- The B series bores were installed as part of the ongoing baseline monitoring program for the needs of future mining within the Donaldson lease areas, initially the West Borehole Seam extraction proposed in the Tasman Extension Project;
- SP and VW series bores and Big Ben Bore are those monitoring the neighbouring Bloomfield Colliery; and
- WWA series bores are located at the West Wallsend Colliery south of the Tasman Extension Project.

Hydrographs and hydrostatic head profiles for all standpipe piezometers and multi-level vibrating wire piezometers are provided in Appendix B, with key piezometers presented in Figures 4.9 to 4.18. The groundwater level hydrographs show changes in levels with time, in response to both mining effects and seasonal recharge effects.

Donaldson Open Cut Mine Area

Figure 4.9 shows hydrographs for all the DPZ bores used in the calibration of the groundwater model. Many of these are no longer functioning as they were located within the open cut area and have been progressively mined out.

Monitoring of water levels has been regularly maintained throughout the continued life of the mine. A number of piezometers show drawdown effects of mining from the Donaldson Open Cut Mine, especially DPZ4B, DPZ6, DPZ8 and DPZ9 (all screened in the Donaldson and Big Ben Seams); and DPZ15, DPZ16 and DPZ17 (all screened in the Buchanan and Ashtonfield seams) (Figure 4.9). Bores DPZ4, DPZ15, DPZ16, DPZ 18 and DPZ19 have all been mined out.

Bore DPZ17, located just outside the mining lease area, shows gradual recovery of the groundwater level after January 2004, in response to progressive pit backfilling from the eastern end of the open cut, as mining advanced to the west, allowing groundwater to rise up into the backfill (Figure 4.9). Similarly, DPZ8 indicated drawdown responses to mining activity in late 2007 and early 2008, followed by a slight recovery in water levels. Water levels in DPZ8 have been relatively constant from the end of 2010.

Bores DPZ3 and DPZ20 are both located within overburden above the Upper Donaldson Seam. DPZ3, to the north-west of the Donaldson mine site, indicates steady water levels until the end of 2003, followed by an increase of approximately 5m, with relatively steady water levels observed from the start of 2008 onwards. DPZ20 also observed relatively constant water levels, however it should be noted that scarce monitoring data was available between mid 2006 and late 2010.

Bore DPZ13 is located within the north-east section of the Abel Underground Mine area, and since the start of 2012 is indicating a response to the current Abel mining operation in the underlying Upper Donaldson Seam.

Tasman Underground Mine and Tasman Extension Area

TA23 (Fassifern Overburden) located south of the Tasman Underground Mine at an elevation of 379mAHD, has monitored water levels at approximately 237mAHD from 2006 to 2009 before being cemented (Figure 4.10). This indicated water level is more than 100 m higher than measured elsewhere in the range. The higher groundwater levels are due to the high elevation of the sub-crop area where this strata is recharged.

Regional flow patterns at depth are also influenced by low water levels that are known to occur within the abandoned workings of the West Borehole Seam associated with the former Stockrington Colliery. Regional monitoring bores in the vicinity of the existing Tasman Underground Mine show a very strong downward hydraulic gradient beneath the Sugarloaf Range, with a water level difference of over 40m between the Fassifern Seam and the underlying West Borehole Seam. This downward gradient was present prior to commencement of mining at Tasman, and indicates that the Fassifern Seam and higher groundwater is perched above the deeper groundwater; providing confirmation that vertical permeability is very low, and that the main flow paths within the Permian strata are along the coal seams and parallel to bedding in the interburden layers.

Within the Fassifern Seam in the vicinity of the existing Tasman Underground Mine, TA24 (Figure 4.10) shows progressive depressurisation in response to mining from 2006, and by mid 2011 the piezometer has almost been dewatered. However this downward trend commenced prior to mining, so may suggest another cause for the response. TA24 is located close to the area where mining commenced at Tasman Underground Mine (Figure 3.1).

Within the West Borehole Seam, a steep hydraulic gradient exists between subcrop on the western margins at elevated levels, and historic workings where water levels are believed to be at around -67.5mAHD, based on measurement in a water disposal borehole in the Tasman Underground Mine. Figure 4.11 shows water levels within the West Borehole Seam which illustrate the gradient observed within that coal seam. The water levels within the individual bores are observed to be relatively stable.

Bores B004 and B005 are single vibrating wire installations in the vicinity of the historical mining areas of the abandoned Stockrington Colliery. Water levels are relatively stable, with some variability possibly indicating a subdued recharge response. The West Borehole Seam outcrops in the floor of the Black Hill Quarry, providing potential for enhanced recharge.

Abel Underground Mine Area (including the Modification)

Figure 4.12 shows hydrographs for C063 which is located to the east of the Abel Underground Mine adjacent to the F3 freeway. Bore C063 has two vibrating wire piezometers, placed in the Lower Donaldson Seam (C063A) and within sandstone interburden below the Buttai Seam (C063B) at respective depths of 280 and 129m. No response to mining at the Abel Underground Mine is observed in C063A within the Donaldson Seam. The Krecji Fault is a significant structure identified between Abel Underground Mine and C063A which has caused disruption of the geologic strata. The lack of drawdown response in the Donaldson Seam east of this fault indicates that the fault is preventing the eastward migration of groundwater depressurisation. The water level decline observed in C063B suggests a very slow recession following installation in 2005, considered to be an indication of extremely low permeability, and not as a result of mining stresses. Accordingly, neither bore was used in the model calibration.

Hydrographs for bores C081A and C081B are plotted on Figure 4.12. Both bores show questionable data through the period February 2009 and January 2010, believed to be due to operator or recording errors. The data from this period is included in the hydrographs, but are not considered in the following comments on hydrograph responses to mining.

Bore C081A monitoring the Donaldson Seam (Figure 4.12) shows a strong drawdown response to mining at the Abel Underground Mine from August 2008 continuing through into 2011.

Shallow bore C081B, screened in weathered Permian, shows no drawdown response to mining, but shows a very slight downward trend through the period from the start of 2009 to the middle of 2010 (Figure 4.12).

The large drawdown in the Donaldson Seam observed at C081A, has led to a reversal of the previous upward hydraulic gradient between the Permian coal measures and the overlying alluvium/regolith (Figure 4.12). This bore is located at a low-lying site on the western margin of the Pambalong Nature Reserve in the lower-lying eastern parts of the model area, south of the Abel Underground Mine. The site is more than 2km south of the current active Abel mining area. Prior to mining, the groundwater pressure in the Donaldson Seam was 20m higher than the groundwater level in the shallow alluvium/regolith (and 22m above ground level), however the Donaldson Seam pressure is now well below the surficial groundwater level, and well below ground level. The lack of response observed in the surficial groundwater indicates that there is negligible hydraulic connection between the surface and the Donaldson Seam.

Bore C080 is a single standpipe piezometer screened in the Donaldson Seam. The hydrograph (Figure 4.13) shows drawdown due to mining at Donaldson prior to 2007, and then shows further drawdown believed to be in response to the Abel Underground Mine starting in 2009. Slight recovery in water levels is observed from early 2011 onwards.

Bore C072 site has three piezometers, one of which (C072A) was damaged and lost shortly after construction. Hydrographs for the remaining piezometers in the Donaldson Seam and weathered overburden (Figure 4.13) show no significant response to mining, but C072 (Donaldson Seam) instead displays a trend of increasing water levels. This is believed to be due to a partial failure of the cement grout around the piezometer, providing limited connection to other parts of the sequence.

Bore C078A (Donaldson Seam) and C078B (weathered overburden) likewise show no response to mining at the Abel Underground Mine (Figure 4.14).

The data from these monitoring bores support the assessment that there is low vertical hydraulic connectivity between the surficial groundwater and the deeper Permian groundwater. Connective cracking from the Abel Underground Mine may have minor localised impacts on shallow aquifers immediately above the mined extraction panels, in the north-eastern part of the Abel mine.

Bores C082 and C087 (Figure 4.14) are shallow standpipe piezometers in the regolith. Both show relatively stable water levels since early 2007.

Standpipe piezometer C082, located just north of Pambalong Nature Reserve, monitors groundwater levels within shallow weathered Permian overburden and is screened from 14 to 20m below surface. Groundwater levels are relatively stable as shown in Figure 4.14, with a subdued response to rainfall, by comparison with the residual mass rainfall curve also presented on Figure 4.14. The hydrograph for C072, monitoring the Donaldson Seam - Sandgate Seam interburden at a depth of 42 to 45m, also shows a subdued response to rainfall, and no response to mining.

C123 and C223 (Figure 4.15) are multi-level vibrating wire piezometers located between the Abel Underground Mine and Tasman Underground Mine operation areas (Figure 3.1).

Figure B14 in Appendix B provides hydrographs and a hydrostatic head profile for C123. Water levels in the Lower Donaldson became erratic from early 2010, suggesting a failure of the piezometer, and this record was not used as a model calibration target.

The hydrostatic head profile for C223 (Figure B18 in Appendix B) shows a linear trend with groundwater pressures generally along the 45° hydrostatic line, but with the deeper strata (Buttai and Donaldson Seams) being slightly depressurised, possibly due to long-term mining at Donaldson Open Cut Mine and Bloomfield Colliery. Hydrographs indicate relatively consistent decline in groundwater levels.

Both C123 and C223 indicate that pressures within the deeper strata are lower than pressures in stratigraphically higher lithologies as is also indicated around the Tasman Underground Mine further south under the Mt Sugarloaf range (see piezometers C141, C148, B002 and B029 in Figures B16, B17, B20 and B23 respectively in Appendix B).

North of the Abel Underground Mine area, bore C138 is located west of the Abel Underground Mine and south-southwest from the Bloomfield Colliery (Figure 3.1).

Figure B15 of Appendix B illustrates the hydrographs and hydrostatic head profile for C138. At the time of installation in 2008, groundwater pressures were well below sea level in the Donaldson Seam and deeper strata, at approximately -7 to -13mAHD. Groundwater levels have subsequently shown a continued downward trend, to between -17 and -26mAHD by mid-2011 (Figure 4.16). These are assessed to be responding to mining operations at Bloomfield Colliery. In contrast, the piezometer placed 25m above the Lower Donaldson Seam (C138E) shows little drawdown, and suggests that the overburden is largely insulated from the Bloomfield dewatering, and also highlights the low vertical hydraulic conductivity characteristic of interburden units. A gap in monitoring occurred between early 2011 and early 2012, at which time the lowest water levels are recorded at this monitoring location. Subsequently, water levels are observed to be either stable (C138E) or recovering slightly.

Piezometers C141 and C148 are located to the west of the Abel Underground Mine and south of Bloomfield Colliery (Figure 3.1). Both show generally lower groundwater levels, albeit not as low as in C133 and C138 (Figure 4.17). These bores all also show the influence of mine dewatering at Bloomfield. Piezometers set in strata above the Donaldson Seam in C141 show only limited drawdown effects.

Bloomfield Mine Area

Figure 4.18 shows hydrographs for the monitoring bores within the Bloomfield mine area used in the calibration of the groundwater model. Monitoring data was only available to the end of 2009.

A combination of standpipes and vibrating wires has been installed at 8 locations across the Bloomfield mine site. Different monitoring horizons within the Permian stratigraphic units all display the same declining trends in water levels at sites 1, 7 and 8, indicating interconnecting between the units at these locations due to historical mining activity. This interconnectivity between units is also observed at Site 6; however the declining water level response is less marked.

The Big Ben Bore is located within an old mine shaft, and is used for recovery of water from tailings disposed of to former underground mine workings. The water level monitored in Big Ben Bore is a pumping water level, and so is somewhat variable, but since the start of 2003, generally rising water levels are observed.

4.8 Groundwater Quality

Assessments of groundwater and surface water quality can be useful in understanding conceptual hydrogeology, particularly in relation to electrical conductivity (EC)/salinity and the relative concentrations of the major ions in solution. Different strata horizons can demonstrate differing salinities, which tend to be lower in areas of high recharge or connectivity with surface waters. Piper Trilinear Plots which display the relative concentration of the major cations and anions provide an assessment of the recharge-discharge processes, and also allow a comparison of water samples derived from different environments within the hydrological system. Recently-recharged water tends to be dominated by calcium and bicarbonate ions and thus plots closer to the left-hand apex of the diamond field in the Piper diagram, while waters further from the source of recharge tend to be higher in sodium and chloride and plot closer to the right-hand side of the Piper diagram.

No groundwater sampling has been undertaken specifically for the Modification. The following previous investigations were reviewed to provide an understanding of the existing conditions across the region:

- In 2002, groundwater quality in the vicinity of the Tasman Underground Mine was characterised by the collection of samples from monitoring piezometers installed in seven exploration drillholes within and around the mine site as part of the groundwater impact assessment studies for the Tasman Underground Mine (PDA, 2002). Three sampling rounds were conducted between September and December 2001;
- In 2006, groundwater quality in the vicinity of the Abel Underground Mine was characterised by the collection of samples from monitoring piezometers installed within and around the mine site as part of the impact assessment studies for the Abel Underground Mine (PDA, 2006); and

- In May and December 2007 (winter and summer), groundwater samples were collected in from the Bloomfield Colliery standpipe piezometers, and submitted to accredited laboratory ALS Environmental for detailed chemical analysis (Aquaterra, 2008). EC and pH were measured in the field and at the time of sampling. The standpipes have subsequently been sampled quarterly since September 2010 and analysed for EC, pH and the major ions.

4.8.1 Salinity

The salinity of groundwater within the Abel Underground Mine area and surrounds is variable (PDA, 2002; PDA, 2006; Aquaterra, 2008), with total dissolved solids (TDS) ranging from less than 500 to 16,000mg/L. The highest salinities were reported from the surficial groundwater, i.e. the colluvium/weathered Permian (13,000mg/L TDS in C078B, and 7440mg/L TDS in C081B) and the overburden (8890mg/L TDS in C062B). High salinities have also been reported at Bloomfield from the Rathluba Seam, which lies stratigraphically beneath the Donaldson Seam, with TDS values up to about 9,000mg/L. The lowest reported salinity of 518mg/L was from the Donaldson Seam at bore C062A.

Across the model area, elevated salinity is found within much of the Permian coal measures, ranging from less than 600µS/cm EC in the more permeable coal seams to more than 16,000µS/cm EC within some of the less permeable overburden/interburden units.

Salinity in the creeks was found to be highly variable, as salinity is often found to be elevated in the colluvium. During periods of high runoff, salinity can be very low, often less than 300mg/L TDS. However, during dry periods, shallow groundwater seepages (often from ephemeral, perched regolith aquifers) can increase creek salinities, with values of between 1,000 and 15,000mg/L TDS being recorded in Four Mile Creek. Therefore, salinity is not considered to be a good indicator of the degree of connectivity between surface water systems and deeper regional groundwaters in this area due to the high variability in surface water flow rates and quality, as well as the presence of high salinity in the shallow alluvium and colluvium.

4.8.2 pH

The pH of the groundwater in the Model Area for the Modification is found to be generally close to neutral, or slightly acidic, with pH values ranging from 6.2 to 7.4 (PDA, 2002; PDA, 2006; and Aquaterra , 2008).

4.8.3 Dissolved Metals

Sampling of dissolved metals within the Model Area for the Modification produced the following observations (Aquaterra, 2008):

- Generally low concentrations relative to ANZECC (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, with the exception of copper and zinc. The concentrations of copper exceeded the ANZECC guideline value of 0.0014mg/L in all samples. The zinc guideline value of 0.008mg/L was exceeded in all but 2 samples;
- Exceedance of the cadmium guideline value of 0.0002mg/L was reported from the two samples from SP4-2 at Bloomfield. Both samples from SP3-1 reported elevated manganese concentrations above the ANZECC guideline (ANZECC, 2000). The nickel guideline value was also exceeded in several samples. Finally, one exceedance for aluminium was reported (the December sample from SP3-1); and
- Dissolved iron concentrations were also found to be relatively high in some samples (ranging up to 85mg/L); although no ANZECC guideline value is set.

4.8.4 Nutrients

Limited sampling for nutrients has only been undertaken at the Bloomfield Colliery in 2007. The sampling revealed concentrations of all parameters tested (ammonia, nitrite, nitrate and total Kjeldahl Nitrogen; and total phosphorous and reactive phosphorous) to be generally within the ANZECC guidelines, with a very slight exceedance for ammonia only in one sample from SP2-1 (ANZECC, 2000).

4.8.5 Major Ion Chemistry

The chemistry of groundwater samples can be evaluated with the aid of a Piper Trilinear Diagram. The major ion concentrations are plotted on the Piper Diagram as percentage milli-equivalents, with one triangular field for the major cations (calcium, sodium and magnesium) and another for the major anions (chloride, sulphate and bicarbonate). The plotted positions for each sample are then projected into the central diamond field and the intersection located, thus defining a unique plotted point for each sample, allowing a generalised classing of groundwaters and evaluation of groundwater evolution and mixing processes.

Figure 4.19 presents a composite Piper plot of the groundwater samples from within the Model Area for the Modification. The plot shows the groundwater sample from bore C062A (which is located at a coal seam sub-crop) plotting near the centre of the Piper diamond, whereas the remaining groundwater samples are grouped close to the right hand side of the diagram. The Piper Plot shows that the groundwater is of a sodium chloride type, indicating little evidence of proximity to recharge. However, as with salinity, there is no clear distinction between hard rock and colluvial groundwater types, so few significant conclusions can be drawn about conceptual hydrogeology from these results.

4.9 Existing Groundwater Use

Groundwater generally occurs throughout the area, but there are no significant exploitable aquifers underlying or close to the Abel Underground Mine area. Due to the variable salinity and low bore yields, the use of groundwater, other than environmental use and mine dewatering/inflow, in the vicinity of the Abel Underground Mine is negligible (PDA, 2006).

The NSW Office of Water retains a database of registered bores and wells in NSW. This database includes exploration/test wells that may not have been completed as permanent structures, observation/monitoring bores, and privately owned bores and wells currently in use or abandoned. A search of this database identified 34 registered bores within 5km of the Abel Underground Mine (shown in Figure 4.20). A summary of the registered bore details for these bores is provided in Table 4.3, with additional details provided in Appendix C.

Table 4.3: Registered Bore Locations within 5km of the Abel Underground Mine

Bore No.	Easting	Northing	Depth (m)	Intended Use	Salinity (ppm)
GW051353	365,986	6,365,810	49.7	Domestic/stock	3001-7000
GW053411	361,215	6,366,699	20	Irrigation	0-500
GW053412	361,240	6,366,730	7.9	Irrigation	0-500
GW058760	371,142	6,371,207	33	Farming	0-500
GW061307	371,299	6,371,148	30	Domestic/stock	501-1000
GW078044	370,428	6,370,151	30.1	Monitoring	Not recorded
GW078045	371,836	6,369,892	30.5	Monitoring	Not recorded
GW078046	368,651	6,368,741	30.4	Monitoring	Not recorded
GW078047	370,784	6,368,800	54.3	Monitoring	Not recorded
GW078120	371,176	6,368,590	24	Monitoring	Not recorded
GW078121	368,619	6,367,262	43	Monitoring	Not recorded
GW078122	368,666	6,367,663	35.4	Monitoring	Not recorded
GW078123	369,309	6,368,165	33	Monitoring	Not recorded
GW078124	369,883	6,368,018	40	Monitoring	Not recorded
GW078125	370,970	6,368,464	30	Monitoring	Not recorded
GW078126	371,890	6,367,736	30	Monitoring	Not recorded
GW078127	369,073	6,366,406	30	Monitoring	Not recorded
GW078128	370,912	6,366,923	30	Monitoring	Not recorded

Bore No.	Easting	Northing	Depth (m)	Intended Use	Salinity (ppm)
GW078161	372,698	6,359,492	84	Monitoring	Not recorded
GW078201	373,395	6,360,150	31	Monitoring	Not recorded
GW078578	363,861	6,358,055	99	Farming	Not recorded
GW078814	363,496	6,360,108	256.5	Test bore	Not recorded
GW078815	364,714	6,359,586	131.1	Test bore	Not recorded
GW078816	363,491	6,360,077	310.5	Test bore	Not recorded
GW079061	372,859	6,359,576	0	Monitoring	Not recorded
GW079063	373,130	6,359,725	47	Monitoring	Not recorded
GW079065	372,696	6,360,132	0	Monitoring	Not recorded
GW079892	366,598	6,372,257	0	Monitoring	Not recorded
GW079948	370,081	6,372,613	0	Monitoring	Not recorded
GW080034	365,222	6,370,959	0	Monitoring	Not recorded
GW200626	371,366	6,362,331	4.2	Test bore	Not recorded
GW200627	371,461	6,362,472	4.2	Test bore	Not recorded
GW200628	371,384	6,362,453	4.2	Test bore	Not recorded
GW200629	371,585	6,362,633	4.2	Test bore	Not recorded

The majority of the bores located within 5km of the Modification are monitoring or test bores, predominantly associated with monitoring the current and future impacts of mining activities within the area. Stock/domestic bore GW051353 is associated with the Abel Underground Mine; while farming bore GW078578 is associated with the Tasman Underground Mine.

Of the bores not associated with Donaldson mining operations, two bores (GW058760 and GW0061307) are located to the north of Donaldson Open Cut Mine and to the north of the Newcastle Coal Measures sub-crop. This location is stratigraphically higher than the Modification and outside the sub-crop of the Donaldson Seam. Irrigation bores GW053411 and GW053412 are located within the down gradient section of Surveyors Creek near the confluence with Wallis Creek north of George Booth Drive.

4.10 Groundwater Dependent Ecosystems

There are a number of localities which could support GDEs within or adjacent to the Abel Underground Mine area (refer to Figure 4.3). These include:

- Rainforest Protection Zones – located along drainage lines;
- Swamps – located within alluvium associated with Long Gully and Blue Gum Creek; and
- Pambalong Nature Reserve/Hexham Swamp (downstream of the Abel Underground Mine area).

Approximately 37 hectares of sub-tropical rainforest is located in the Long Gully sub-catchment and in an unnamed gully at the south-eastern extent of the Abel Underground Mine area (refer Figure 4.3). The Abel Underground Mine Environmental Assessment (Donaldson Coal, 2006) suggested that these rainforest areas are GDEs. During a long dry period in late 2005 through to 2006 base flow was still evident in these gullies. This suggests that the subsurface structure allows the retention of rainfall in a perched water table separate from the deep groundwater. This is also supported by local accounts of clean water flow down Long Gully, appearing and continuing for some time, following the 1989 earthquake (Donaldson Coal, 2006).

Pambalong Nature Reserve is located immediately downstream of the Modification and is largely dependent on freshwater flows from Blue Gum Creek and Long Gully. Pambalong Nature Reserve is a freshwater wetland consisting of a series of small swamps. It is at the western edge of a chain of wetland reserves, including Hexham Nature Reserve and Kooragang Nature Reserve, which form the Hunter Estuary wetlands.

Pambalong Nature Reserve and Hexham Swamp are listed under State Environmental Planning Policy (SEPP) 14 Coastal Wetlands, with SEPP 14 Coastal Wetlands 840, 841 and 841a (located within these systems) designated as High Priority Groundwater Dependent Ecosystems under Schedule 4 of the *Hunter Unregulated and Alluvial Water Sources WSP*. Similarly, Woodberry Swamp is also listed under this SEPP, with SEPP 14 Coastal Wetlands 828b designated as a High Priority Groundwater Dependent Ecosystem. Viney Creek and Weakleys Flat Creek, both of which are located within the Modification footprint, meet approximately 1km north-west of the Abel Underground Mine area before discharging into a swamp which is connected to Woodberry Swamp.

According to PDA (2006), groundwater in the alluvium associated with Blue Gum Creek, Pambalong Nature Reserve and Hexham Swamp is believed to be in direct hydraulic connection with the surface water in these wetlands, based on close correlation between the surface water and groundwater levels. There is believed to be relatively free interchange of water between the alluvium and the surface water bodies, with the groundwater discharging to the surface water at most times, and possibly in the reverse direction for short periods following periods of heavy rainfall.

On the other hand, there is believed to be minimal interaction between the surface drainage system (including the alluvial and other surficial groundwater), and the deeper groundwater within the coal measures. Likewise, there is believed to be limited interaction between groundwater in the alluvium and deeper groundwater in the coal measures.

5. CONCEPTUAL MODEL

The conceptual model is a simplified representation of the real groundwater system, identifying the most important geological units and hydrogeological processes, while acknowledging that the real system is inherently more complex. The conceptual model forms the basis for the numerical groundwater flow model. The conceptual model for the Modification groundwater system is provided in Figure 5.1.

The conceptual understanding supports the presence of two generalised groundwater systems within the Abel Underground Mine area, consistent with the *Hunter Unregulated and Alluvial Water Sources* WSP, these being:

- Porous Rock groundwater system - including the Tomago and Newcastle Coal Measures; and
- Alluvial groundwater system – located within low-lying areas, and associated with Wallis Creek to the west, and Pambalong Nature Reserve/Hexham Swamp to the east.

Recharge to the groundwater systems occurs via rainfall and runoff infiltration, lateral groundwater flow and minor leakage from surface water sources (e.g. Wallis Creek). Although groundwater levels are sustained by rainfall infiltration, they are controlled by topography, geology and surface water levels in local drainage systems. Local groundwater systems tend to mound beneath hills, with ultimate discharge to local drainage lines and loss by evapotranspiration through geological outcrops and vegetation where the water table is near the ground surface (generally within 2 to 3m of ground level).

Evapotranspiration will vary across the Abel Underground Mine area due to variability in ground coverage, topography and depth to water. Water levels are close to surface in lower-lying areas to the south-east of the Abel Underground Mine area, associated with the alluvium around Blue Gum Creek; as well as areas close to Viney Creek to the north-east.

During mining, the water levels in parts of the porous rock groundwater system will be reduced in the vicinity of each mine in the area.

5.1 Hydrogeological Units

The local geology has been represented by a 20 layer model. These layers are largely defined by the main coal seams noted in Section 4.4 and the associated interburden intervals. The top layer (Layer 1) represents alluvium where present, and elsewhere the weathered regolith. Model layering is described in greater detail in Section 7.5.

It should be noted that some ‘perched’ groundwater does also occur within the upper weathered mantle of the Permian coal measures and in elevated terrain occupied by Triassic sandstones of the Narrabeen Group. These perched groundwater systems have not been incorporated into the numerical groundwater model, as they are local in nature and of limited utility for other users and the environment.

5.2 Hydraulic Properties

The permeability of the coal measures is generally low, with rock mass hydraulic conductivities more than two orders of magnitude lower than the unconsolidated alluvium. It has also been observed that hydraulic conductivity decreases significantly with increasing depth of cover.

Within the coal measures themselves, the most permeable horizons are the coal seams, which commonly exhibit hydraulic conductivities one to two orders of magnitude higher than the siltstones, claystones, shale and sandstone units of the interburden strata. Within the Abel Underground Mine area, testing of the laminated mudstones/claystones has typically shown hydraulic conductivities to be lower than 1 x 10^{-6}m/d.

The coal seams are generally more brittle, and therefore more densely fractured, than the overburden and interburden strata, which cause them to be more permeable. Within the coal seams the groundwater flows predominantly through cleat fractures, with very little evidence of structure-related fracturing. Due to the laminar nature of the coal measures, groundwater flow generally occurs within, or along the boundaries between, stratigraphic layers. This means that effective rock mass vertical permeability is significantly lower than horizontal permeability (typically two or more orders of magnitude).

The results of previous core permeability testing did not show a noticeable decrease in permeability with depth for the coal seams; however this is probably the result of testing in near surface areas where mining operations occur. Despite this, decreasing permeability is expected with greater depth of cover and increased geostatic pressures, and/or remoteness from outcrop and near-surface effects of weathering.

Based on the results of the field testing, and the analysis in Section 3.3, an estimate of the likely characteristics for the coal measures strata within the Model Area for the Modification was postulated, summarised in Table 5.1.

Table 5.1: Probable Ranges of Hydraulic Conductivity within the Model Area for the Modification

Hydrogeologic Unit	**Estimated Hydraulic Conductivity – Shallow (<150m) strata**		**Estimated Rock Mass Hydraulic Conductivity – Deeper Strata**	
	Kh (m/d)	**Kv (m/d)**	**Kh (m/d)**	**Kv (m/d)**
Weathered Permian/Regolith	0.1 – 0.5	0.01 – 0.05	N/a	N/a
Coal Measures Interburden	0.001 - 0.01	0.0001 - 0.005	0.0001 - 0.005	0.00001 - 0.0005
Fassifern Seam	0.01 – 0.2	0.001 – 0.02	N/a	N/a
West Borehole Seam	0.005 – 0.2	0.0005 – 0.02	0.0005 - 0.02	0.00005 – 0.002
Upper Donaldson Seam	0.005 – 0.2	0.0005 – 0.02	0.0005 - 0.02	0.00005 – 0.002
Lower Donaldson Seam	0.005 – 0.2	0.0005 – 0.02	0.0005 - 0.02	0.00005 – 0.002
Ashtonfield Seam	0.005 – 0.1	0.0005 – 0.01	0.0005 – 0.02	0.00005 – 0.002

Intermediate seams such as the Sandgate have not been tested, but given the nature of the coal, are likely to have similar hydraulic properties to the Donaldson Seams.

Direct testing data are not generally available for specific storage (Ss - also referred to as elastic storage) of coal seams or interburden. However, good estimates can be made based on Young's Modulus (tensile modulus) and porosity. For coal, Ss generally lies in the range 5×10^{-6} to $5\times10^{-5}m^{-1}$, and interburden is generally slightly higher than this, due to the greater porosity (Mackie, 2009).

Faults and dykes in the area are not thought to be transmissive and are likely to represent a minor barrier to groundwater flow in most cases. The 'basic' igneous nature of the dykes means that they will tend to weather to impermeable clays, whereas the faults cause displacement of the bedding and therefore interruption of the primary groundwater flow paths. Larger, continuous dykes and faults are only present within the southern and eastern parts of the model area for the Modification, which are located away from the environmental receptors and proposed mine development areas.

The Krecji Fault, previously mentioned in Section 4.5, is a mapped fault structure within shallow stratigraphy which has disturbed the Donaldson Coal Seams and overlying strata to the east of the Abel Underground Mine. Coal extraction near this zone has indicated that the structure does transmit groundwater at shallow depths, which has resulted in higher than expected groundwater inflows into the Abel Underground Mine during late 2011 and early 2012.

The behaviour of faults at greater depth is expected to be more as barriers than as preferential flow paths. Although the elevated inflows being experienced at Abel are anticipated to be short term due to the limited storage available within the fault zone structures, the higher than anticipated inflows to the Abel Underground Mine have been used as a calibration measure. No hydraulic testing of the fault zone area has been undertaken, however observed inflows suggest that the fault zone is more permeable than the host rocks.

However, as well as possibly being a local source of higher groundwater inflows, the lack of drawdown response east of the Krecji Fault from early mining at the Abel Underground Mine suggests that the fault is also acting as a regional barrier to groundwater flow, possibly preventing groundwater impacts from extending east of the fault to areas beneath the Hexham Swamp/Hunter River wetland areas. As a conservative measure, the fault was not represented in the model as a barrier boundary structure, but hydraulic continuity was assumed across the fault to the east. This is likely to have over-predicted regional impacts from mining.

5.3 Subsidence Fracturing

There are a number of physical hydrogeological effects that are expected to occur during the Modification due to mining and subsidence related fracturing. These effects, including the changes to the hydraulic nature of overburden material caused by the caving and subsidence above panels, need to be represented using specific modelling approaches.

The impact of mining on the permeability of caved overburden has been based on in-field monitoring and groundwater modelling experience, combined with research available for subsidence impacts on hydraulic properties. The *Review of Industry Subsidence Data in Relation to the Influence of Overburden Lithology on Subsidence and an Initial Assessment of a Sub-Surface Fracturing Model for Groundwater Analysis* (ACARP, 2003) contains assessments of the impact of various mining methods on overlying rock mass permeability, based on the depth of overburden above the mined seam and the degree of subsidence associated with the relevant mining method.

5.3.1 Mine Geometry

The Modification involves the modification of the current approved method of extraction (bord and pillar) to include shortwalls, longwalls, thin seam first workings and pillar extraction methods (refer to Figures 1.2 and 1.3).

A summary of the proposed dimensions of the mining geometry for the Modification is provided in Table 5.2 (from MSEC, 2012).

Table 5.2: Geometry of the Proposed Mining Techniques for the Abel Upgrade Modification (from MSEC 2012)

Panels	Overall Void Length including First Workings (m)	Overall Void Width Including First Workings (m)	Overall Solid Pillar Width (m)
Approved Bord and Pillar	300 ~ 2000	160	19.5
Upper Donaldson – Shortwalls	1130 ~ 1250	120	20
Upper Donaldson – Thin Seam Bord and Pillar	1050 ~ 1950	155	95 ~ 110
Lower Donaldson - Shortwalls	1170 ~ 1360	120	25
Lower Donaldson - Longwalls	1420 ~ 2470	180 - 230	30 ~ 35

5.3.2 Estimated Height of Subsidence Fracturing

The estimated heights of fracturing in the overburden for the bord and pillar panels were originally determined by Strata Engineering (2006) as part of the approved Abel Underground Mine EA, while the shortwalls, longwalls and pillar production panels in the proposed modification have been determined by MSEC (2012). Both consultants reported using the method described in the ACARP Research Project C10023 (ACARP, 2003).

As described in the Part 3A Environmental Assessment, "*Continuous sub-surface cracking refers to the extent of fracturing above a total extraction panel that would provide a direct flow-path or hydraulic connection to the workings, if a sub-surface aquifer or coal seam were intersected*" (Strata Engineering, 2006). The height of continuous cracking is referred to as the "A Horizon", and is the distance of concern in relation to assessing potential groundwater impacts.

Furthermore, as described in the Part 3A Environmental Assessment, "*Discontinuous fracturing refers to the extent above a total extraction panel that…does not provide a direct flow path or* *connection to the workings and is more likely to interact with surface cracks or joints."* (Strata Engineering, 2006). The height of discontinuous cracking is referred to as the "B Horizon".

The estimated height of sub-surface fracturing is based on the depth of cover and either the maximum conventional tensile strain or the maximum subsidence. A summary of the estimated heights of continuous fracturing for the approved bord and pillar panels (from Strata Engineering, 2006) and the proposed shortwalls, long walls and thin seam pillar extraction panels (from MSEC, 2012) is provided in Table 5.3.

Table 5.3: Estimated Heights of Sub-Surface Cracking Based on ACARP 2003 (from Strata Engineering 2006 and MSEC 2012)

Location	Depth of Cover (m)	Maximum Predicted Conventional Tensile Strain (mm/m)	Maximum Predicted Subsidence (mm)	Estimated Height of the A Horizon (m)	Estimated Height of the B Horizon (m)
Shortwalls in the Upper Donaldson Seam	50	25	1700	41	50
	200	5	1200	112	192
Shortwalls in the Lower Donaldson Seam	150	10	1700	96	150
	300	1	800	141	267
Pillar Production Panels and Longwalls	170	10	3100	133	170
	350	3	2000	238	350
Bord and Pillar in the Lower Donaldson Seam (vicinity of Viney Creek)	130	8	1000	49	107
Bord and Pillar in the Lower Donaldson Seam (vicinity of Blue Gum Creek/Long Gully)	280	3	600	48	188
Bord and Pillar in the Lower Donaldson Seam (vicinity of Blue Gum Creek)	300	2	500	32	187
Bord and Pillar in the Upper Donaldson Seam (vicinity of 'Panels A and B')	60	25	1000	41	60
Bord and Pillar in the Upper Donaldson Seam (vicinity of Viney Creek)	110	8	1300	47	94
Bord and Pillar in the Upper Donaldson Seam (vicinity of Buttai Creek)	150	6	900	53	121
	200	4	750	66	158

5.3.3 Subsidence Control Zones

The Project Approval (05_0316) for the Abel Underground Mine includes subsidence management commitments for surface features. There would be no change to these commitments due to changes in mining methodology at the Abel Underground Mine associated with the Modification.

As such, the Modification will continue to employ Subsidence Control Zones (SCZs) to control height of fracturing in sensitive areas to manage subsidence effects in the vicinity of sensitive surface features, such as rainforest, Schedule 2 stream (third order and above streams) and Blue Gum Creek alluvium protection zones (refer to Figure 5.2). The SCZs may involve either limiting extraction to first workings (i.e. no pillar extraction) or exclusion of mine workings in some areas.

Where the approved bord and pillar extraction underlies Schedule 2 streams, alluvium or rainforest communities (refer to Figure 5.2); the extraction will be limited to first workings only.

SCZs have been established around Schedule 2 Streams such as Blue Gum Creek and Long Gully based on "*the provision of a minimum barrier of 40m between the 20 millimetre line of subsidence and the bank of any Schedule 2 Stream*" (Abel Underground Mine, Statement of Commitments).

As such, the proposed shortwalls, longwalls and thin seam pillar extraction panels have been set back from the Schedule 2 streams so that no more than 20mm of subsidence is predicted within the 40m buffer zones from the banks of these streams (MSEC, 2012).

According to MSEC (2012), the swamps along Blue Gum Creek are located within the limit of alluvium of this stream, as shown in Figure 5.2. The proposed shortwalls and longwalls have been set back from the stream so that no more than 20 mm of subsidence is predicted within the limit of alluvium and therefore the swamps. There is no mining proposed in the vicinity of the Pambalong Nature Reserve.

The proposed shortwalls and longwalls have been set back from the rainforest communities so that again no more than 20mm of subsidence is predicted within the mapped extents of these areas (Figure 5.2). For example, the width of one of the shortwall panels in the Lower Donaldson Seam has been narrowed to 180m at the northern end, so as to limit the maximum predicted subsidence to 20mm within the adjacent rainforest protection zone (MSEC, 2012).

5.3.4 Fracture Zone Implementation in the Model

Fracture zones were implemented in the model to account for the following mining areas associated with the Modification:

- Mining areas with no constraints on development and associated subsidence (i.e. longwall and shortwall areas, and bord and pillar areas with full extraction);
- Bord and pillar mining areas with first workings only; and
- Areas with no mine workings.

Within areas with no restriction on subsidence, implementation of the fracture zones was constrained by the maximum heights of continuous cracking provided by Strata Engineering (2006) and MSEC (2012), outlined in Table 5.3. No fracturing was applied above areas designated as first workings only, or areas with no mine workings.

The layer definition within the model has allowed mined coal seams to be represented individually. In areas with no restriction on subsidence, this allows the overburden to be subdivided into multiple layers and therefore allows subsidence caving and fracturing effects to be simulated to various heights above each seam that is mined, so that the impact of progressive caving and fracturing associated with the mining is adequately represented.

Within the model four ‘zones’ of subsidence permeability change have been developed below, within and above the mined coal seam:

- The permeability of the model layer directly beneath underground mined areas has been altered – with a uniform increase in vertical hydraulic conductivity to three times the *in situ* parameters being applied;
- A high permeability, caved zone where the overburden has collapsed following subsidence – vertical permeability has been assumed to have increased to 10m/d based on conservative estimates used in previous coal mining-related modelling studies;
- A zone of continuous cracking immediately above the mined coal seam. Within this zone enhanced permeability occurs due to discrete vertical fractures that connect with horizontal layer separation features, allowing water to travel between and along layer boundaries. The fractured zone has been simulated with horizontal hydraulic conductivity enhanced by a factor of two, and with vertical hydraulic conductivity enhanced according to a log-linear monotonic (ramp) function. The application of this function (Merrick pers comm.) is described in more detail in Section 7 under Prediction Simulation Hydraulic Properties. The function varied the vertical hydraulic conductivity field within the deformation zone overlying coal extraction areas and “weighted” the permeability changes based on layer thickness. Limits for the variability were governed by predicted fracture height and predetermined upper and lower bounds of hydraulic conductivity. The tortuous flow paths that are created along horizontal and vertical fractures result in a zone where the overall permeability is lower than the caved zone below; and

- A zone of discontinuous cracking. The fractured zone has been simulated with horizontal hydraulic conductivity enhanced by a factor of two, with no change to vertical hydraulic conductivity. As previously stated, in some areas of the mine, this discontinuous cracking may extend up to the surface and has therefore been implemented all the way up to layer 1 in these areas.

A fifth 'zone' of subsidence permeability change can also occur – surface cracking. According to MSEC (2012), shortwall, longwall and bord and pillar mining can result in surface cracking, heaving, buckling, humping and stepping at the surface. The extent and severity of these mining induced ground deformations are dependent on a number of factors, including the mine geometry, depth of cover, overburden geology, locations of natural jointing in the bedrock and the presence of near surface geological structures. This zone was not incorporated into the groundwater model as subsidence control zones have been implemented in the mine plan to limit surface subsidence and cracking in sensitive areas, however further discussions in regards to its occurrence and potential impacts are provided in MSEC (2012).

5.4 Existing Mine Workings

Figure 5.3 presents the existing and abandoned mining areas that occur within the Model Area for the Modification. Extensive abandoned mine workings are known to occur within the West Borehole Seam in the south-western part of the Abel Underground Mine area (former Stockrington No. 2 Colliery).

According to PDA (2006), it is likely that enhanced hydraulic conductivity exists within the previously mined areas of the West Borehole seam, and disturbed overburden strata. However, the extent and nature of subsidence and cracking associated with mining of the West Borehole seam is not known, nor is the extent to which the workings have become re-saturated following cessation of mining. However, it is likely that there is a body of groundwater within the residual mine voids and fractured overburden, and that this zone would have a substantially higher hydraulic conductivity and specific yield than the undisturbed coal measures sediments.

Additionally, active mining is occurring within the West Borehole Seam at the West Wallsend Colliery in the southern part of the Model Area. The degree of connectivity between the active West Wallsend Colliery and the older mine workings is also currently unknown. However, the available evidence indicates that there is extensive depressurisation of the West Borehole Seam due to past mining. Evidence from a single bore at the existing Tasman Underground Mine which intersects the West Borehole Seam indicates that the water level within the Stockrington workings close to the Abel Underground Mine area is around -67.5mAHD.

A water level of -67.5mAHD indicates that hydrogeologically, the dewatered voids associated with the abandoned Stockrington mine provide a significant groundwater sink in a regional context. While this level can only be considered as pseudo-steady state, the workings have been abandoned for some time and this level is significantly lower than the western (Wallis Creek) and eastern (Hunter River) boundary conditions which have been evoked in the model. The Old Stockrington No. 2 Colliery consists of first workings bord and pillar extraction panels. Mining was completed in the early 1980s.

Existing mine workings in the Donaldson Seams (at the Abel Underground Mine and Donaldson Open Cut Mine), the Fassifern Seam (at the Tasman Underground Mine) and shallower seams (at the Donaldson Open Cut Mine and Bloomfield Colliery) have all been included in the model using the most recent reported proposed mine schedules. The limited former mining of the Great Northern Seam above the existing Tasman Underground Mine has not been included in the model.

5.5 Receptors and Potential Impact Assessment Targets

In order to ensure that this model can be used for robust groundwater impact assessments, all potentially significant surface water receptors were considered as part of this study, along with the potential mechanisms for surface/groundwater interaction. All permanent water bodies and ephemeral streams of third order or greater magnitude are shown on Figure 4.3 (within the Abel Underground Mine area) and Figure 4.20 (within the Model Area).

5.5.1 Permanent Water Bodies

In terms of licensing and potential environmental impacts, permanent water bodies generally form the most sensitive environmental receptors to any changes in the groundwater regime. A summary of the nature and hydrogeological significance of each of the permanent water bodies in the study area is provided in Table 5.4.

Table 5.4: Summary of Permanent Water Bodies in the Study Area

Name of Water Body	Description and Nature of Surface/Groundwater Interaction
Hexham Swamp & Pambalong Nature Reserve	Both of these water bodies are primarily surface water fed, although they both sit within alluvial layers. Hexham Swamp exists due to the low lying nature of the terrain and the presence of the barrage near the Hunter River, which causes water to back up and fill ditches, etc. within the swamp. Prior to installation of the barrage, the swamp was subject to tidal effects. It is the Hunter's largest and biologically diverse wetland and one of the largest in NSW. However, after thirty years of limited tidal exchange from the operation of floodgates at the mouth of Ironbark Creek, the estuarine, aquatic and terrestrial ecosystems of the wetland have become severely degraded (HCRCMA, 2010). Pambalong Nature Reserve exists within a naturally low lying area to the west of Hexham Swamp, and water levels appear to have been increased by the presence of a high invert level in the drainage culvert beneath the F3. This causes water flowing down from Blue Gum Creek to back up and support the large pools within the nature reserve area. The close correlation between groundwater levels in the alluvium around the wetlands of Pambalong Nature Reserve and the swamp water levels indicate that the alluvium and the swamp are in good hydraulic connection. There is believed to be relatively free interchange of water between the alluvium and the surface water bodies, with some discharge from the alluvium to the surface during drier periods, and flows from the swamps to the alluvium during wetter periods (PDA, 2006).
Wallis Creek	This creek is associated with reasonably significant alluvial deposits, and these shallow alluvial aquifers are likely to be in hydraulic continuity with the creek.
Lake Macquarie	This is a saline environment that is directly connected to the Tasman Sea. Levels in the lake are not significantly affected by groundwater.
Cockle Creek	This is directly connected to Lake Macquarie, and as such will be tidally dominated in its lower reaches. Significant alluvium is present in the middle reaches, and it is likely there is some baseflow connection between the creek and its alluvium.
Hunter River	The Hunter River is tidal and saline dominated within the Model Area. Although groundwater and alluvium may influence water quality to a certain extent, levels outside of flood periods are essentially dominated by the sea and tidal ranges.

6. MINING PROPOSAL

6.1 Mining Schedule

The proposed mining schedule for the development and extraction of the panels within the Upper Donaldson and Lower Donaldson Seams for the Modification are shown in Figures 6.1 and 6.2, respectively.

The proposed mining schedule extends to 30 June 2028. A summary of the schedule for the proposed Abel Modification, and the schedules that have been assumed for the existing Abel Underground Mine, existing Tasman Underground Mine, proposed Tasman Extension Project, Donaldson Open Cut Mine, Bloomfield Colliery and the West Wallsend Colliery, are provided in Tables 6.1 and 6.2.

6.2 Model Implementation

In order to investigate the incremental effects of mining as proposed in the Modification, operational mining impacts and residual impacts following post mining recovery have also been assessed with the aid of a numerical groundwater model.

The mining schedules for the Modification and the other existing operations have been implemented within the model. Bloomfield Colliery has been operating for some time, commencing well before the calibration period undertaken during the modelling study. The Bloomfield mine was incorporated into the steady state condition, with an updated mine schedule evoked during transient calibration and predictive modelling.

The underground mining and dewatering activity is defined in the model using drain cells within the layers representing the mined coal seams, with modelled drain elevations set to 0.1m the base of the Upper and Lower Donaldson Seams (Layers 13 and 15, respectively). These drain cells are applied wherever workings occur, and were progressed through annual increments in a transient model set-up.

The model set-up involved changing the parameters with time in the goaf and overlying fractured zones directly after mining of each panel, whilst simultaneously activating drain cells along all development headings. Drain cells in the development headings were activated in advance of the panel extraction and subsequent subsidence. Conductance in the drain cells was set at 1,000m^2/d.

Open cut mining was progressed in the model by implementing new drain cells in active mine areas and de-activating drains in areas as they are backfilled with overburden.

Table 6.1: Underground Mine Schedules Used for the Impact Assessment – Abel and Donaldson Operations

Period	Stress Period	Length (days)	From	To	Abel Upper Donaldson		Abel Lower Donaldson		Current Abel Underground Mine		Donaldson Open Cut	
					Mining	Drain (model reach number)	Mining	Drain (model reach number)	Panels/ Development Heading	Drain	Mining	Drain (model reach number)
CALIBRATION	SS	-	-	31/12/2005	-	-	-	-	-	-	-	-
	1	180	1/01/2006	30/06/2006	-	-	-	-	-	-	2006	1100
	2	183	1/07/2006	31/12/2006	-	-	-	-	-	-	2006	1100
	3	180	1/01/2007	30/06/2007	-	-	-	-	-	-	2007	1101
	4	183	1/07/2007	31/12/2007	-	-	-	-	-	-	2007	1101
	5	181	1/01/2008	30/06/2008	-	-	-	-	N – S Mains Development	133	2008	1102
	6	183	1/07/2008	31/12/2008	-	-	-	-	N – S Mains Development	157	2008	1102
	7	180	1/01/2009	30/06/2009	-	-	-	-	N – S Mains Development	134	2009	1103
	8	183	1/07/2009	31/12/2009	-	-	-	-	E – W Mains Development	158	2009	1103
	9	180	1/01/2010	30/06/2010	-	-	-	-	Panel 1	135	2010	1104
	10	183	1/07/2010	31/12/2010	-	-	-	-	Panel 2 & 3	159	2010	1104

Period	Stress Period	Length (days)	From	To	Abel Upper Donaldson		Abel Lower Donaldson		Current Abel Underground Mine		Donaldson Open Cut	
					Mining	Drain (model reach number)	Mining	Drain (model reach number)	Panels/ Development Heading	Drain	Mining	Drain (model reach number)
PREDICTIVE MODELLING	11	365	1/01/2011	31/12/2011	2011-2012	201			-	-	2011	1105
	12	366	1/01/2012	31/12/2012	2012-2013	202	2012-2013	302	-	-	2012	1106
	13	365	1/01/2013	31/12/2013	2013-2014	203	2012-2013	302	-	-	2013	1107
	14	365	1/01/2014	31/12/2014	2014-2015	204	2014-2015	304	-	-	-	-
	15	365	1/01/2015	31/12/2015	2015-2016	205	2015-2016	305	-	-	-	-
	16	366	1/01/2016	31/12/2016	2016-2017	206	2016-2017	306	-	-	-	-
	17	365	1/01/2017	31/12/2017	2017-2018	207	2017-2018	307	-	-	-	-
	18	365	1/01/2018	31/12/2018	2018-2019	208	2018-2019	308	-	-	-	-
	19	365	1/01/2019	31/12/2019	2019-2020	209	2019-2020	309	-	-	-	-
	20	366	1/01/2020	31/12/2020	2020-2021	210	2020-2021	310	-	-	-	-
	21	365	1/01/2021	31/12/2021	2021-2022	211	2021-2022	311	-	-	-	-
	22	365	1/01/2022	31/12/2022	2022-2023	212	2022-2023	312	-	-	-	-
	23	365	1/01/2023	31/12/2023	-	-	2023-2024	313	-	-	-	-
	24	366	1/01/2024	31/12/2024	-	-	2024-2025	314	-	-	-	-
	25	365	1/01/2025	31/12/2025	-	-	2025-2028	315	-	-	-	-
	26	365	1/01/2026	31/12/2026	-	-	-	-	-	-	-	-
	27	365	1/01/2027	31/12/2027	-	-	-	-	-	-	-	-
	28	366	1/01/2028	31/12/2028	-	-	-	-	-	-	-	-
	29	365	1/01/2029	31/12/2029	-	-	-	-	-	-	-	-
	30	365	1/01/2030	31/12/2030	-	-	-	-	-	-	-	-
	31	365	1/01/2031	31/12/2031	-	-	-	-	-	-	-	-

Table 6.2: Underground Mine Schedules Used for the Impact Assessment – Bloomfield, Tasman and West Wallsend Operations

Period	Stress Period	Length (days)	From	To	Bloomfield Open Cut		Tasman Extension West Borehole Underground		Tasman Underground		West Wallsend Underground	
					Mining	Drain (model reach number)	Panels / Development Heading	Drain (model reach number)	Panels / Development Heading	Drain (model reach number)	Longwall Panels (panel number)	Drain (model reach number)
CALIBRATION	SS	-	-	31/12/2005	-	-	-	-	-	-	<14	60
	1	180	1/01/2006	30/06/2006	-	-	-	-	-	-	14-34	62
	2	183	1/07/2006	31/12/2006	-	-	-	-	-	-	14-34	62
	3	180	1/01/2007	30/06/2007	2007	3000	-	-	Mains Development	50	34-36	63
	4	183	1/07/2007	31/12/2007	2007	3000	-	-	Mains Development	50	34-36	63
	5	181	1/01/2008	30/06/2008	2008	3000	-	-	Panel 1	50	35-37	65
	6	183	1/07/2008	31/12/2008	2008	3000	-	-	Panel 2 & 3	50	35-37	65
	7	180	1/01/2009	30/06/2009	2009	3000	-	-	Panel 4 & 5	50	37-38	67
	8	183	1/07/2009	31/12/2009	2009	3000	-	-	Panel 6 & 7	50	37-38	67
	9	180	1/01/2010	30/06/2010	2010	3000	-	-	Panel 8 & 9	50	38, 70	69
	10	183	1/07/2010	31/12/2010	2010	3001	-	-	Panel 10, 11 & 12	50	38, 70	69

Period	Stress Period	Length (days)	From	To	Bloomfield Open Cut		Tasman Extension West Borehole Underground		Tasman Underground		West Wallsend Underground	
					Mining	Drain (model reach number)	Panels / Development Heading	Drain (model reach number)	Panels / Development Heading	Drain (model reach number)	Longwall Panels (panel number)	Drain (model reach number)
PREDICTIVE MODELLING	11	365	1/01/2011	31/12/2011	2011	3002	-	-	Panel 13 & 14	50	39-40	71
	12	366	1/01/2012	31/12/2012	2012	3003	-	-	Panel 15 & 16	50	39-40	71
	13	365	1/01/2013	31/12/2013	2013	3004	N- S Mains Development	89	Panel 18	50	40, 72	73
	14	365	1/01/2014	31/12/2014	2014	3004	-	90	Retreat	50	41-42	74
	15	365	1/01/2015	31/12/2015	2016	3005	-	91	-	-	42-43	76
	16	366	1/01/2016	31/12/2016	2017	3006	-	92	-	-	43-45	78
	17	365	1/01/2017	31/12/2017	-	-	-	93	-	-	44-46	80
	18	365	1/01/2018	31/12/2018	-	-	-	94	-	-	46-47	82
	19	365	1/01/2019	31/12/2019	-	-	-	95	-	-	47-48	84
	20	366	1/01/2020	31/12/2020	-	-	-	96	-	-	48-50, 87	86
	21	365	1/01/2021	31/12/2021	-	-	-	97	-	-	49-50	88
	22	365	1/01/2022	31/12/2022	-	-	-	98	-	-	-	-
	23	365	1/01/2023	31/12/2023	-	-	-	99	-	-	-	-
	24	366	1/01/2024	31/12/2024	-	-	-	100	-	-	-	-
	25	365	1/01/2025	31/12/2025	-	-	-	101	-	-	-	-
	26	365	1/01/2026	31/12/2026	-	-	-	102	-	-	-	-
	27	365	1/01/2027	31/12/2027	-	-	-	103	-	-	-	-
	28	366	1/01/2028	31/12/2028	-	-	-	104	-	-	-	-
	29	365	1/01/2029	31/12/2029	-	-	-	-	-	-	-	-
	30	365	1/01/2030	31/12/2030	-	-	-	-	-	-	-	-
	31	365	1/01/2031	31/12/2031	-	-	-	-	-	-	-	-

7. GROUNDWATER SIMULATION MODELLING

7.1 Objective

The overall objective of the modelling was to develop and calibrate a numerical groundwater model to predict potential impacts of underground mining and mine development on the groundwater system and potential environmental receptors. To enable this, a regional model has been constructed that can examine synergistic impacts from open cut and underground operations across the area. The model was subjected to transient calibration against the observed impacts of recent mining in the model area. It was also designed to address the issues highlighted by an independent reviewer (Kalf and Associates, 2006) engaged by the NSW Department of Planning at the time of submission of the Abel Underground Mine EA. In summary these were:

- The vertical hydraulic conductivity of the alluvium (Layer 1) was excessively low;
- There were concerns over the use of arbitrary General Head Boundaries relatively close to the eastern-most extent of the mining area; and
- There was no transient calibration of the model.

As well as addressing these regulatory requirements, the model has been constructed with the capability to carry out mining simulation to enable the reliable prediction of groundwater inflow rates to the mine. These inflow rates inform the water balances involved in potential mine development scenarios across multiple seams and multiple areas.

7.2 Model Selection

The MODFLOW numerical groundwater flow modelling package has been used for this study with the SURFACT Version 3 module (HydroGeoLogic, Inc., 2006), operating under the Groundwater Vistas Version 5 graphic interface software package (Environmental Simulations, Inc., 2005).

The MODFLOW package has industry-leading modules for simulating surface water and groundwater interaction which enable assessment of impacts on creeks and rivers. The SURFACT module enables simulation of both saturated and unsaturated flow conditions and provides for more stable drying and re-wetting of cells in thin model layers (especially the active coal seams).

The DRGM was developed as a medium complexity model consistent with the best practice groundwater modelling guidelines applicable at the time (MDBC, 2001). In June 2012, new guidelines were promulgated by the National Water Commission (Barnett *et al*., 2012). The 2012 national guidelines build on the 2001 MDBC guide, with substantial consistency in the model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details. The 2012 guide notably proposes a new method of model complexity classification. For the DRGM, and subsequent version used for the assessment of the Modification, model confidence level under the Australian Groundwater Modelling Guidelines (Barnett et al, 2012) may be classified as Class 2 (effectively “medium confidence”), which is an appropriate level for this Modification context.

7.3 Model Development

7.3.1 Regional Groundwater Model

In 2010, Aquaterra developed the Donaldson Regional Groundwater Model (DRGM) following the conditional approval for the Abel Underground Mine which required further development of the regional and local groundwater model. The model was designed to incorporate deeper layers and a larger regional extent that would integrate the Bloomfield Colliery operations and areas of possible future mine development by Donaldson Coal.

Hence the DRGM was developed to provide Donaldson Coal with a ‘platform’ for all future numerical groundwater assessments across its existing mine and exploration leases. The DRGM was produced both as an operational/regulatory planning tool, and to satisfy the requirements of Schedule 4, Condition 12 of the planning approval for the Abel Underground Mine. It also satisfies the Statement of Commitments contained within that planning approval.

Overall it was considered that the DRGM was a suitable platform that could be used to carry out the numerical evaluation of groundwater impacts that might be associated with future mining development in the Donaldson area. It is soundly based on the conceptual hydrogeology for the region, has satisfactory calibration and consistency with previous models, and model run times that make it a practical tool for impact assessment and operational predictive analysis. As such, the DRGM provides the platform from which numerical groundwater modelling for the Modification has been based.

7.3.2 Tasman Extension Project Groundwater Model

The current groundwater model, which was first employed for the Tasman Extension Project, encompasses a much greater extent than has previously been considered for any of Donaldson Coal's individual projects, including the Donaldson Regional Groundwater Model (as shown in Figure 7.1).

The model's geological layering and hydrogeological processes are derived from the regional model, with some modification within the Tasman Underground Mine Area (including the proposed extension) due to updated geological and mine scheduling data incorporated during the recent undertaking of the Tasman Extension Project Groundwater Assessment (RPS Aquaterra, 2012).

7.3.3 Refinements to Tasman Extension Project Groundwater Model Specific to Modification

As part of this groundwater assessment, the groundwater model employed for the Tasman Extension Project was subsequently refined to be also used for the Modification. These refinements included:

- Refinement of the model cell size to 50 by 50m within the Modification area;
- Redesign of the river features within the Modification area (required due to the refinement of the model cell size);
- Incorporation of updated mine plans within the Bloomfield and Donaldson Open Cut mine sites; and
- Incorporation of the Abel Modification mine plan (including the implementation of subsidence-related fracture zones).

7.4 Model Domain, Boundaries and Grid

The current Modification model domain and boundaries were selected to satisfy the regulatory and operational constraints discussed in Section 1.2. An overview of the model domain and model boundaries is provided in Figure 7.1. The extents of previous models are also shown for comparison.

The model contains in excess of 1,900,000 active cells over 20 layers. The surface area of Layer 1 extends over 550km^2. A cross-section of the model is provided in Figure 7.2, while the recharge zonation enacted within the model is provided in Figure 7.3. The zones of recharge were defined using the regional geology map. The lateral extents of the different geology at surface within the model domain were used in conjunction with their published recharge values to assign recharge zones.

A cell size of 100 by 100m was used globally across most of the model domain. Grid spacing was further refined in the proposed Tasman Extension Abel Underground Mine area and Modification Abel Underground Mine area to a minimum cell size of 50 by 50m. While the potential impacts from the mining activities relate to regional scale effects, and experience has shown that discretisation of mine plans beyond the global scale discretisation has no significant impact on predicted mine inflows or impacts for mines, the grid refinement allowed for improved detailing of the mine plan scheduling.

The following boundaries were set for the model domain:

- A no-flow boundary was chosen for the northern side of the model as all active layers sub-crop on the northern side of the model domain;
- The southern model boundary is some distance from any potential mining and is generally parallel to the believed direction of regional groundwater flow, so it was also represented as a no flow boundary;
- The western boundary of the model is Wallis Creek. It is a permanent water course, and as such provides a suitable boundary on the western side of the model. It has been represented using river cells; and
- Careful consideration was given to the representation of the eastern boundary, which was set as a General Head Boundary (GHB) at Easting 379000 globally, while a Constant Head Boundary was set along the alignment of the Hunter River in Layer 1. Although the selected boundary is relatively close to the north-eastern extent of the Abel Underground Mine workings, and some concerns were raised by Kalf and Associates (2006) in relation to this during the review for the Abel Underground Mine development consent, it was considered that a GHB boundary was still the best option for the eastern boundary. Justification for the use of a GHB includes the following:
  - There is no information on strata geometry beyond this point. The geological map (Hawley and Brunton, 1995) shows that this area is entirely overlain by alluvium and there is therefore no information about sub-crops of the Permian strata. This, combined with the fact that there is a syncline marked to the immediate east of the model boundary, means that there is considerable uncertainty over the geometry of the strata layers in that area. Attempting to represent this through the use of an extended model domain, with associated recharge and no-flow boundaries would introduce greater levels of uncertainty into the model. If this boundary condition set up was implemented, then the volume of water entering the model would largely depend on assumptions about sub-cropping of strata layers beneath the alluvium. Extending the model would therefore not improve the certainty of predictions, and would make it more difficult to quantify model uncertainty in this area.
  - The model produced for the Abel Underground Mine EA (PDA, 2006) indicated that the Abel Underground Mine will only cause groundwater levels near this boundary to reduce to around 0mAHD. It was therefore anticipated that there would be very little inflow or outflow across the boundary as a result of mining stresses, and this has been confirmed by the impact assessment runs described in Section 7.8. As transient conditions do not result in large head gradients near the boundary, the GHB will provide a good representation of the outflow (initially) and inflow (following mining development) that will occur in the regional flow patterns – provided conductance values that are suitably representative of the rock mass transmissivity are calculated and used. The GHB boundary was therefore only really significant during steady state model calibration, as it effectively controlled the steady state groundwater levels at this boundary. However the likely sub-cropping of the Permian layers beneath the Hunter River mean that the nearest Permian recharge boundary is effectively set at just over 0mAHD, so the presence of the GHB and the head elevation used should be a good representation of long-term dynamic reality in this area.
  - The model domain incorporates all of the potentially sensitive receptors, including Pambalong Reserve and Hexham Swamp. All significant, non-tidal creeks and rivers that may be affected by mining activities were fully contained within the model domain. As shown in Figure 4.20, the majority of the registered bores within the region lie to the north and east, outside of the model boundary. A number of these on the eastern side are buffered by the Hunter River, and therefore outside the zone of influence from mining activities.

- The eastern GHB was set with a head level of 0mAHD, and the conductance value (C) was calculated based on the equation C=KA/L, where K = hydraulic conductivity, A = face area of the cell, and L = horizontal distance between cell centres. This equation ensured that the amount of water entering the cell at the boundary was the same as the amount of water that would pass through the cell, given Darcian flow (Q=KiA) between cells in an extended model. This resulted in a conductance of $0.25m^2/d$ for most layers. The Basal layer (Layer 18) was given a higher conductance due to its much greater thickness, with values of between 2 and $6m^2/d$.

7.5 Model Layers and Geometry

Based on the conceptual hydrogeology described in Section 5, the following model layers were defined for the Modification model:

- Layer 1: Alluvium and Regolith. Across the model domain, the alluvium and regolith was uniformly set at 20m;
- Layer 2: Overburden and coal seams above Fassifern Seam. This layer extends from the base of the Layer 1 regolith down to the Fassifern Seam in areas inside the Fassifern outcrop. Elsewhere it was set as a 'dummy layer' (see below). The representation of this layer was probably the greatest simplification in the model, as Layer 2 actually covers bands of Narrabeen Group sandstones, as well as Coal Measures siltstones, coal and claystones. This was considered to be a justifiable simplification, as the geological strata being represented by Layer 2 only occurs high up on the Sugarloaf Range. There are no environmental receptors within this area, and the only influence on mine inflows is for the Tasman Underground Mine in the Fassifern Seam. However, it meant that the calibration targets for Layer 2 had to be treated with caution;
- Layer 3: Fassifern Seam. Geometry was calculated based on the sub-crop pattern with a slightly basinal structure. Layer thickness was set at a constant 6m;
- Layers 4 to 6: Fassifern – West Borehole interburden. The interburden between these seams was split into three layers in order to allow for modelling of potential changes to hydraulic properties if high subsidence impact mining (e.g. secondary extraction or longwall mining) is carried out within the West Borehole Seam;
- Layer 7: West Borehole Seam. The seam geometry was based on the updated resource model provided by Ellemby resources. Some extension to the southern model boundary was required, and the edges of the geometry had to be modified to ensure that they reconciled with known sub-crop geometry. The seam thickness was taken from the previous Abel Underground Mine model;
- Layer 8: West Borehole – Sandgate interburden. This includes minor coal seams, as described previously. As there is only 50m between the Sandgate and West Borehole seams, the interburden was represented as a single layer in the model;
- Layer 9: Sandgate Seam. The geometry of this seam is not currently as well defined as the other coal seams, so based on investigation borehole records, it was set at a constant level of approximately 50m below the West Borehole Seam (except near sub-crop, where it was limited to one-third the distance between the West Borehole and Donaldson seams). Layer thickness was estimated at 7m, based on borehole records;
- Layer 10 to 12: Sandgate – Donaldson interburden. This interburden was split into three layers, for the same reasons as described for Layers 4 to 6 above;
- Layer 13: Upper Donaldson Seam. As with the West Borehole Seam, this was defined using the updated resource model. Definition near the western sub-crop was also relatively uncertain, so the geometry was modified according to the known, published sub-crops. Seam thickness was based on the Abel Underground Mine model;
- Layer 14: Upper Donaldson – Lower Donaldson interburden. Thickness of this layer was defined from the resource model details for the Upper and Lower Donaldson Seams. The interburden thickness increases to the south;

- Layer 15: Lower Donaldson Seam. As with the Upper Donaldson Seam, this was defined using the updated resource model. It has the same definition uncertainty near the western subcrop line;
- Layer 16: Donaldson – Big Ben interburden. This interburden unit is relatively thin, but does correspond to the Thornton claystone, so represents a very low permeability unit;
- Layer 17: Big Ben Seam. This is fairly consistent at approximately 5m below the base of the Donaldson Seams, with a 7m thickness;
- Layer 18: Big Ben – Ashtonfield interburden. Given the limited thickness of this layer, it is unlikely that this will need to be separated into additional layers to allow for the impacts of mining from the Ashtonfield Seam, so it was represented as a single layer;
- Layer 19: Ashtonfield Seam. The general geometry and seam thickness for this layer was taken from the Bloomfield Colliery model, extended to the south as a constant depth beneath the Donaldson Seam; and
- Layer 20: Basal Layer. Geologically, this layer includes a number of different lithologies, including the coal measures below the Ashtonfield Seam, and the underlying older formations. This layer was set with a minimum thickness of 200m at the base of the model.

An example cross-section of the model layers within the MODFLOW-SURFACT model is shown in Figure 7.2.

It should be noted that all layers are present across the entire active model area, and each layer (apart from Layer 1 and Layer 20) represents a single hydrogeological unit. Where a hydrogeological unit is absent, then to maintain continuity in the model, the layer representing that unit in the model has been extended across the remaining model domain as a 0.5m thick 'dummy' layer, to which has been assigned the same properties as the highest underlying 'active' layer that exists in that area. For example, in the north of the model, north of their subcrop lines, all of the layers except the basement (Layer 20) are absent. The model therefore contains an 'actual' Layer 1 Regolith, underlain by a 0.5m 'dummy' layer for each of Layers 2 to 19, with Basal Layer hydraulic properties assigned to ensure that in the model they behave as if they were part of the basement.

The use of dummy layers has allowed the impacts predicted by the model to be examined separately for each hydrogeological unit across the full model area.

7.6 Model Calibration

7.6.1 Calibration Approach

Model calibration involves comparing predicted (modelled) and observed data and making modifications to model input parameters where required (within reasonable limits defined by available data and sound hydrogeological judgment) to achieve the best possible match.

Model calibration performance is demonstrated in both quantitative (value matching) and qualitative (pattern-matching) terms, by:

- Scatter plots of modelled versus measured head, and the associated statistical measure of the scaled root mean square (SRMS) value;
- Water balance comparisons;
- Contour plans of modelled head;
- Hydrographs of modelled versus observed bore water levels;
- Mine inflow comparisons; and
- Baseflow comparisons.

The SRMS value is the Root Mean Square (RMS) error term divided by the range of heads across the site and it forms a quantitative performance indicator. Given uncertainties in the overall water balance volumes (e.g. it is difficult to directly measure evaporation and baseflow into the creeks), it is considered that a 10% SRMS value is an appropriate target for this study, with an ideal target for long-term model refinement recommended as 5% or lower. This approach is consistent with the Australian best practice groundwater modelling guidelines (Barnett *et al.* 2012; MDBC, 2001).

Calibration can be carried out as either steady state (i.e. calibration to assumed long-term equilibrium conditions) or transient (i.e. calibration to the impacts of time-dependent stresses such as pumping/dewatering and/or climatic variation).

Initial calibration was undertaken for steady state conditions, whereby the model was used to compare assumed long-term average groundwater levels with model-predicted groundwater levels prior to the transient calibration period (2006 – 2010).

Steady state calibration was followed by transient or "history match" calibration using the steady state calibration to set initial conditions. The transient calibration period included open cut and underground mining at Donaldson Open Cut Mine, Abel and Tasman Underground Mines and Bloomfield Colliery.

Transient calibration was to a degree restricted by the number of monitoring locations within the Permian units. Attention was focused on achieving a level of inter-connection between underground mining areas to match the assessed drawdown response seen. Variable fracture zone parameters using a "ramp function" as described in Section 5.3.4 were applied to Permian interburden/overburden to achieve this response.

7.6.2 Calibration Targets

In order to judge how well the model fits the actual groundwater system, calibration targets are used. For example, groundwater flow models calculate the groundwater level at many locations. When the groundwater level is measured in a monitoring bore at some or all of these locations, then a comparison can be made. A calibration target is a point in the aquifer where a measurement of water level has been made. Calibration targets may be either steady-state or transient. In this case, transient calibration targets have been used. The model compares target values (i.e. observed water levels over time) against model results, and interpolates results in both space and time to compute an error or residual. Calibration targets can also be developed for inflow of groundwater to underground workings.

A total of 50 groundwater monitoring locations, including standpipes and multilevel vibrating wire piezometers with 107 monitored horizons (Appendix D), provided approximately 3,000 transient water level targets which were initially included in the calibration.

The calibration targets are distributed throughout the model layers. Transient groundwater levels were taken from all records at each borehole where data was available. A full list of the calibration targets, including the layers monitored is included in Appendix D. The drain cell set up used for the transient calibration is shown in Appendix E.

Groundwater inflows to active mining areas provide a valuable calibration measure and are critical for achieving a robust calibration. Data for mine inflows is recorded at Abel Underground Mine, and this data has been used during calibration refinement to ensure robust predictive results.

7.6.3 Steady State Calibration

Steady state (or baseline 'long-term') calibration was carried out as the first stage of the calibration process. The primary purpose of initial steady state calibration was to allow for the generation of an initial head distribution for all model layers and to check assumptions for the conceptual hydrogeological processes.

The steady state model has been calibrated to groundwater levels recorded as close as possible to the beginning of 2006, with the assumption that these represent long-term average groundwater levels. Estimated pre-mining water levels were included in the calibration data set for a number of bores installed after 2003. However, the pre-mining water levels in all bores have, to some extent, been influenced by the surrounding mining operations including both active and abandoned projects. With this in mind, the steady state model was principally used to provide a reasonable set of starting conditions for the transient calibration model.

Calibration was carried out against 60 targets, using a combination of auto-sensitivity analysis and manual modification of model zones and parameters. Steady state calibration results for the SRMS was good, at 4.5%.

7.6.4 Transient Calibration

Transient calibration against groundwater levels was carried out for the period January 2006 to June 2012 inclusive. The water level outputs in the targets from the steady state model in 2005 were used as the initial water level heads in the targets for the transient model. The transient model period (2006 to 2012), included the Donaldson and Bloomfield open cut mines, as well as the initial two and four years of development at Abel Underground Mine and Tasman Underground Mine respectively. All mines were represented using a conventional drain cell representation approach. The drain cell set up used for the transient calibration is shown in Appendix E. The SRMS value for the six year calibration period is 4.3%.

Calibrated Hydraulic Properties

Table 7.1 summarises the calibrated hydraulic properties for the Modification model. The hydraulic conductivity zonation set up used for the transient calibration is shown in Appendix F.

Table 7.1: Calibrated Hydraulic Properties

Layer	Zone[1]	Formation and Area Represented	Kh (m/d)	Kv (m/d)	S (Sy)[2]	Notes
1	1	Regolith	1.00E-02	1.00E-03	5.00E-02	
	2	Wallis Creek, Cockle Creek, Hexham Swamp (and Pambalong) Alluvium	5.00E+00	1.00E-02	1.00E-01	Kh consistent with Abel EA report, Kv increased as per comments detailed in Kalf Associates, 2006.
	19	Donaldson Open Cut Backfilled	1.00E+00	1.00E-01	5.00E-02	
	20	other creeks	2.00E-01	1.00E-02	5.00E-02	
	34	Old Bloomfield Mining area	5.00E-01	5.00E-01	5.00E-02	
2	33	Overburden and coal seams above Fassifern Seam	1.00E-03	1.00E-03	2.00E-05	Deeper cover depth
	15		1.00E-04	5.00E-05	2.00E-05	
	4		1.00E-03	5.00E-03	2.00E-05	Shallower cover depth
3	3	Fassifern Seam	1.00E-02	5.00E-03	1.00E-02	Deeper cover depth
	22		2.00E-02	5.00E-05	1.00E-02	Shallower cover depth
4	6	Fassifern - West Borehole interburden	1.70E-03	2.00E-05	2.00E-03	
	8		1.00E-03	1.00E-05	2.00E-03	
5	As per layer 4					
6	As per layer 4					
7	16	West Borehole Seam	2.00E-02	1.00E-03	5.00E-03	Deeper cover depth
	23		1.00E-02	1.00E-03	5.00E-03	Shallower cover depth
	21	Old West Borehole mining area	1.00E+01	1.00E-03	1.00E-01	Older workings (predominantly bord and pillar)
	26		2.00E+00	1.00E-01	1.00E-01	More recent workings (old panels)
	27		2.00E+00	1.00E-05	1.00E-01	
8	5	West Borehole - Sandgate interburden	7.00E-03	5.00E-03	2.00E-03	Deeper cover depth
	37		1.00E-03	1.00E-06	2.00E-03	
	24		1.00E-02	1.00E-03	2.00E-03	Shallower cover depth
9	32	Sandgate Seam	2.00E-03	5.00E-04	5.00E-03	Deeper cover depth

Layer	Zone[1]	Formation and Area Represented	Kh (m/d)	Kv (m/d)	S (Sy)[2]	Notes
	38		5.00E-03	1.00E-04	5.00E-03	
	9		1.00E-02	1.00E-03	5.00E-03	Shallower cover depth
10	39	Sandgate - Donaldson interburden	8.00E-04	8.00E-07	2.00E-03	Main area
11	10		1.00E-04	1.00E-06	2.00E-03	
12	40		3.00E-04	6.00E-06	2.00E-03	
	25		2.50E-04	1.00E-05	2.00E-03 - 5.00E-03	Subcrop area only - based on higher recharge and Bloomfield model
13	50	Upper Donaldson Seam	1.00E-03	1.00E-04	5.00E-03	Deeper cover depth
	55		5.00E-02	1.00E-03	5.00E-03	
	56		1.00E-02	5.00E-03	5.00E-03	
	57		5.00E-03	1.00E-04	5.00E-03	
	51		1.00E-03	1.00E-04	5.00E-03	Shallower cover depth
14	7	Donaldson Seams interburden	2.00E-04	2.00E-05	2.00E-03	Deeper cover depth
	42		1.00E-04	1.00E-07	5.00E-03	
	28		5.00E-04	1.00E-06	5.00E-03	Shallower cover depth
15	50	Lower Donaldson Seam	1.00E-03	1.00E-04	5.00E-03	Deeper cover depth
	18		6.00E-02	6.00E-04	5.00E-03	
	30		1.00E-02	3.00E-05	5.00E-03	
	41		2.00E-03	1.00E-04	5.00E-03	
	51		1.00E-03	1.00E-04	5.00E-03	Shallower cover depth
16	7	Donaldson – Big Ben interburden	2.00E-04	2.00E-05	2.00E-03	Deeper cover depth
	42		1.00E-04	1.00E-07	5.00E-03	
	28		5.00E-04	1.00E-06	5.00E-03	Shallower cover depth
17	14	Big Ben Seam	5.00E-02	5.00E-03	5.00E-03	Deeper cover depth
	29		5.00E-03	3.00E-04	5.00E-03	
	43		3.00E-03	1.00E-04	5.00E-03	Shallower cover depth
18	28	Big Ben - Ashtonfield interburden	5.00E-04	1.00E-06	5.00E-03	Deeper cover depth
	44		5.00E-04	1.00E-07	2.00E-03	
	12		5.00E-04	2.00E-04	2.00E-03	Shallower cover depth
19	36	Ashtonfield Seam	1.00E-03	6.00E-04	5.00E-02	Deeper cover depth
	52		1.00E-03	1.00E-04	5.00E-02	
	17		5.00E-02	8.00E-03	5.00E-02	Shallower cover depth
20	13	Basement layer	1.00E-04	5.00E-05	5.00E-02	Deeper cover depth
	46		5.00E-04	5.00E-04	5.00E-02	
	15		1.00E-04	5.00E-05	5.00E-02	Shallower cover depth

1. Zone number refers to hydraulic conductivity distributions presented in Appendix F. It is noted that only relevant hydrogeologic units are presented in this table;

2. Refer to Appendix F for spatial distribution of storage coefficient. Values for Ss or Sy are presented in Table 7.1 refer to the nominated hydrogeological unit rather than zone number.

Calibration Statistics

The scatter diagram of measured versus modelled groundwater level targets is plotted in Figure 7.4, and it can be seen that the model is reasonably well balanced against the measured targets (i.e. there is no systematic under or over prediction). There is one bore (TA41B) which does exhibit modelled head that greatly exceed monitored heads. This bore is located in the south-western corner of the model, to the west of West Wallsend Colliery, where there is greater model uncertainty due to the lack of data in this area.

Scatter plots of modelled versus measured water levels for 88 monitored horizons show reasonable agreement between observed and computed water levels across shallow and deep model layers, with an SRMS error of 4.3% (within the target range of 10%), and coefficient of determination of 0.97. The SRMS value (Table 7.2) is the RMS value divided by the range of heads across the site, and forms the main quantitative performance indicator. This result is consistent with the relevant groundwater modelling guidelines (MDBC, 2001; Barnett *et al*., 2012).

Table 7.2: Calibration Statistics

Calibration Statistic	Value
Number of Data Points	2606
RMS	12.6 m
SRMS	4.25%
Coefficient of Determination (CD)	0.97

Water Balance

There are multiple opportunities for groundwater to discharge from, and recharge to, the groundwater system/model. Those implemented in the model include:

- Baseflow/leakage in the Hunter River (represented by a Constant Head boundary in MODFLOW);
- Baseflow/leakage in other major and minor watercourses (represented by the river cells in MODFLOW);
- Outflow/inflow to the eastern margin boundary (represented by GHB in MODFLOW);
- Mine inflows to active mining areas including Tasman and Abel Underground Mines (represented by the drain cells in MODFLOW);
- Rainfall Recharge;
- Evapotranspiration (ET); and
- Seepage face (discharges).

The simulated water balance at the end of transient calibration across the entire model area is summarised in Table 7.3. The total predicted inflow (recharge) to the aquifer system, in the modelled area, is approximately 25 megalitres per day (ML/day), comprising river leakage from the surface watercourses (approximately 46%), rainfall recharge (approximately 27%) and changes in storage (approximately 15%). The remainder is predominantly accounted for with inflow from the Hunter River, represented by a constant head boundary.

It is assumed that any water carried by ephemeral streams would have a negligible contribution to groundwater recharge through leakage.

Table 7.3: Simulated Water Balance at End of Transient Calibration

Water Source	Inflow (ML/d)	Outflow (ML/d)
Storage	3.74	0.12
Constant Head (Hunter River)	2.98	0.28
Drains (mine inflow)	0.00	5.56
Recharge (Direct Rainfall)	6.71	0.00
Seepage Face	0.00	1.05
ET	0.00	13.07
River (Leakage/Baseflow)	11.28	4.47
GHB	0.00	0.03
Total	24.69	24.58
% Discrepancy	0.46%	

Evapotranspiration, mine inflows and baseflows represent the major outflows to the model. Evapotranspiration accounts for about 53% of the water balance outflow. Mine inflows account for about 23% of the total discharge under transient conditions, while baseflows to creeks, streams and rivers account for about 18%. High elevation ground seepage, changes in storage and head dependent boundaries account for the remainder. The water balance residual of 0.46% is 0.11ML/day. This is considered an adequate discrepancy, as the MDBC groundwater modelling guideline suggests a 1% limit or up to 2% for complex models.

Calibrated Water Levels Prior to the Modification

Model-predicted groundwater levels prior to the proposed Modification are shown in Figures 7.5 to Figure 7.7. These figures show groundwater levels in the alluvium/regolith (Layer 1), the Upper Donaldson Seam (Layer 13) and the Lower Donaldson Seam (Layer 15) at the end of the calibration period (June 2012). The presence of ‘dry cells’, particularly prevalent in Layer 1 where the relevant layers of strata are or becomes de-watered, is consistent with drilling which showed generally no or negligible groundwater in the surficial material in upland areas.

The regolith in Layer 1 is generally dry in elevated areas covering a large proportion of the model domain (Figure 7.5). Layer 1 is saturated in lower elevations, with groundwater occurring in the alluvium and adjacent colluvium on the slopes adjacent to the various surface watercourses, including the alluvium associated with Blue Gum Creek and Hexham Swamp. Within the proposed Modification area the piezometric groundwater levels dip in the direction that the various surface watercourses drain, as outlined in Section 4.2.

Water levels within the Upper Donaldson Seam (Layer 13) are shown in Figure 7.6 with potentiometric groundwater levels predominantly dipping to the south-east in the Abel Underground Mine area. Significant drawdown is evident in the vicinity of the mining activity occurring in the Upper Donaldson Seam within the north-eastern section of the Abel Underground Mine which has operated since 2008. The observed drawdowns would also be due to the current Bloomfield Donaldson Open Cut operations.

Water levels within the Lower Donaldson Seam (Layer 15) are shown in Figure 7.7 with potentiometric groundwater levels predominantly dipping to the south-east in the Abel Underground Mine area. Drawdown is again evident in the vicinity of the mining activity occurring in the Upper Donaldson Seam. While there has been no active mining in the Lower Donaldson Seam at Abel, the drawdown shown on Figure 7.7 is the result of the depressurisation and leakage to the overlying Upper Donaldson Seam. This drawdown does not occur to the same vertical extent as that which occurs in the Upper Donaldson Seam, although the horizontal extent is relatively similar.

Match to Measured Groundwater Levels

Transient calibration hydrographs were produced for 107 monitoring points, which includes groundwater levels in multiple seams from the alluvium right through to the Ashtonfield Seam. The calibration hydrographs are presented in Appendix G. While the calibration performance of the groundwater model is satisfactory overall, there are some areas and groups of monitoring bores that have not calibrated well. There are a number of reasons for this which are detailed as follows.

Layer 1 bores generally calibrate well, apart from the 7 West Wallsend bores WWA1 to WWA7. The construction details of these bores are not known. Likewise the West Wallsend mine layout and recent operational history are not known in detail. The poor calibration of this group of bores is believed to be a result of the lack of detailed knowledge of the West Wallsend mine plan/schedule prior to and during the calibration period.

There are also a number of bores close to the Bloomfield Project that do not calibrate well. These include piezometers at a number of different stratigraphic levels (i.e. in a range of model layers). While the current and recent mining schedule and mine plan layouts at Bloomfield are well known and have been incorporated into the model, the historical mining at Bloomfield is less well known and has resulted in significant interconnection of strata from the surface down to at least the Rathluba Seam, thus effectively interconnecting all model layers. A further complication that has not been able to be represented in the groundwater model is the use of former workings at Bloomfield for underground disposal of tailings from the Bloomfield CHPP, and the recovery of water from the tailings by pumping from an old mine shaft. There has also been historical mining at older mines, such as the old Buchannan Colliery mine to the west of Bloomfield, about which there is insufficient knowledge to incorporate the workings into the groundwater model.

A number of the Abel Underground Mine multi-level VW piezometer bores in the region to the south of Bloomfield show generally downward trends in all piezometers, not just in the Donaldson Seam and its overburden strata. This suggests that all levels are at least partially hydraulically connected. The downward trend observed in these piezometers may be an indication that the influence of mining in the Donaldson Seam is also being reflected in layers higher and lower in the sequence. Possible explanations of this response are as follows:

- The grouting may not have completely sealed the borehole after placement of the piezometers, allowing hydraulic connection between two or more of the piezometers via the hole;
- The piezometers may be responding to some regional effect rather than one or more of the local mines; or
- It may be due to the interconnection brought about by the historical mining at Bloomfield and adjacent mines.

The water level trends seen on these bores cannot be related to any current or recent mining at Abel, Donaldson, Bloomfield or Tasman. Accordingly, the model does not calibrate well in some cases. The multi-level bores which are believed to be influenced by one or other of the above effects, or affected by strata interconnection caused by the historical mining, include the following:

- B002, B029, B030, B031;
- C123, C223, C138, C141, C148; and
- VW1, VW6, VW7, VW8.

C063B, which is screened in the Donaldson Seam, shows no response to the mining to date in that seam at Abel, even though the groundwater model is predicting impact at that site. The bore is believed to be located to the east of the Krecji Fault, or another fault, that is acting as a regional barrier to flow, thus preventing the effects of mining extending far in the easterly direction.

Finally, a number of piezometers in the vicinity of Tasman are showing responses that cannot be correlated with mining activity at Tasman. For example, TA24 shows a consistent downward trend, but the trend starts before mining commenced at Tasman.

Pressure Head Profiles

Steady state pressure head cross-sections have been completed, the locations of which are provided in Figure 7.8.

Figure 7.9 presents an east-west steady state cross-section at Northing 6366225 (Row 100). Depressurisation is observed to occur almost down to the Upper Donaldson Seam, associated with the existing Abel and Donaldson mine operations to the north.

Figure 7.10 presents a south-north steady state cross-section at Easting 367325 (Column 175). Depressurisation within the upper geological layers (West Borehole Seam) is observed to occur, associated with the abandoned Stockrington workings in the southern section of the Abel Underground Mine area.

Figure 7.11 presents a south-north steady state cross-section at Easting 369825 (Column 225). Depressurisation within the Upper Donaldson Seam is observed to occur, associated with the existing Abel and Donaldson mine operations.

Mine Inflows

Simulated mine inflows within the current Abel operations from the calibration model run (up to the end of 2012), have been summarised in Table 7.4. Figure 7.12 provides a comparison of these simulated mine inflows against actual mine inflows available from February 2011 onwards.

Table 7.4: Average Modelled Abel Mine Inflows during Calibration (2006 – 2012).

Timeframe	Modelled Mine Inflow (ML/yr)
January 2006 – June 2009	0
July 2009 – Dec 2009	110.0
Jan 2010 – June 2010	60.7
July 2010 – June 2011	463.9
July 2011 – June 2012	387.6

While it can be observed that the average modelled Abel mine inflows from January to July 2012 are slightly underestimated when compared against the measured inflows (as indicated in Figure 7.12), the large increase in inflows during mine operations since the start of 2011 has been captured and overall the observed inflows are reasonably well matched.

Baseflows/Stream Leakage

Simulated baseflows within the watercourses in the vicinity of the Abel Underground Mine area (as outlined in Section 4.2) are provided in Figure 7.13. This figure details the modelled baseflow from the calibration model run (up to the end of 2012), summarised in Table 7.5. Locations of the river and creeks listed in Table 7.5 are shown on Figure 4.3.

Table 7.5: Average Modelled Baseflow during Calibration (2006 - 2012)

Surface Water Body	Modelled Baseflow (ML/yr)[1]
Blue Gum Creek	0.72
Hexham Swamp	-2556
Long Gully	-0.0006
Buttai Creek	0.29
Four Mile Creek	-0.0068
Weakleys Flat Creek	7.14
Viney Creek	0.96
Minmi Creek	1.89

[1] Positive modelled baseflow represents flow from the groundwater to the surface water body.

Table 7.5 indicates that Hexham Swamp is currently contributing leakage to the underlying alluvial groundwater system (as indicated in the water balance provided in Table 7.3). The remaining creeks within the Model Area are generally shown to provide minimal flow to the groundwater, or are obtaining insignificant baseflows from the groundwater system.

Seepage face options were made active within the river cells which enabled water rejected from model layers at sub-crop areas to be captured within the river cell boundary conditions. From the water balance presented in Table 7.3 it can be observed that a small proportion (4.3%) of outflow exited the model through this seepage. It has been assessed that the majority of this component would be assigned to evapotranspiration.

7.7 Sensitivity Analysis

Auto sensitivity analysis was carried out in order to examine the sensitivity of the overall model calibration to variations in Kh, Kv and recharge in each of the model zones. Summary graphs of the auto-sensitivity results for the final steady state model are provided in Figures 7.14 to 7.16.

The model was found to be most sensitive to the following parameters:

- Recharge along elevated ridgeline areas and the regolith; and
- Horizontal and vertical hydraulic conductivity within the historical Bloomfield Colliery workings and the West Borehole Seam.

The sensitivity analysis for the steady state model showed that results are most significantly affected by assumptions made over recharge to the Triassic Narrabeen Group along elevated ridgeline areas (Zone 9) and the regolith overlying the centre and south-eastern portion of the Model Area (Zone 6).

In addition, horizontal hydraulic conductivity parameters for the in situ rock mass were found to be sensitive within the historical Bloomfield Colliery workings (Zone 34) and the West Borehole Seam (Zone 23) as the magnitude of the multiplier increased.

Overall, vertical hydraulic conductivity does not appear to be as sensitive as horizontal hydraulic conductivity. The main exceptions to this were again the historical Bloomfield Colliery workings (Zone 34) and the West Borehole Seam (Zone 23) which actually exhibits greater sensitivity than horizontal hydraulic conductivity, particularly as the magnitude of the multiplier increases.

The impact of changes to these parameters on the model predictions were subsequently examined by uncertainty analysis modelling, described in Section 7.9.

7.8 Prediction Modelling

7.8.1 Prediction Simulations

Simulation of Modified Mining Operations

In order to assess the impacts that the Modification could have on the hydrogeological environment, the calibrated MODFLOW-SURFACT groundwater model was used to simulate the operational and post mining recovery stages of the Modification.

The proposed Modification has been simulated from the commencement of mining in the Upper Donaldson Seam in 2009 (during the model calibration period) to the end of extraction within the Lower Donaldson Seam in 2028. The adopted schedule of extraction is summarised in Tables 6.1 and 6.2, which incorporates expected future mining operations in proximity to the Modification.

As described above for the calibration modelling, mining was simulated by means of drain cells in active mining areas in each mined coal seam, and hydraulic properties for subsidence affected zones above extraction panels altered accordingly (refer to Section 5.3 for further details).

The model simulation runs included a post-mining recovery period of 100 years.

Simulation of Approved Mining Operations

In addition to simulation of the Modification described above, the currently approved operations at the Abel Underground Mine have also been simulated from commencement of mining in the Upper Donaldson Seam in 2009 (during the model calibration period) to the end of extraction within the Lower Donaldson Seam in 2028. The mining schedule for the development and extraction of the panels within the Upper Donaldson and Lower Donaldson Seams for the Approved mine plan are shown in Figure 7.17.

The main differences between the two models are:

- Bord and pillar method of extraction is only applied in the Approved mine plan model, with the associated fracture zone implementations;
- Differences in the layout and timing of the extraction panels, as per Figures 6.1, 6.2 and 7.17; and
- The incorporation of Upper Donaldson Seam thin seam works in the Approved mine plan model.

Prediction Simulation Hydraulic Properties

The calibrated hydraulic conductivity values were adjusted in the prediction simulation using the application of a ramp function to approximate the potential effect of deformation due to mining in layers 5 and 6 for the Tasman Extension Project area (West Borehole Seam being mined in layer 7) and Layers 2 to 12 for the Abel Underground Mine area (Donaldson Seams being mined in Layers 13 and 15). Refer to point three below.

In summary the adjustments to the calibrated values were as follows;

- Horizontal hydraulic conductivity, Kh, in prediction simulation (Layers 1 to 20, except Layer 7, 13 and 15) were set to twice the horizontal hydraulic conductivity in the calibrated model. It is noted that changes were applied only within the spatial extent of the mine plan.
- Kv in the Surficial Aquifer (Layer 1) in the prediction simulation was set to 5 times the calibrated Kv.
- In Layers 2 to 12 (except for Layer 7), Kv was varied using a log-linear relationship (ramp function) with depth, from 0.00033m/day (Layer 2) through to 0.0043m/day (Layer 12) for the Abel Underground Mine Area and 0.000380m/day (Layer 5) and 0.00063m/day (Layer 6) for the Tasman Extension Project area.
- Horizontal and vertical hydraulic conductivity, Kv, of the West Borehole Seam (Layer 7), Upper Donaldson Seam (Layer 13) and Lower Donaldson Seam (Layer 15), were set to 10m/day and 10m/day respectively to simulate the void space.
- Kv of Layer 14 (Donaldson Seams Interburden) was changed to 0.01m/day from their calibrated values.
- Kv in Donaldson – Big Ben Interburden (Layer 16) in the prediction simulation was set to 3 times to the calibrated Kv.
- Within the spatial extent of the mine plan, the specific yield was set at 0.025 in all layers in the prediction simulation. The values for specific storage were not changed.

It is important to note that the spatial extent of the changes in each layer of the prediction model was limited to the footprint of the mine plan. The ramp function was only applied above areas where full secondary extraction occurs. Tabulation of model parameters used in the prediction simulation is presented in Appendix L.

7.8.2 Mine Inflows

Model predictions of total mine inflows to the modified underground workings during the course of operational mining are shown in Figure 7.18. Modelled mine inflows for the approved mine plan and measured mine inflows are also shown for comparative purposes.

Figure 7.18 indicates that for the modified mine plan, inflows begin within the first six months of development with an average inflow of approximately 0.3ML/day occurring during this period. This increases to a peak inflow of approximately 6.3ML/day in June 2016, which corresponds to the development of longwall panels in the shallower Upper Donaldson Seam (Figure 6.1). The peak inflow for the modified mine plan is lower than the peak inflow for the approved mine plan (7.0ML/day). This is because the area of extraction in the peak year of inflow for the approved mine plan is greater than the area of extraction for the peak year of inflow for the modified mine plan.

From June 2017 to June 2021, inflows for the modified mine plan are sustained between around 4.1 and 4.8ML/day as the bord and pillar mining advancing in the deeper Upper Donaldson Seam is successively undermined by the longwall panels in the Lower Donaldson Seam. This period represents the most significant departure between the approved and modified mine plans in terms of predicted groundwater inflows (i.e. greater inflows for the modified mine plan). The increased inflows for the modified mine plan in comparison to the approved mine plan are attributed to the greater subsidence fracturing and increased permeability induced by the longwall mining. Inflows for the modified mine plan then decline to less than an average of 2ML/day from July 2021, with another small increase in inflows between July 2024 and June 2026 with an average inflow of 2.6ML/day. Post-June 2026 inflows drop to below those of the approved mine plan and less than an average of 1.7ML/day as mining of the final up-dip panels and retreat excavation of the East-West Mains occurs at the end of the mining schedule.

7.8.3 Predicted Water Levels during Mining Operations and Post-Mining Recovery

Mining Operations

Model-predicted groundwater levels before mining and at the end of mining operations for the Modification are shown in Figures 7.19 to 7.21. They demonstrate the cumulative impact of the Modification and surrounding mine operations. All of these figures show groundwater levels in the relevant layer within the vicinity of the Abel Underground Mine area (at the start and end of mining, 2009 and 2028 respectively), as well as the presence of 'dry cells' where the relevant layers of strata have become de-watered. These figures provide the following details:

- Figure 7.19 shows water levels in the alluvium and regolith (Layer 1), at the start of mining (2009) and at the end of mining (2028);
- Figure 7.20 shows water levels in the Upper Donaldson Seam (Layer 13) in the same periods as above; and
- Figure 7.21 shows water levels in the Lower Donaldson Seam (Layer 15) in the same periods as above.

A large proportion of the alluvium and regolith across the model domain is unsaturated (dry), generally corresponding to areas of elevated terrain around the Abel Underground Mine area (Figure 7.19). The water levels in the immediate vicinity of the watercourses that flow through the mine lease remain relatively consistent. A minor reduction in water levels is noted in the regolith overlying the north-eastern area of Abel in proximity to the outcrop of the Donaldson Seams. Some depressed water levels are observed prior to mining to the north of the Abel mine plan area, around the neighbouring Bloomfield and Donaldson open cut mine operations.

Within the Upper Donaldson Seam (Layer 13), Figure 7.20 indicates that groundwater levels are significantly reduced across the Abel Underground Mine area at the end of the Modification operations. The centre of the water level drawdown occurs in the deeper section of the southern panels, where water levels reduce to approximately -180mAHD. There is also a localised cone of drawdown evident in the central-eastern section of the Modification, where water levels reduce to approximately -130mAHD.

Within the Lower Donaldson Seam (Layer 15), Figure 7.21 indicates that a similar pattern of groundwater levels are predicted across the Abel Underground Mine area at the end of the Modification operations as predicted in the Upper Donaldson Seam. However the vertical extent of water level reduction is greater. The centre of the water level drawdown that occurs in the deeper section of the southern panels is approximately -200mAHD, and for the localised cone of drawdown evident in the central-eastern section of the Abel Underground Mine area the water level reduces to approximately -160mAHD.

Further illustrations of groundwater level impacts are provided in pressure head profiles along two north-south and one east-west cross-sections in Figures 7.22 to 7.24. The section locations are shown on Figure 7.8. At the commencement of mining, no depressurisation is observed in the deeper coal seams, with only the depressurisation within the upper geological layers (West Borehole Seam) being associated with the abandoned Stockrington workings in the southern section of the Abel Underground Mine area. This depressurisation is particularly evident on Figure 7.23 (as indicated by the 50 m head contour) and is still present at the end of mining (2028).

By the end of the Modification operations, depressurisation is observed to occur down to the Donaldson seams in the areas of shallower depth to cover in the immediate vicinity of the Modification as water levels are drawn down to the elevations in these seams during mining. Surficial groundwater levels are maintained, as too are the shallower groundwater levels under higher cover depth below elevated terrain.

Post-Mining Recovery

Post-mining recovery water levels are provided in Figures 7.25 to 7.27 for the alluvium/regolith, Upper Donaldson Seam and Lower Donaldson Seam.

Figure 7.25 shows groundwater levels 100 years after completion of mining in the alluvium/regolith (Layer 1) which indicates a minimal change in water levels to the south of the Abel Underground Mine area. Water levels are shown to be very consistent from pre-mining through to post-mining recovery. In the north-east of the Abel Underground Mine area where some minor drawdown was noted at the end of mining, a continued equilibration with the underlying depressurised layers has resulted in a further decline in water levels, albeit relatively minor. A slight recovery in water level is noted in the vicinity of the Tasman operations.

Figures 7.26 and 7.27 show groundwater levels 100 years after completion of mining in the Upper and Lower Donaldson seams (Layers 13 and 15 respectively). In both these layers a reduction in the number of dry cells, representing dewatered extent, within the Abel mine area is observed. However significant depressurisation is still observed as water levels are still reduced to -150 mAHD and -130mAHD in the Upper and Lower Donaldson seams respectively in the deeper section of the southern Modification panels.

The lack of long-term recovery of groundwater levels/pressures is further demonstrated by the pressure head cross-sections provided in Figures 7.28 to 7.30. These figures indicate that depressurisation within the Upper Donaldson Seam and the seams above are still present. Depressurisation is also still present near the open cut mines to the north of Abel; however there is greater recover of groundwater levels in this area.

7.8.4 Predicted Baseflow/Stream Leakage Changes

Predicted baseflow within the watercourses in the vicinity of the Abel Underground Mine area from the Modified and Approved mine plan models are summarised on in Figure 7.31 with individual baseflow impacts shown on Figures 7.32 to 7.34. Figure 7.31 includes modelled baseflow from the prediction model runs (2009 to 2132), incorporating both the mining operation and post-mining recovery period, and summarised in Table 7.6. Locations of the watercourses are shown on Figure 4.3.

Table 7.6: Average Modelled Baseflow during Mine Operation and Recovery

Surface Water Body	Approved Mine Plan		Modified Mine Plan	
	Mine Operation Average Baseflow (ML/yr)[1]	Post-Mine Recovery Average Baseflow (ML/yr)[1]	Mine Operation Average Baseflow (ML/yr)[1]	Post-Mine Recovery Average Baseflow (ML/yr)[1]
Blue Gum Creek	0.62	1.35	0.66	1.40
Hexham Swamp	-2584	-2586	-2584	-2586
Long Gully	0.00	0.00	0.00	0.00

Surface Water Body	Approved Mine Plan		Modified Mine Plan	
	Mine Operation Average Baseflow (ML/yr)[1]	Post-Mine Recovery Average Baseflow (ML/yr)[1]	Mine Operation Average Baseflow (ML/yr)[1]	Post-Mine Recovery Average Baseflow (ML/yr)[1]
Buttai Creek	0.27	0.22	0.22	0.00
Four Mile Creek	-0.01	-0.01	-0.01	-0.01
Weakleys Flat Creek	7.16	7.17	7.16	7.17
Viney Creek	0.45	0.33	0.67	0.19
Minmi Creek	1.89	1.92	1.88	1.87

[1] Positive modelled baseflow represents flow from the groundwater to the surface water body.

In general only Hexham Swamp has any significant fluxes in terms of river stream leakage. All other drainages within the vicinity of the Abel Underground Mine area are essentially ephemeral and only flow under periods of sustained rainfall.

Over the scheduled life of the mine, only Hexham Swamp (modified and approved), and to a lesser extent Viney Creek (modified and approved) and Buttai Creek (approved) indicate a decrease in baseflow (or increase in river leakage). The remaining watercourses indicate minimal or no observed changes in baseflow.

Over the 100-year recovery period it can be observed that baseflow to Blue Gum Creek increases quite significantly, to more than double that at the start of mining. This increased baseflow is attributed to recovery of water levels in the vicinity of the Tasman operations. The remaining watercourses tend to either remain relatively constant following the cessation of mining, or show no significant change.

In terms of differences between the modified and approved mine plan model scenarios, the following observations are noted:

- No discernible difference in baseflow within Weakleys Flat Creek, Long Gully and Four Mile Creek;
- The modified mine plan exhibits slightly higher baseflows or lower stream leakage within Blue Gum Creek, Hexham Swamp and Viney Creek during scheduled life of mine; and
- The modified mine plan exhibits slightly lower baseflows within Buttai Creek, Minmi Creek and Viney Creek during post-mining recovery.

7.9 Uncertainty Analysis

Uncertainty analysis is the process by which the impacts of variations in critical parameters (identified as being "sensitive" during the sensitivity analysis) on model predictions and model reliability is assessed.

The sensitivity analysis for the steady state model was presented in Section 7.7. In order to assess the impact from uncertainty of those parameters considered to be most sensitive, and to what extent these could impact on mine inflows and baseflow, the prediction model was run multiple times while altering the magnitude of the sensitive parameters.

The initial sensitivity analysis found that the overall model was most sensitive to Zones 23 and 34 when considering both horizontal and vertical hydraulic conductivity. However, upon initial running it was found that alteration of these zones had no impact on the mine inflows and baseflow results within the Abel Underground Mine area, due to their distance from the Modification area. Therefore, to obtain the most relevant results from the process, the most sensitive horizontal and vertical hydraulic conductivity zones within the Abel Underground Mine area were selected for continued uncertainty analysis. These were found to be zones 1 and 2 for both horizontal and vertical hydraulic conductivity zones.

The final uncertainty model runs included:

- Uncertainty model runs 1 and 2, in which horizontal hydraulic conductivity of the regolith and alluvium (Zones 1 and 2), incorporating the Abel Underground Mine area, was multiplied by a factor of 0.1 and 10 respectively;
- Uncertainty model runs 3 and 4, in which vertical hydraulic conductivity of the regolith and alluvium (Zones 1 and 2), incorporating the Abel Underground Mine area, was multiplied by a factor of 0.1 and 10 respectively; and
- Uncertainty model runs 5 and 6, in which recharge to the elevated ridgeline area (Zone 9) and regolith (Zone 6) was multiplied by a factor of 0.1 and 10 respectively.

The changes to simulated mine inflows and baseflow due to the parameter changes are provided in Figures 7.32 to 7.34, which show that:

- An increase in recharge has the most significant impact on the combined baseflow to all watercourses in the vicinity of the Abel Underground Mine area, producing consistently increasing baseflow;
- Horizontal hydraulic conductivity has the most significant impact on baseflow to Hexham Swamp. Increasing Kh by a magnitude of 10 increases the leakage to the aquifer by 4000m^3/day, while decreasing the magnitude also produces a notable effect;
- A change in vertical hydraulic conductivity has little impact on baseflows and mine inflows; however an increase in vertical hydraulic conductivity results in the highest peak inflow (2361ML/yr), which is 30ML/yr higher than the maximum inflow for the Modification base case; and
- The greatest minimum and maximum proportionate changes observed for mine inflows are observed when the horizontal hydraulic conductivity is increased by 10.

Results of the uncertainty analysis show that there is little predicted impact on mine inflows from uncertainty in the most sensitive model parameters.

8. POTENTIAL IMPACTS OF Abel Upgrade Modification

This section contains a summary of the impacts on the hydrogeological environment from the Modification, including the subsequent 100 year period of post-mining recovery.

The main effect of the underground mining upon the groundwater regime occurs due to changes in bulk rock mass permeability in the area immediately above the mine, caused by the fracturing associated with subsidence, and the subsequent pumping out of groundwater that enters the mine as a consequence. Details of these mechanisms, and the quantification of the effects on rock mass permeability, have been provided in Section 5.3. This caving, and associated extraction of groundwater via mine dewatering, has a number of effects on the hydrogeological system during mine operations that have been evaluated as part of the impact assessment. These are summarised as follows:

- Impacts on groundwater levels within the Permian hard rock strata and the alluvium during and after completion of mining;
- Impacts on watercourses in the vicinity of the Modification during and after completion of mining;
- Impacts on existing groundwater users;
- Impacts on GDEs;
- Impacts on water quality – including mine inflows and its management; and
- Impacts due to climate change.

The groundwater model has been used to predict the incremental impacts of the Modification compared to the approved impacts associated with approved mine plan for the Abel Underground Mine. To enable this, the model was run separately for the Approved mine plan and the Modification mine plan. By subtraction, the predicted impacts associated with the Modification in isolation have been identified.

Water accounting and licensing arrangements are discussed in Section 9, while a brief discussion of absolute water level and baseflow impacts due to the Modification is provided in Appendix H.

8.1 Groundwater Level Impacts

8.1.1 Mining Phase

Drawdowns at the end of mining attributable to the Modification in isolation are shown in Figures 8.1 to 8.3 for the alluvium/regolith, Upper Donaldson Seam and Lower Donaldson Seam, respectively. The absolute drawdown at the end of mining for the Modified and Approved mine plans are provided in Appendix I.

The regolith in Layer 1 is largely dry above the Abel Underground Mine area prior to commencement of the Modification, and the area of dry regolith is predicted to increase slightly through the life of the mine. Figure 8.1 shows that across the Abel Underground Mine area in general, the Modification is predicted to have very limited drawdown impacts above those already approved, with a maximum increase in drawdown of approximately 1m observed in the alluvium, which remains partially saturated. More drawdown is exhibited under the Approved mine plan within the north-east section of the Abel Underground Mine area, due to differences in mine panel layout. The maximum difference in drawdown is approximately 2m here with the Modified mine plan resulting in less drawdown.

In Figures 8.2 and 8.3 it can be observed that in general, more drawdown is exhibited under the Approved mine plan than under the Modified mine plan for both of the Donaldson seams (the maximum difference is approximately 60m). For the Modified mine plan less drawdown is predicted in the Upper Donaldson in the north-eastern and south-eastern mined areas and in the unmined area between the northern and southern longwall panels. Increased drawdown is predicted in the south-west of the Abel Underground Mine area.

For the Lower Donaldson Seam, the Modified mine plan is predicted to result in less drawdown across the entire northern Abel Underground Mine area and in the south-west compared to the Approved mine plan. The only area where significantly increased drawdown is predicted is in the south-east of the Abel Underground Mine area.

8.1.2 Post-Mining Recovery

Residual drawdowns at the end of 100-year post-mining recovery attributable to the Modification in isolation are shown in Figures 8.4 to 8.6 for the alluvium/regolith, Upper Donaldson Seam and Lower Donaldson Seam, respectively. The absolute drawdown at the end of 100-year post-mining recovery for the Modified and Approved mine plans are provided in Appendix J, while the simulated recovery hydrographs for all modelled bores across the Model Area are provided in Appendix K.

Figure 8.4 shows that across the Abel Underground Mine area in general, the Modification is predicted to have very limited drawdown impacts above those already accounted for under the Approved mine plan in Layer 1, with a maximum increase in drawdown of approximately 5m above the active mining areas in the north. To the north-east of the Abel Underground Mine area a reduced impact is predicted with the Modified mine plan predicted to have a 5m reduction in drawdown compared to the Approved mine plan after the 100 year recovery period.

Figures 8.5 and 8.6 show that in general, significantly less residual drawdown is expected under the Modified mine plan than was predicted under the Approved mine plan. In the Upper Donaldson Seam, the majority of the Abel Underground Mine area has a reduced residual drawdown with the only exception being in the south-west corner of the Abel Underground Mine area. In the north-eastern Abel Underground Mine area the residual drawdown is predicted to be reduced by 80m for the Modified mine plan whereas in the south-west an additional 40m of drawdown is predicted at the end of the recovery period. For the Lower Donaldson Seam the entire Abel Underground Mine area is predicted to have less residual drawdown under the Modified mine plan with only two small areas of very minor increased drawdown predicted.

8.2 Potential Baseflow/Stream Leakage Impacts

The majority of the area above the Modification either drains towards Hexham Swamp to the east, via Long Gully and Blue Gum Creek, or Woodberry Swamp to the north-east via Weakleys Flat Creek and Viney Creek. Other portions of the Abel Underground Mine area are located in the ephemeral headwaters of Four Mile Creek and Buttai Creek.

Only Hexham Swamp and Weakleys Flat Creek have any significant fluxes in terms of river stream leakage or aquifer discharge (baseflow). All other drainages are essentially ephemeral and only flow following periods of sustained rainfall.

Changes to baseflow due to the Modification in isolation are shown in Figure 8.7. This figure shows that overall the Modification is predicted to have very limited impact above those already accounted for under the Approved mine plan. The only watercourses which exhibit a small reduction in baseflow due to the Modification are Buttai Creek, Viney Creek and Minmi Creek. These reductions generally occur in the post-mining recovery period, and all equate to less than $1m^3$/day.

On the other hand, some watercourses exhibit a slight reduction in negative baseflow impacts, compared to the approved baseflow impacts associated with Approved mine plan. During the life of mine, the change in baseflow is positive for Viney Creek (however it does then become negative during the course of recovery, as stated above). Hexham Swamp and Blue Gum Creek both also exhibit a small reduction of less than $1m^3$/day in baseflow impact. These relative reductions in negative baseflows (i.e. when compared on a year by year basis) are due to changes in the timing of extraction for the Modified and Approved mine plans.

The potential exists for subsidence-induced fracturing to occur at the surface. However the likelihood of this occurring has been mitigated by the inclusion of SCZs in the vicinity of Schedule 2 streams. Further discussion on potential subsidence-induced impacts on streams is provided in Section 5.1 of MSEC (2012).

8.3 Groundwater Dependent Ecosystems

As discussed in Section 4.9, there are a number of localities which could support GDEs within or adjacent to the Abel Underground Mine area. These include Rainforest Protection Zones located along watercourses, swamps located within alluvium associated with Long Gully and Blue Gum Creek, and Pambalong Nature Reserve and Hexham Swamp downstream of the Abel Underground Mine area.

The Modification uses SCZs to manage subsidence effects in the vicinity of sensitive surface features, such as rainforest, Schedule 2 streams (third order and above streams) and Blue Gum Creek alluvium protection zones. Due to the implementation of these Subsidence Control Zones, Figures 7.19 and 7.25 indicate that there are minimal changes to groundwater levels in the vicinity of Hexham Swamp, as well as the watercourses supporting Rainforest Protection Zones and alluvium associated with Long Gully and Blue Gum Creek (i.e. due to the total impacts predicted for the Modification). In addition, Section 8.2 noted that the total impact of the Modification on flows within Hexham Swamp is insignificant, as it only accounts for approximately 0.5% of the total river stream leakage volume. The modelling results also indicated no impact on flows in Blue Gum Creek or Long Gully, as shown in Figure 7.31.

The potential exists for subsidence-induced fracturing to occur at the surface. However the likelihood of this occurring has been mitigated by the inclusion of the SCZs. Further discussion on potential subsidence-induced impacts on GDEs is provided in Sections 5.6 and 5.7 of MSEC (2012).

Impacts on flows and groundwater levels in the alluvium within the Abel Underground Mine area are predicted to be insignificant, both during mining and post-mining. Therefore, it is considered very unlikely that there would be any impact on the GDEs outlined above. Regardless, monitoring of potential impacts of the Modification on GDEs in the vicinity of the Abel Underground Mine area (including Hexham Swamp) would still be conducted as part of the Biodiversity Management Plan for the Abel Underground Mine (Section 4 of the EA).

8.4 Existing Groundwater Users

Of the 34 registered bores within 5 km of the Modification identified in Section 4.8, 28 are classified as monitoring or test bores. Of the six remaining bores, stock/domestic bore GW051353 is associated with the Abel Underground Mine; while farming bore GW078578 is associated with the Tasman Underground Mine.

Two bores GW058760 and GW0061307 are located to the north of Donaldson Open Cut Mine and to the north of the Newcastle Coal Measures sub-crop. This location is stratigraphically higher than the Modification and outside the sub-crop of the Donaldson Seam. Irrigation bores GW053411 and GW053412 are located within the down gradient section of Surveyor Creek near the confluence with Wallis Creek, approximately four kilometres to the west of the Modification.

Figure 8.8 shows the location of all the registered bores within 5 km of the Abel Underground Mine area, with an indication of “intended use” classification provided. The predicted drawdown at the end of mine life (2028) in the alluvium/regolith is also shown. All of the private (i.e. non-mine owned) registered bores are outside the predicted zone of influence of drawdown in the alluvium (Figure 8.8), as well as the more extensive zone of drawdown in the deeper Permian seams (refer to Appendix I).

It is therefore predicted that the Modification will not impact on any private registered groundwater bore or well, or other groundwater users.

8.5 Potential Water Quality Impacts

It is expected that the quality of groundwater inflows to the modified Abel underground mine will initially be similar to the current groundwater inflow to the Donaldson open cut and the approved Abel Underground Mine already in operation, with TDS around 1500-2000mg/L and pH around 7. According to PDA (2006) a gradual increase in salinity may occur over time, to an eventual salinity of around 3000-4000mg/L TDS.

A site water balance and surface water impact assessment, which considers the quantity and quality of groundwater inflows, is provided in Appendix C of the EA.

Following completion of the mining at the Abel Underground Mine and recovery of groundwater levels, groundwater levels will remain below ground level in the vicinity of the mine portal, and there is not expected to be any ongoing discharge of mine water.

In the event that there is any minor reduction in groundwater baseflow contribution to the surface watercourses due to the Modification, the impact on water quality in the streams would be beneficial, as the groundwater quality is commonly poorer than the quality of surface runoff.

8.6 Climate Change and Groundwater

Climate change is expected to have varying impacts on groundwater; however few modelling studies on the impacts of climate change to groundwater levels have taken place so far. Modelling of climate change takes into account surface water and groundwater interactions, and inter-annual temporal variations.

The NSW Climate Impact Profile - The Impacts of Climate Change on the Biophysical Environment of New South Wales (DECCW, 2010) projects the following changes to the climate of the Modification region by 2050:

- Increased maximum and minimum temperatures in all seasons;
- An increase in summer rainfall, with no decrease during winter. These projected changes are within the historical variation in rainfall;
- Increased evaporation due to increased projected temperatures. The projected increases in evaporation are likely to counteract the expected increases in summer rainfall across the state; and
- Increased rainfall intensity for flood producing rainfall, particularly for short duration storms.

Annual rainfall is expected to change by -10% to +5% by 2030 (Pittock, 2003) in parts of south-eastern Australia. In addition, annual temperatures are projected to increase by 0.4 to 2.0ºC (relative to 1990) at that time.

The approach taken for this assessment involved running the prediction model for the Modification over three scenarios:

- Rainfall infiltration reduced by 20%;
- Rainfall infiltration increased by 20%; and
- Rainfall infiltration was increased by 20% and evapotranspiration was increased by 10%.

Results for each scenario are detailed in Table 8.1 and illustrated in Figures 8.9, 8.10 and 8.11. The Base Case (calibrated recharge and evapotranspiration) incorporates the Modified mine plan, as well as all current, future and historical workings in the Model Area.

In Table 8.1 the modelled baseflows corresponding to each watercourse in the vicinity of Modification are shown on the left of the table. The changes in volumes following the completion of each of the three scenarios described above are shown on the right hand side of the table. It is important to note that these quantities are a change in the volume of baseflow, and not a total baseflow volume.

The outcomes of the climate change prediction scenarios include the following:

- In general, the parameter changes implemented have a low impact on alterations to baseflow. The exception to this is Hexham Swamp, where the largest increase in leakage to the aquifer is observed under the rainfall infiltration increased by 20% and evapotranspiration increased by 10% scenario. While the leakage increases by approximately 460m^3/day, this only equates to about 6% of the total leakage. Hexham Swamp shows the greatest sensitivity to the variability in recharge and evapotranspiration parameters as it covers a large surface area within the model (approximately 12.3km^2).

- When rainfall infiltration is reduced by 20% the baseflow in all the watercourses is reduced (with the exception of Long Gully and Four Mile Creek which remain constant).
- When rainfall infiltration is increased by 20% the baseflow in all the watercourses increases by a similar volume (with the exception of Long Gully and Four Mile Creek which remain constant).
- When rainfall infiltration is increased by 20% and evapotranspiration increased by 10%, the baseflow in Hexham Swamp, Buttai Creek, Weakleys Flat Creek and Viney Creek reduces, while the baseflow increases in Blue Gum Creek and Minmi Creek.

Table 8.1: Change in Average Modelled Baseflow during Mine Life (2009 – 2028) taking into account impacts due to climate change

	Base Case	Base Case	Infiltration reduced by 20%	Infiltration reduced by 20%	Infiltration increased by 20%	Infiltration increased by 20%	Infiltration increased by 20% ET increased by 10%	Infiltration increased by 20% ET increased by 10%
Surface water body	**Modelled Baseflow at 2009 (m3/day)**	**Modelled Baseflow at 2028 (m3/day)**	**Change in Modelled Baseflow at 2009 (m3/day)**	**Change in Modelled Baseflow at 2028 (m3/day)**	**Change in Modelled Baseflow at 2009 (m3/day)**	**Change in Modelled Baseflow at 2028 (m3/day)**	**Change in Modelled Baseflow at 2009 (m3/day)**	**Change in Modelled Baseflow at 2028 (m3/day)**
Blue Gum Creek	1.90	1.88	-0.24	-0.72	+0.70	+1.93	+0.06	+1.06
Hexham Swamp	-7056.06	-7077.79	-47.21	-49.75	+47.22	+49.72	-463.53	-462.92
Long Gully	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Buttai Creek	0.80	0.28	-0.07	-0.23	+0.07	+0.22	-0.21	-0.06
Four Mile Creek	-0.02	-0.02	0.00	0.00	0.00	0.00	0.00	0.00
Weakleys Flat Creek	19.59	19.62	-0.12	-0.24	+0.12	+0.24	-0.74	-0.68
Viney Creek	2.66	1.21	-0.19	-0.22	+0.19	+0.70	-0.54	-0.06
Minmi Creek	5.19	5.06	-0.16	-0.59	+0.16	+0.57	-0.26	+0.12

9. Groundwater Accounting and Water Sharing Plan

9.1 Licensing

A water licence is required under either the *Water Act 1912* or the *Water Management Act 2000* (unless an exemption applies) where any aquifer interference activity causes:

- The removal of water from a water source;
- The movement of water from one part of an aquifer to another part of an aquifer; and
- The movement of water from one water source to another water source.

9.1.1 Licensing Under the *Water Act 1912*

In water sources where WSPs do not yet apply, a water licence is required under the *Water Act 1912*. Within the Abel Underground Mine area, the fractured rock aquifer system in the coal measures is such a water source.

This water licence would authorise both the taking of a volume of water from the aquifer and the work or activity that causes this water to be taken. Conditions relating to the management of aquifer interference activities would therefore be placed on the water licence itself.

As the aquifer interference activity is taking groundwater (through the occurrence of mine inflows), a water licence is required under Part 5 of this Act. In Section 7.8.2, it was determined that the predicted maximum average rate of mine inflows will be 6.3ML/day, occurring between July 2015 and June 2016. Donaldson Coal would therefore require a 2304ML/yr volume water licence to account for these inflows.

9.1.2 Licensing Under the Water Management Act 2000

Aquifer interference activities occurring in those water sources where WSPs have commenced under the WM Act 2000 require a water access licence, except where exempt under other legislation or through an Aquifer Interference Regulation.

Where aquifer interference activities induce (take) flow from connected surface water sources, separate access licences are required to account for the take from all individual water sources. The predicted maximum loss of baseflow in specific watercourses during the Approved and Modification operations, as well as post-mining operations, is provided in Table 9.1.

Table 9.1: Predicted Maximum Baseflow Loss

Water Sharing Plan	Management Zone/ Groundwater Source	Predicted Maximum Annual Inflow Volumes (ML/annum)		
		Currently Approved	Change due to the Modification	Modification (Total)
HUAWSP	Wallis Creek Water Source	0.04	(+) 0.15	0.19
	Newcastle Water Source	11.40	(-) 0.01	11.39
Water Act (1912)	Fractured Rock	N/A	N/A	2,304

Donaldson Coal may require unregulated river access licences in the Wallis Creek and Newcastle Water Sources.

If licensed entitlements already held are insufficient, additional entitlements would be obtained by Donaldson Coal.

9.2 Aquifer Interference Approval

Under the WM Act 2000, an aquifer interference activity requires:

- The necessary volumetric water access licences; and
- A separate aquifer interference approval.

An aquifer interference approval confers a right on its holder to carry out specified aquifer interference activities at a specified location or area.

Aquifer Interference approvals are being rolled out across the State under the WM Act 2000. It is understood that the first stage of the roll out will require aquifer interference activities in groundwater that is covered by the WM Act 2000 and underlies Biophysical Strategic Agricultural Land to hold an aquifer interference approval, unless the activity is exempt.

Biophysical Strategic Agricultural Land is defined by Strategic Regional Land Use Plans. The *Upper Hunter Strategic Regional Plan* has been finalised and was released on the 11 September 2012. Review of the Plan suggests that the Abel Underground Mine area lies just outside its extent. This indicates that the “gateway process” of assessment for approval will not be applicable, as it only applies to State significant development applications for mining on Strategic Agricultural Land.

The second stage of the roll out will address the aquifer interference approval requirements for activities in groundwater that does not underlie Biophysical Strategic Agricultural Land.

9.3 Compliance with the Water Sharing Plan

The Modification lies within the Wallis Creek Water Source and Newcastle Water Source of the Hunter Extraction Management Unit under the HUAWSWSP (see Figure 9.1), and is predicted to cause small impacts on surface water baseflows within these water sources.

The WM Act 2000 provides for a system of assessment and licensing and approvals relating to the equitable take of water from water sources, in addition to works and activities occurring within or affecting these water sources. The HUAWSWSP sets out Water Sharing Rules that operate under these water management principles. The Water Sharing Rules that pertain to the Wallis Creek and Newcastle Water Sources are provided in Table 9.2.

Table 9.2: Water Sharing Rules

Subject	Wallis Creek Water Source	Newcastle Water Source
Total surface water entitlement	492ML/yr	551ML/yr
Total groundwater entitlement	0 unit shares/yr	0 unit shares/yr
Access Rules		
Cease to Pump	Existing licence conditions remain for the first five years. From year six of the plan, cease to pump is when there is either no visible inflow to, or outflow from, the pumping pool. From year six of the plan the cease to pump condition will apply to aquifer access licences extracting from all alluvial aquifers within 40m of the unregulated river, except for existing Domestic and Stock access licences and Local Water Utilities Access licences.	
Reference Point	Riffles upstream and downstream of the pump.	
Trading Rules		
Trading INTO the water source	Permitted, subject to assessment, if the trade will not increase the total licensed entitlement for the water source (no net gain*).	Not permitted.
Trading WITHIN the water source	Permitted, subject to assessment.	
Conversion to High Flow Access Licence	Not permitted.	

Subject	Wallis Creek Water Source	Newcastle Water Source
Conversion to Aquifer Access Licence	Not permitted.	

* 'No net gain' trades means that a trade cannot increase entitlement in a water source to a level above that at the start of the Plan.

These rules apply to all surface waters in these water sources, as well as the alluvial groundwater that is highly connected to the surface waters. The Modification will take these rules into consideration prior to, and during operations.

The HUAWSWSP also sets out management rules for the operation of aquifer interception activities. The management rules that pertain to the Wallis Creek and Newcastle Water Sources are provided in Table 9.3.

Table 9.3: Management Rules for Aquifer Interception Activities

	Rule	Applicable Water Source
To minimise interference between neighbouring bores	New activities are not to be located within 400m from an access licence bore.	Both
	New activities are not to be located within 200m from a Basic Landholder Right bore.	
	New activities are not to be located within 50m from the boundary (unless negotiated with neighbour).	
	New activities are not to be located within 500m from a local or major water utility bore (or as otherwise assessed).	
	New activities are not to be located within 400m from departmental monitoring bore (unless negotiated with the department).	
Granting of bores near GDEs	Activities are not to be located within 100m of high priority GDEs (non Karst) for bores used for extracting Basic Landholder Rights	Both
	Activities are not to be located within 200m of high priority GDEs (non Karst) for all other activities requiring an aquifer access licence	
	Activities are not to be located where there is likely to be drawdown at the outside edge of the buffer zones referred to above.	
	Activities are not to be located within 500m of karsts.	
	Activities are not to be located within the bed of the river, unless assessment indicates that work will have minimal harm on the river environment or stability.	
	These rules do not apply to works for monitoring, environmental management purposes or remedial work.	
	The distances from GDEs may be varied for an applicant if a hydrogeological study is undertaken which demonstrates no drawdown of the groundwater at the outside edge of the GDE listed in the Plan.	
	These specified distances may be amended, or high priority GDEs identified within the Plan may be added or removed, based on further studies of groundwater ecosystem dependency undertaken by the Minister.	
Temporary local impact area rules for managing quality and maintaining groundwater levels	In order to protect water quality and maintain groundwater levels within this groundwater source, local restrictions may be applied.	Both

Within the Newcastle Water Source, there are sensitive environmental areas classified under Part 9 Section 41(1) of the HUAWSWSP that are located adjacent to, or nearby the Modification (refer to Figure 9.1). These High Priority Groundwater Dependent Ecosystems are listed in Schedule 4 of the WSP, and are associated with Pambalong Nature Reserve, Hexham Swamp and Woodberry Swamp (refer to Section 4.10). However, as SEPP 14 Coastal Wetlands 828b (associated with Woodberry Swamp) is some distance north-east of the Modification, and the mine plan has been designed in such a way that only first workings are employed in areas underlying alluvium associated with remaining High Priority GDEs, the proposed Modification is not anticipated to have an impact on the alluvial aquifer and as such an aquifer access licence is not required.

Aside from other Donaldson Coal operations, there are no other licensed users within 200m of the proposed Modification (as prescribed under Part 9 Section 39(1)). The Modification will take the additional rules into consideration prior to and during operations, being incorporated into the Groundwater Management Plan (GWMP) for the Modification.

Accordingly, it is considered that the Modification is consistent with the provisions of the HUAWSWSP.

10. MONITORING AND MANAGEMENT

10.1 Impacts of Groundwater Extraction / Dewatering

The groundwater system in the vicinity of all Donaldson projects is already being closely monitored as part of the ongoing underground and open cut mining activities, as detailed in the site GWMP for each operation. It is recommended that the current GWMP for the existing Approved Abel Underground Mine be amended to incorporate the Modification.

In addition, the monitoring network at the Abel Underground Mine should be maintained and expanded, and would include:

- Monitoring of the inflow rate and water quality (EC, TDS and pH) of groundwater inflows;
- Regular monthly measurement of groundwater levels/pressures within all vibrating wire piezometers and standpipes;
- Quarterly sampling of all standpipe piezometers, for laboratory analysis of EC, TDS and pH;
- Annual collection of water samples from all standpipe piezometers for laboratory analysis of a broader suite of parameters including physical properties (EC, TDS and pH), major cations and anions, nutrients and dissolved metals; and
- Installation of additional regional monitoring piezometers in the following areas to resolve some of the existing hydrogeological uncertainties and to provide a more comprehensive monitoring network near the sensitive ecosystems, as recommended in PDA (2006):
  - Multi-level piezometers to the north and west of Pambalong Nature Reserve, to provide additional data on groundwater pressures in the intervening strata between the Donaldson seams and the alluvium (supplementing the existing data from piezometers C081A and B and C082);
  - Multi-level piezometers along the eastern side of the Modification, located at nominally 3 sites between the F3 Freeway and the lease boundary, to resolve the apparent anomalous water levels below sea level at C063A and B, and to provide additional data on groundwater pressures in the intervening strata between the Donaldson Seams and the Hexham Swamp alluvium; and
  - Multi-level piezometers near the western and southern boundaries of the Modification to provide information on groundwater pressures at various depths, as this area currently lacks monitoring points. These piezometers would also aim to provide information on the current status of groundwater in the West Borehole seam near the former workings, prior to mining of the Donaldson Seams approaching that area.

10.2 Subsidence Impact Monitoring

A comprehensive monitoring program is recommended to investigate the subsidence impacts as they develop above initial extraction panels. This monitoring will provide definitive information on the behaviour of the rock strata from subsidence, and will provide more reliable data on which to base the changes to hydraulic conductivities resulting from subsidence fracturing. This will enable the groundwater model to be recalibrated and used to improve the certainty of forward inflow predictions and resulting impacts, before inflows lead to potentially significant water excess.

Some multi-level vibrating wire piezometers are already in place to enable ongoing monitoring. Additional multi-level vibrating wire piezometers are recommended to be installed, particularly in the southern section of the Abel Underground Mine area where multi-seam mining is proposed. Monitoring of these facilities would be conducted in conjunction with the subsidence monitoring recommended by MSEC (2012).

10.3 Review and Reporting

The existing Abel Underground Mine GWMP should be updated to reflect the above monitoring recommendations, as well as the management rules outlined in the HUAWSWSP. As detailed within the existing GWMP, as part of the mine's Annual Environmental Management Report, collated monitoring data should be subjected to an annual review by an approved, experienced hydrogeologist in order to assess the impacts of the Modification on the groundwater environment, and to compare any observed impacts with those predicted from groundwater modelling.

It is also recommended that, in accordance with industry best practice (MDBC, 2001 and Barnett *et al.* 2012) a modelling post-audit should be carried out two years after the commencement of the Modification mining operations. Following this review, if necessary, the groundwater model would be re-run in transient calibration mode, to verify that the actual inflow rates and groundwater level impacts are in accordance with the model predictions described in this report. If necessary, further adjustment would be made to the model at that time, and new forward predictions of mine inflows and water level impacts would be undertaken.

Further post-audits should be carried out at five-yearly intervals throughout the remainder of the Modification, and at any other time should inflows or impacts vary significantly from predictions.

Should any review or post-audit indicate a significant variance from the model predictions with respect to water quality or groundwater levels, then the implications of such variance should be assessed, and appropriate response actions implemented in accordance with the protocols described in the GWMP.

10.4 Recommendation for Development of Response Plans

Trigger Action Response Plans (TARPs) have already been developed as part of the existing Abel Underground Mine GWMP. These should be reviewed to include the issues specified above relating to the Modification.

Notwithstanding that secondary extraction is not proposed directly beneath the watercourses that overlie the Abel Underground Mine area, it is recommended that, in addition to these environmental TARPs, specific operational responses to any connective cracking through the alluvium above the Modification within these drainage lines should be implemented to minimise the risk of water entering the underground workings following periods of sustained rainfall.

If monitoring indicates that connective cracking has occurred, then the triggers discussed within the design section of this EA should be followed.

11. CONCLUSIONS

The groundwater investigations carried out for the Modification have led to the following principal conclusions:

- Groundwater levels in the Permian coal measures including the Donaldson Seams generally fall to the east and west from a central ridge extending south from the Donaldson Open Cut Mine area, and range from around 35mAHD near the central northern end of the Abel Underground Mine area to around 10 to 15mAHD along the eastern boundary, and around 15 to 20m at the north-western corner. The groundwater levels in the Permian coal measures are unrelated to the local topography, and are frequently artesian (i.e. above ground level) in low-lying areas;
- Surficial groundwater levels in the alluvium/colluvium, and including the thin upper highly weathered zone of the Permian coal measures are strongly controlled by the local topography, and appear to be unrelated to the groundwater in the underlying less weathered Permian coal measures. Thus the surficial groundwater water levels are above the Permian groundwater levels in elevated locations and below the Permian levels in low-lying areas;
- The dewatering operations at the Donaldson Open Cut Mine have caused a noticeable cone of drawdown in groundwater levels, ranging up to more than 30m (i.e. to around –15mAHD) along the southern margin of the open cut. The cone of drawdown has extended only a short distance into the north-eastern part of the Abel mining lease area;
- Operations to date in the Donaldson Open Cut and Abel Underground Mines appear to have had negligible impact on groundwater levels in the alluvium/colluvium, or in the Permian coal measures lithologies that are stratigraphically above the zones that have been directly intersected by the open cut and underground;
- Groundwater quality is variable, with salinity ranging from around 500mg/L to more than 13,000mg/L TDS. pH is generally close to neutral;
- The majority of the area above the Abel Underground Mine either drains towards Hexham Swamp to the east, via Long Gully and Blue Gum Creek, or Woodberry Swamp to the north-east via Weakleys Flat Creek and Viney Creek. Other portions of the Abel Underground Mine area are located in the ephemeral headwaters of Four Mile Creek and Buttai Creek;
- Dewatering will be required as part of the Modification. Groundwater inflows have been predicted, based on the most likely set of assumed hydraulic parameters. The total groundwater inflow rate is predicted to reach a maximum of 6.3ML/day in mid-2015;
- Sensitivity and uncertainty analysis modelling suggests that the maximum inflow rates could be between about 5.4 and 6.5ML/day;
- Initial average water quality of groundwater inflows to the Abel underground mine is expected to be similar to that currently entering the Donaldson open cut, with TDS around 1500 to 2000mg/L with a neutral pH of around 7. Over time, a steady increase in salinity may occur, to an eventual salinity of around 3000 to 4000mg/L TDS;
- There is believed to be negligible hydraulic interconnection between the Donaldson seams and the Hexham Swamp/Pambalong Nature Reserve. Limited connection was simulated in the groundwater modelling to assess a possible worst case condition. Drawdowns of less than 0.5m at the completion of extraction and post-mining recovery were predicted by the groundwater model for the alluvium adjacent to Pambalong Nature Reserve, and less than 0.1m beneath the main Hexham Swamp region to the east of the F3 freeway. In practice, minimal impact is expected;
- Recovery of groundwater levels after completion of mining have been assessed by 100 years of post-mining simulation. Pressure heads in the Donaldson Seam in the vicinity of the Modification are shown to remain significantly depressurised across the Abel Underground Mine area. However, the residual drawdown for the Modified mine plan is generally less than that for the Approved mine plan;
- Only Hexham Swamp and Weakleys Flat Creek have any significant fluxes in terms of river stream leakage or aquifer discharge (baseflow). All other drainages are essentially ephemeral and only flow following periods of sustained rainfall;

- Overall, the Modification is predicted to result in very limited changes to baseflow compared to the approved impacts associated with the Approved mine plan. The only watercourses which exhibit a small reduction in baseflow are Buttai Creek, Viney Creek and Minmi Creek. These reductions generally occur in the post-mining recovery period, and all equate to less than $1m^3$/day;
- Some watercourses exhibit a slight reduction in negative baseflow impacts, when compared to the approved baseflow impacts. During the life of mine, the change in baseflow is positive for Viney Creek. Hexham Swamp and Blue Gum Creek both also exhibit a small reduction of less than $1m^3$/day in baseflow;
- No adverse impacts are expected on any GDEs, including Hexham Swamp;
- No existing groundwater supplies are expected to be impacted;
- Donaldson Coal would review its existing water licences in regard to requirements for water licences under Part 5 of the *Water Act 1912* to account for inflows from the fractured rock aquifer system in the coal measures. Unregulated river access licences within the Wallis Creek and Newcastle Water Sources under the *Water Management Act 2000* to account for take from surface water sources may also be required. If licensed entitlements already held are insufficient, these excess entitlements would have to be purchased on the water market; and
- It is considered that the Modification is consistent with the provisions of the HUAWSWSP.

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FIGURES

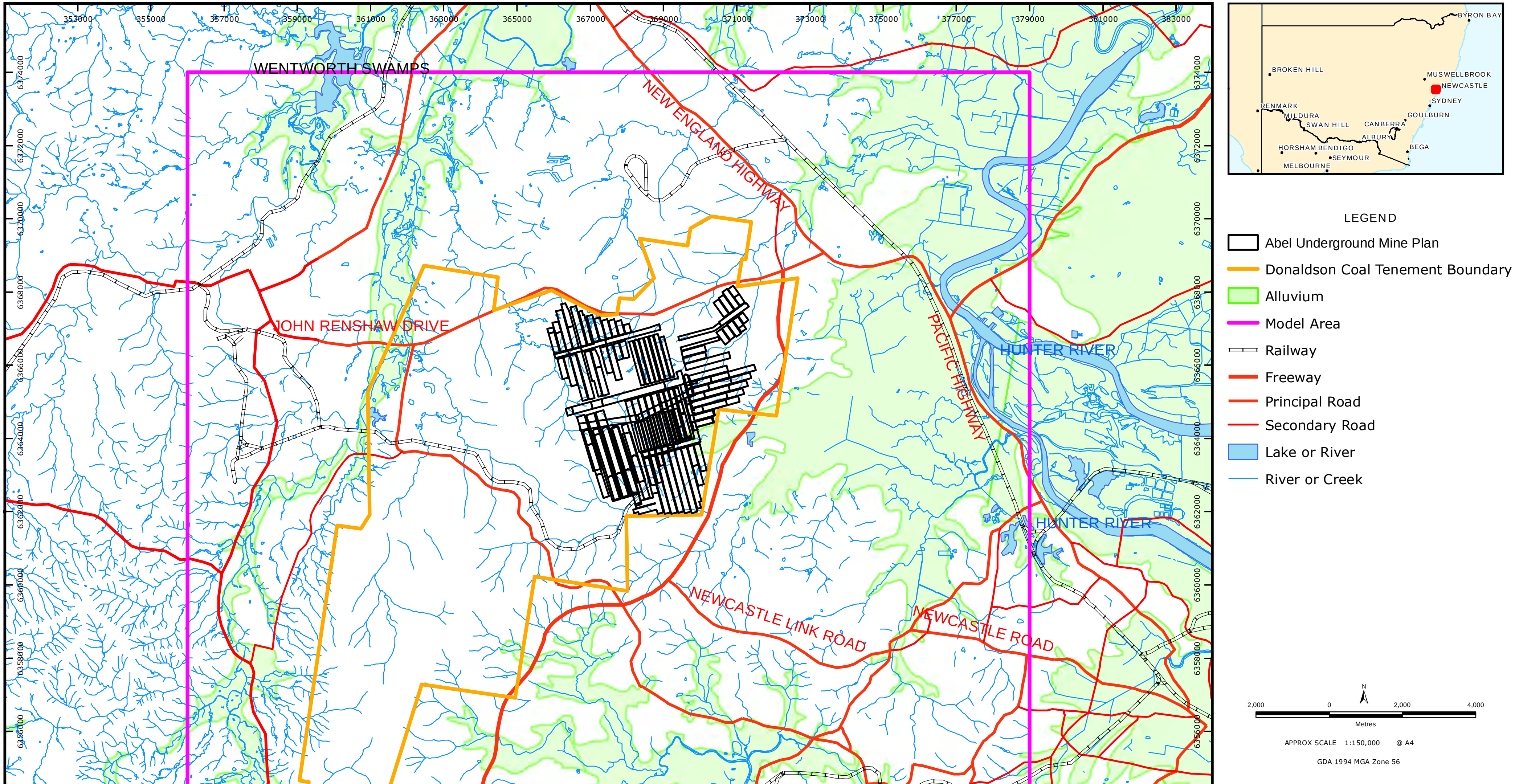

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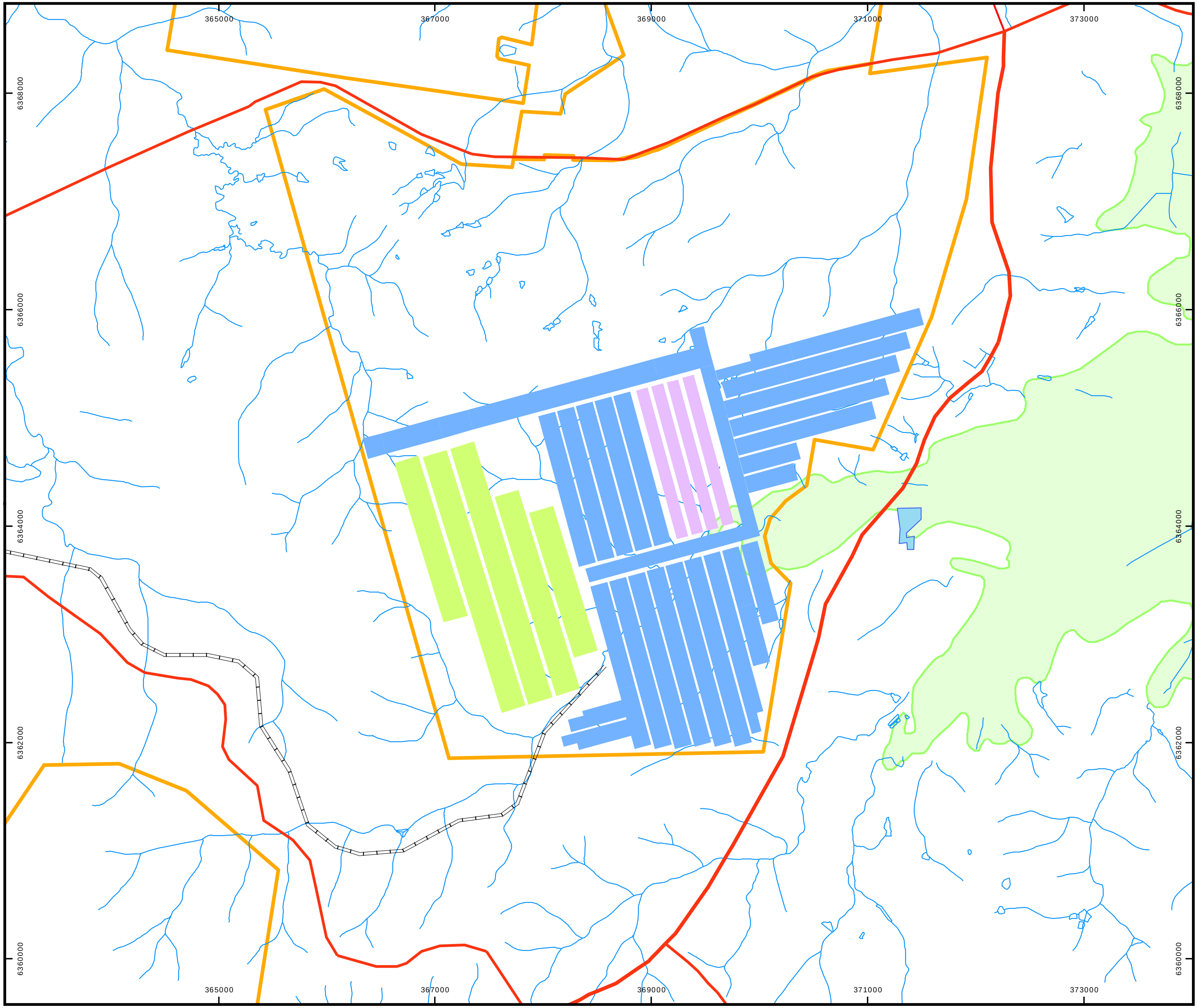
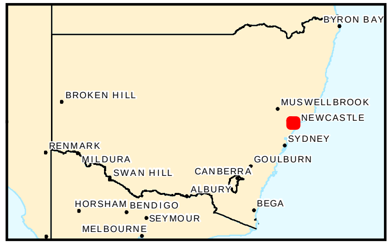
FIGURE 1.1

General Location

S64_002 Rev: A Produced: HZ Reviewed: KB Date: 10/04/2012





LEGEND

- Bord and Pillar Mining
- Longwall
- Shortwall
- Mine Lease
- Railway
- Freeway
- Principal Road
- Secondary Road
- Lake or River
- River or Creek
- Alluvium

N

500 0 500 1,000

Metres

APPROX SCALE 1:50,000 @ A4

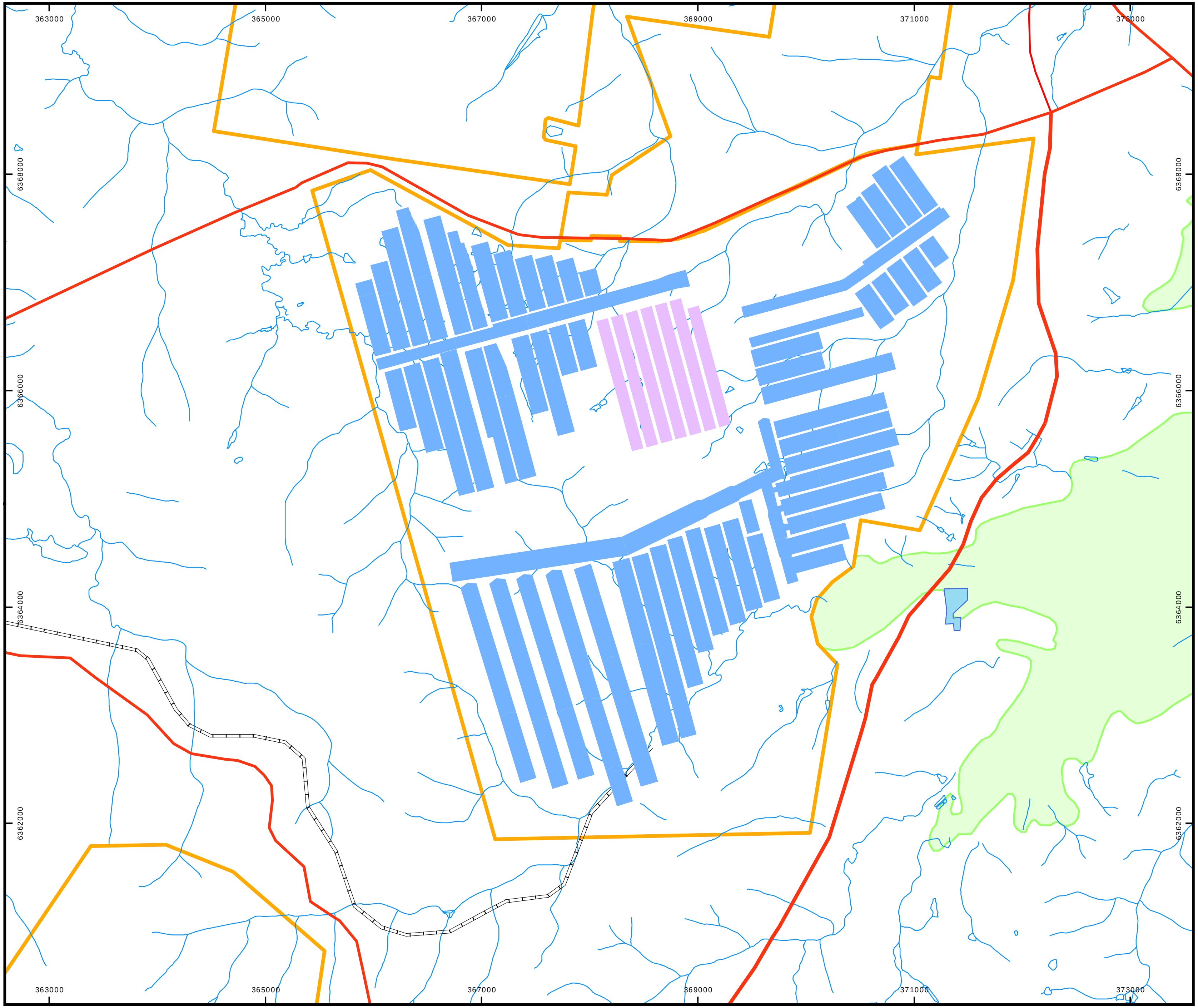
GDA 1994 MGA Zone 56

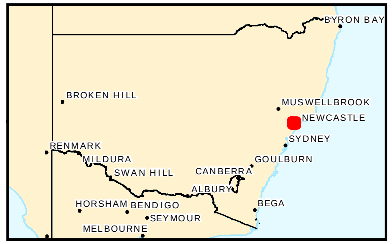
RPS Aquaterra

FIGURE 1.2

Proposed Mine Layout - Lower Donaldson Seam

S64DD_004a Rev: A Produced: HZ Reviewed: KB Date: 10/08/2012





LEGEND

- Bord and Pillar Mining
- Shortwall
- Railway
- Freeway
- Principal Road
- Secondary Road
- Lake or River
- River or Creek
- Mine Lease
- Alluvium

N

500 0 500 1,000

Metres

APPROX SCALE 1:50,000 @ A4

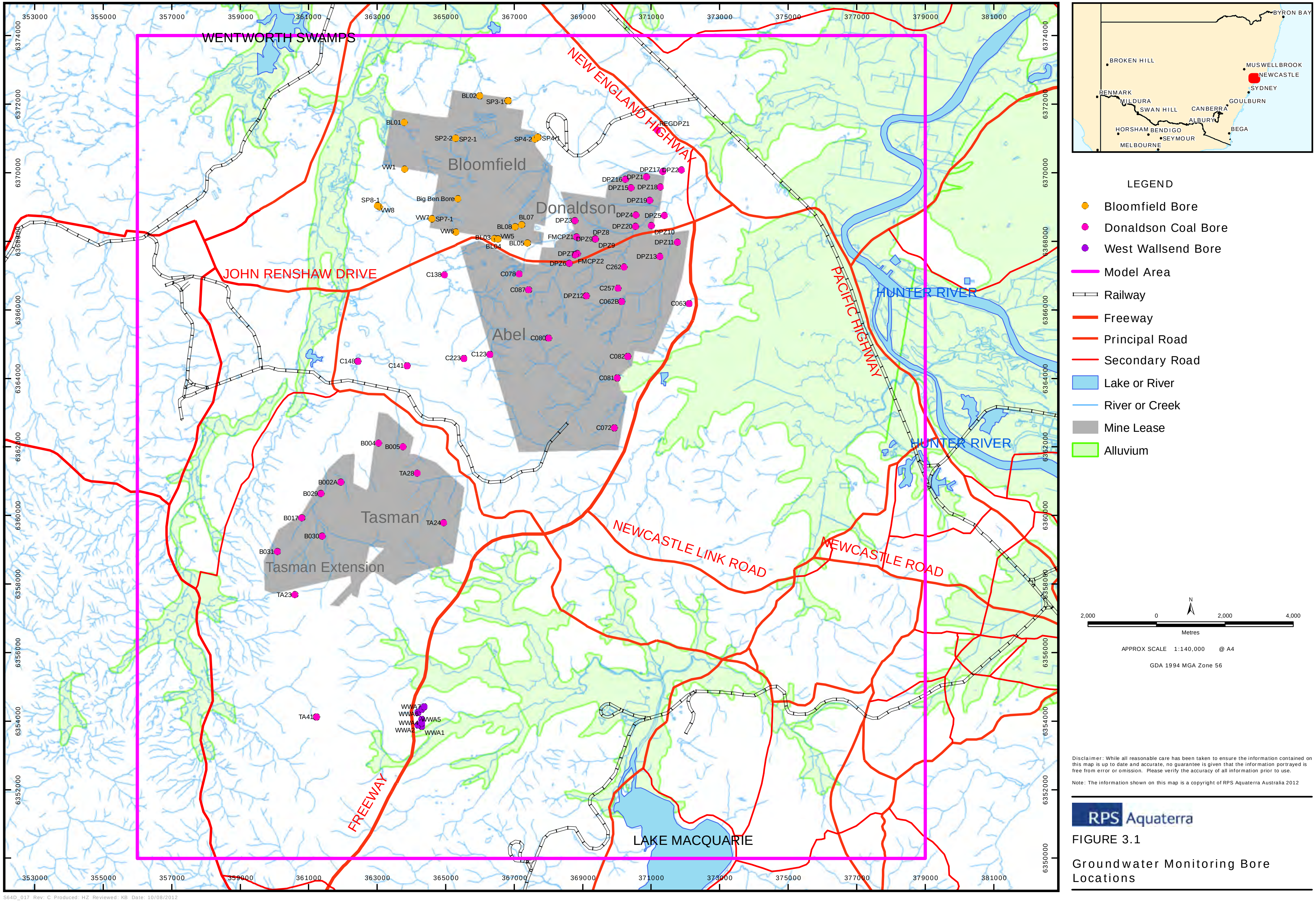
GDA 1994 MGA Zone 56

RPS Aquaterra

FIGURE 1.3

Proposed Mine Layout - Upper Donaldson Seam

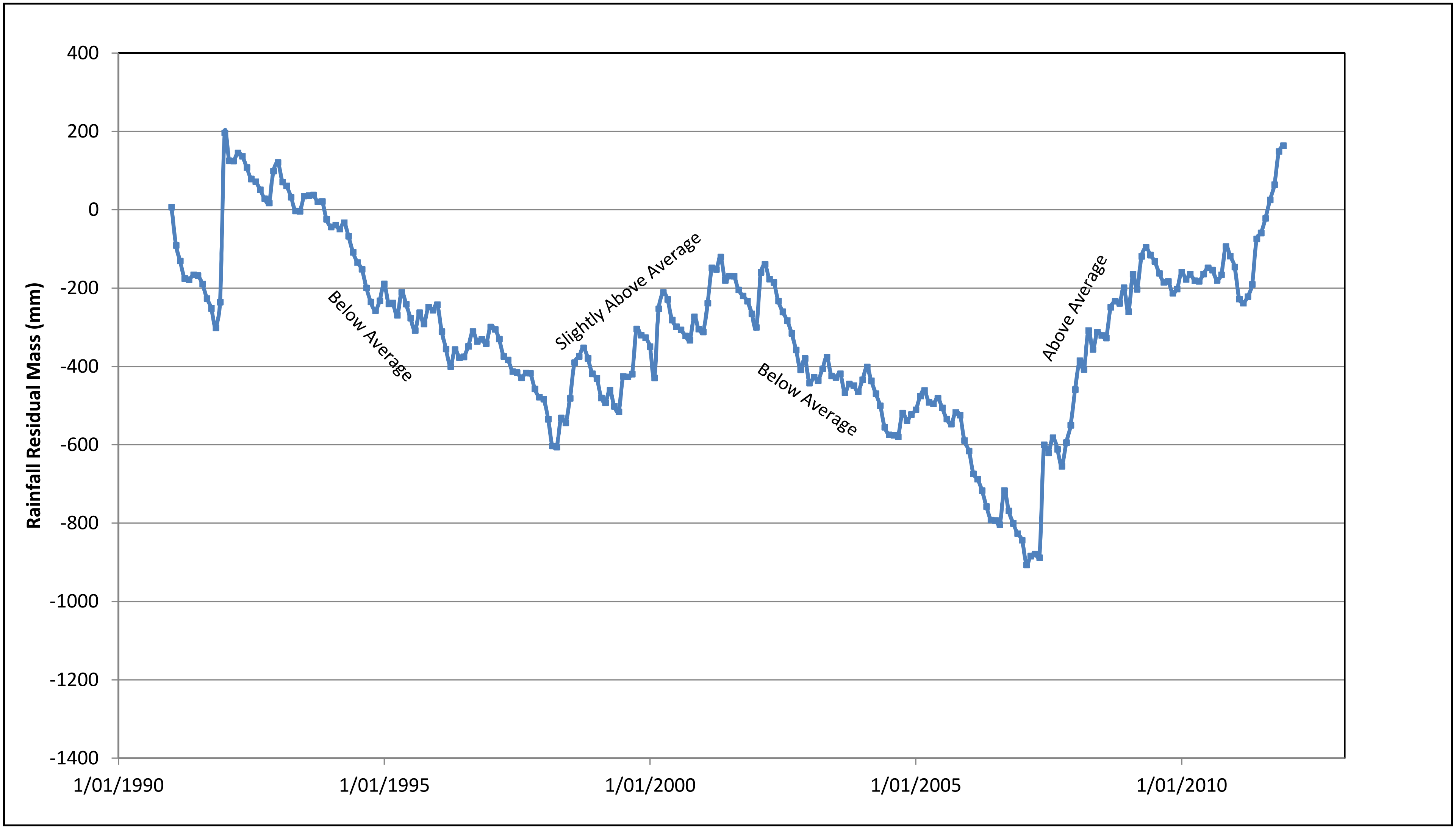
S64_003 Rev: A Produced: HZ Reviewed: KB Date: 10/04/2012



RPS Aquaterra

FIGURE 3.1

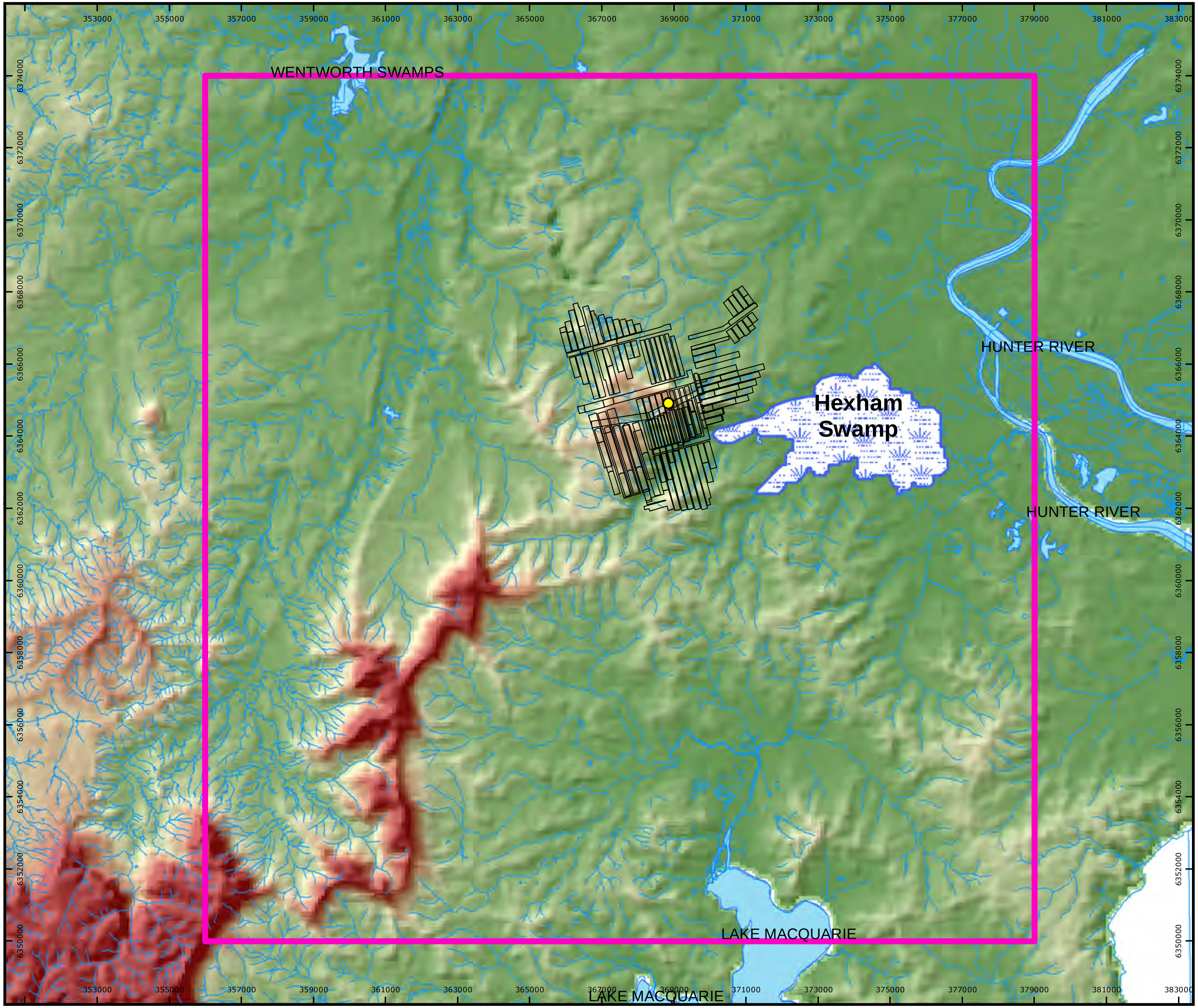
Groundwater Monitoring Bore Locations

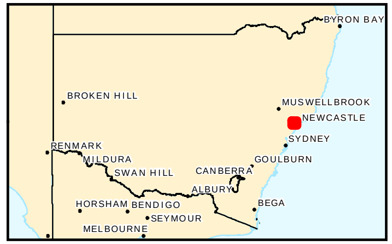


Rainfall Residual Mass Curve - Cessnock FIGURE 4.1

F:\Jobs\S64D\300\Rainfall\[Rainfall Residual Mass CurveCessnock v2 GS.xlsx]F4.1

RPS Aquaterra





LEGEND

Model Area

Abel Underground Mine Plan

Hexham Swamp

River or Creek

Regional Topography

High : 640

Low : -20

Black Hill

2,000 0 2,000 4,000

Metres

APPROX SCALE 1:150,000 @ A4

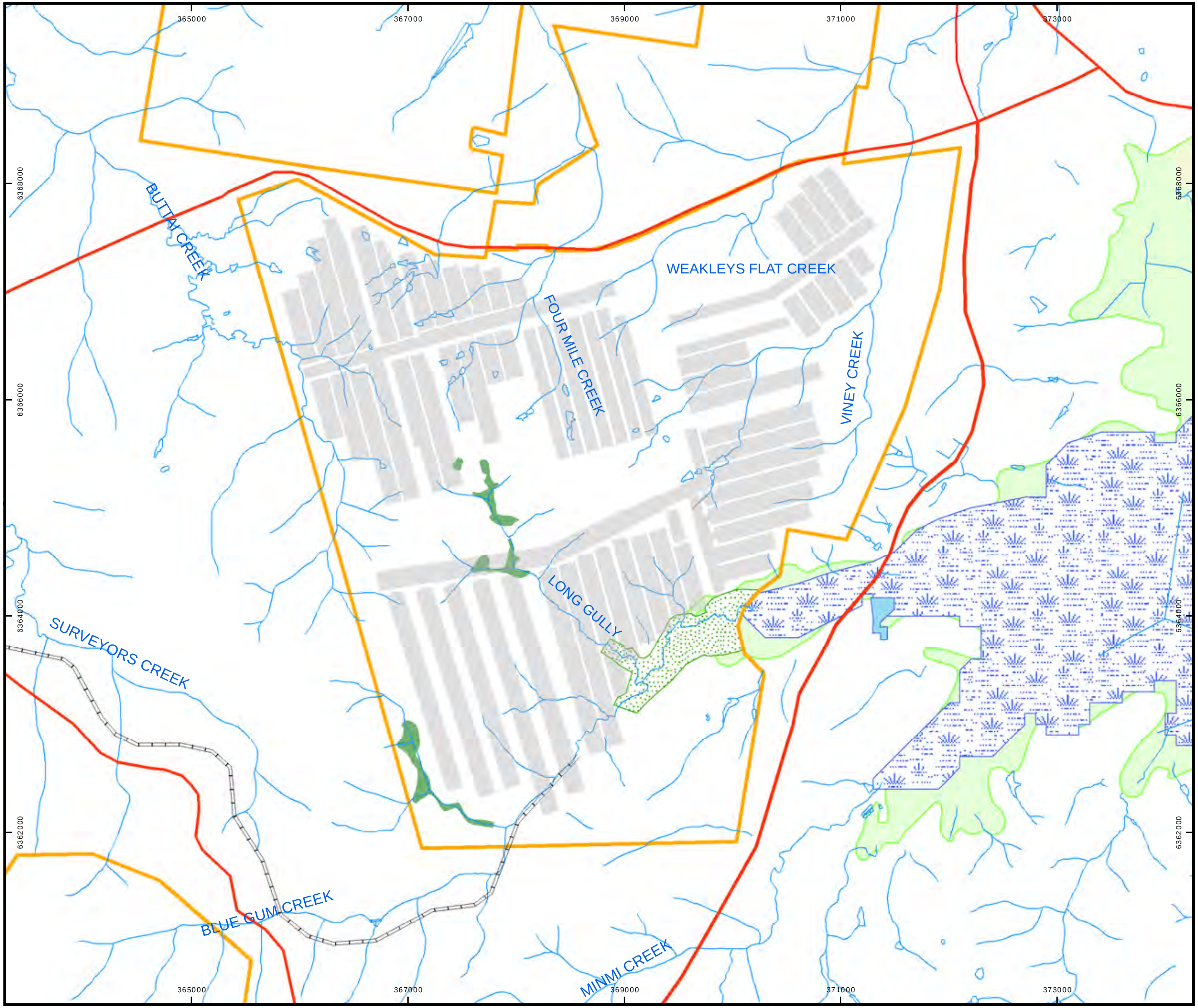
GDA 1994 MGA Zone 54

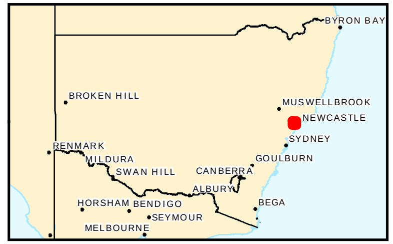
RPS Aquaterra

FIGURE 4.2

Regional Topography

S64_006 Rev: A Produced: HZ Reviewed: KB Date: 10/04/2012





LEGEND

- Abel Underground Mine Plan- Upper Donaldson
- Mine Lease
- Alluvium
- Hexham Swamp
- Rainforest
- Alluvium- Blue Gum
- Railway
- Freeway
- Principal Road
- Secondary Road
- Lake or River
- River or Creek

N

500 0 500 1,000

Metres

APPROX SCALE 1:50,000 @ A4

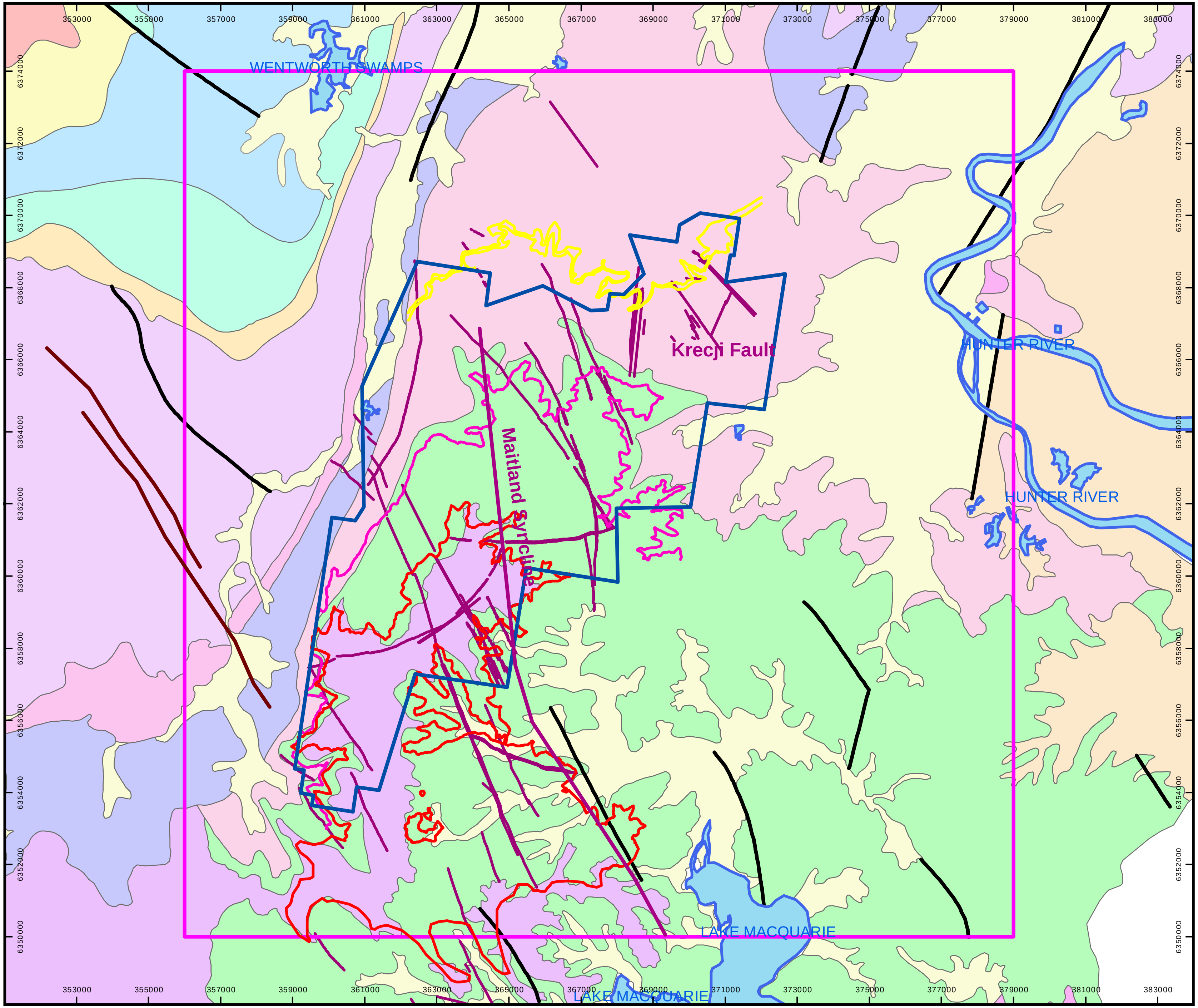
GDA 1994 MGA Zone 56

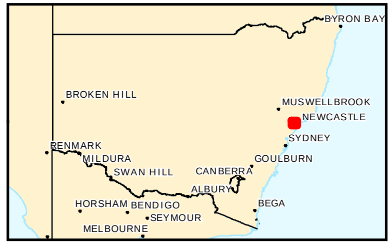
RPS Aquaterra

FIGURE 4.3

Surface Water Features Within the Project Area

S64_005 Rev: A Produced: HZ Reviewed: KB Date: 10/04/2012





LEGEND

- Donaldson Seam Outcrop (Upper & Lower)
- West Borehole Seam Outcrop
- Fassifern Seam Outcrop
- Donaldson Coal Tenement Boundary
- Model Area
- Lake or River
- Fault
- Allandale Formation
- Branxton Formation
- Farley Formation
- Greta Coal Measures
- Lochinvar Formation
- Mulbring Siltstone
- Muree Sandstone
- Narrabeen Group
- Newcastle Coal Measures
- Rutherford Formation
- Tomago Coal Measures
- Alluvium
- Coastal Dunes
- Dunes

N

2,000 0 2,000 4,000

Metres

APPROX SCALE 1:150,000 @ A4

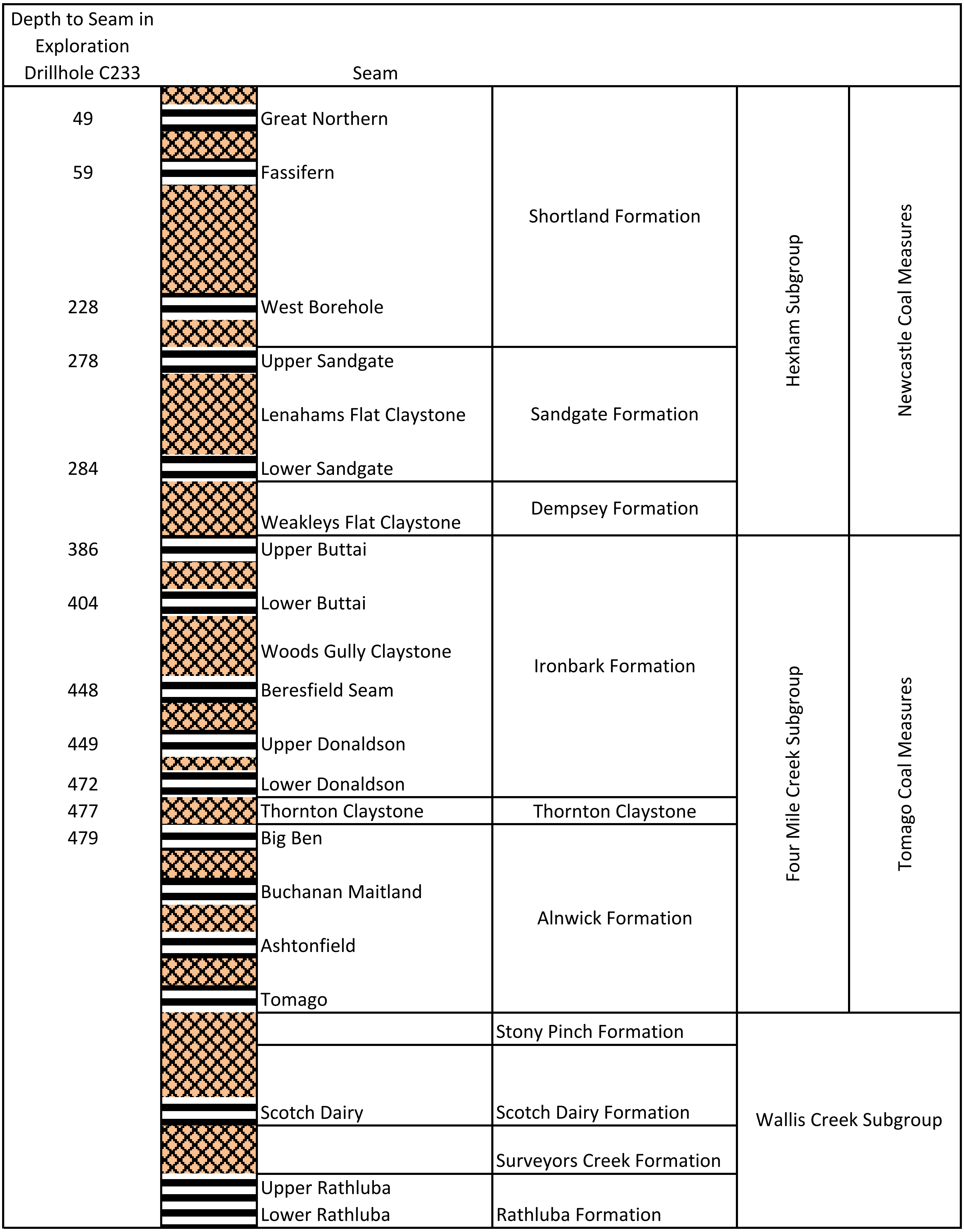
GDA 1994 MGA Zone 56

DATA SOURCES
Geoscience Australia (Geology Map)
Donaldson Coal Pty Ltd (Outcrop Lines)

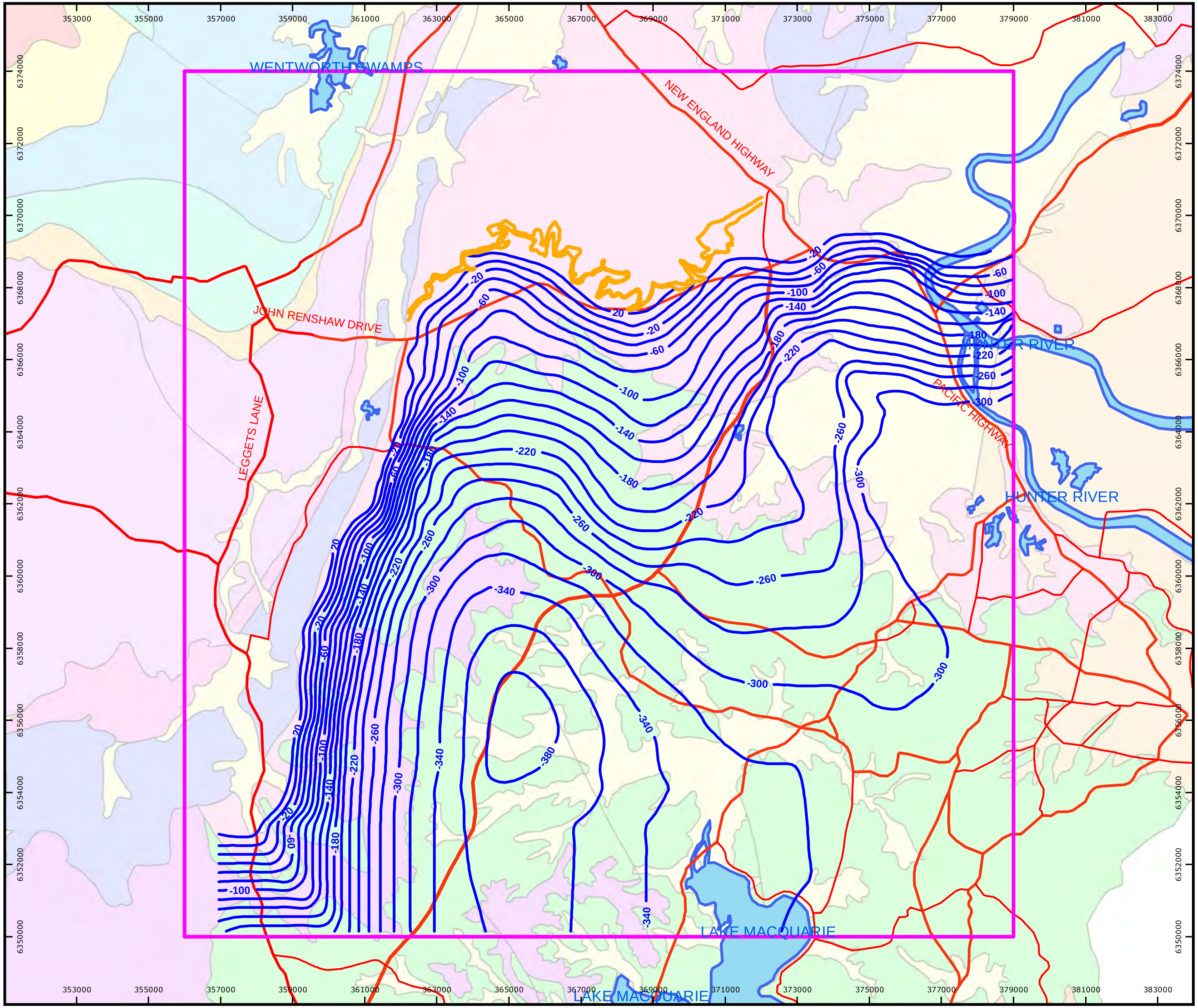
RPS Aquaterra

FIGURE 4.4

Regional Geology



(after Brown and Preston, 1985)



LEGEND

- Donaldson Seam Outcrop (Upper & Lower)
- Base of Upper Donaldson Seam (mAHD)
- Model Area
- Freeway
- Principal Road
- Secondary Road
- Lake or River
- Allandale Formation
- Branxton Formation
- Farley Formation
- Greta Coal Measures
- Lochinvar Formation
- Mulbring Siltstone
- Muree Sandstone
- Narrabeen Group
- Newcastle Coal Measures
- Rutherford Formation
- Tomago Coal Measures
- Alluvium
- Coastal Dunes
- Dunes

2,000 0 2,000 4,000
Metres

APPROX SCALE 1:150,000 @ A4

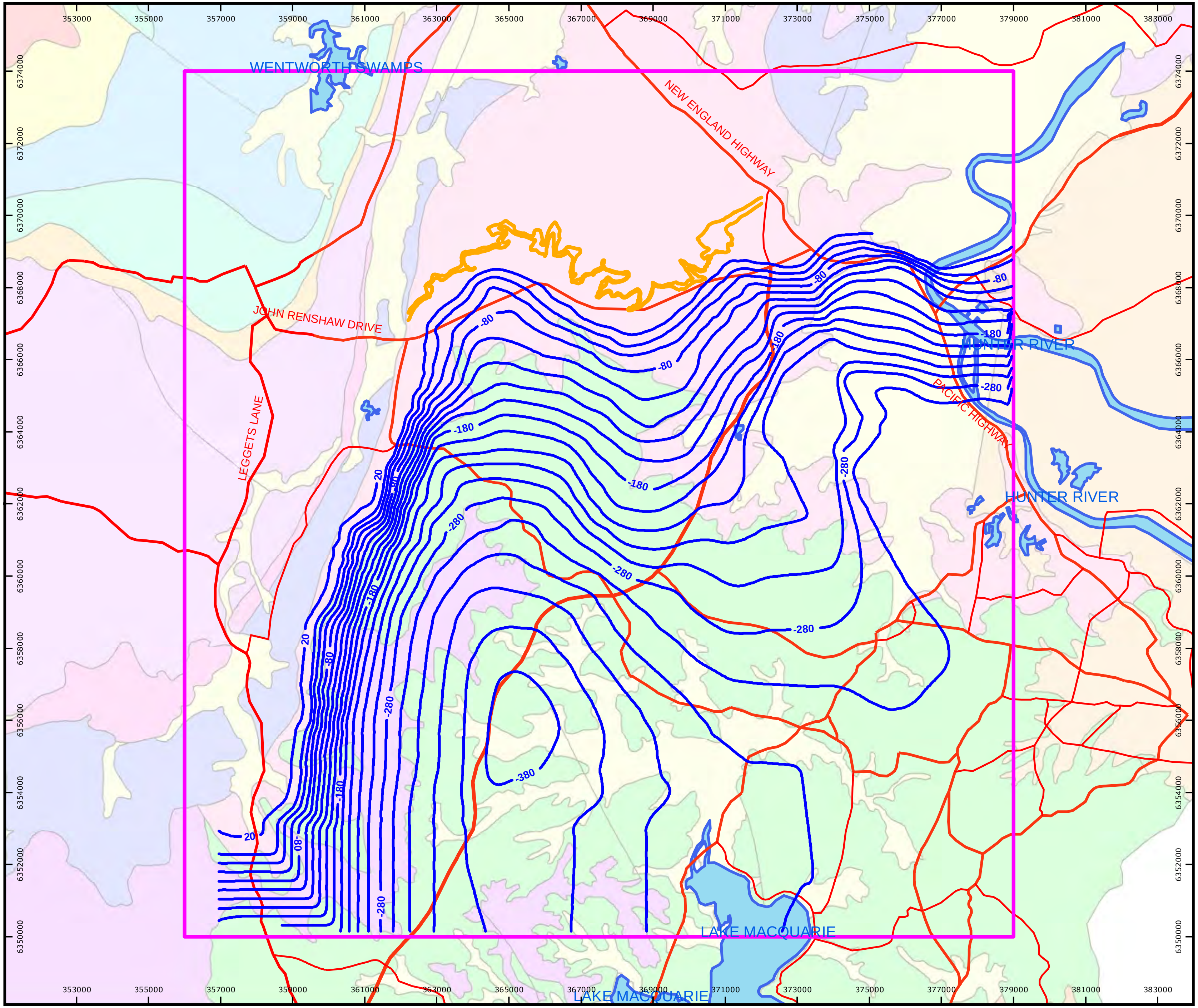
GDA 1994 MGA Zone 56

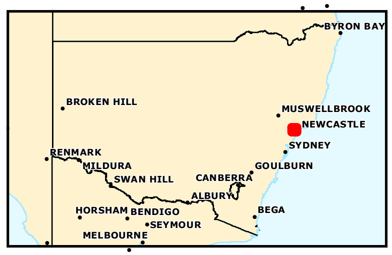
RPS Aquaterra

FIGURE 4.6

Upper Donaldson Seam Geology Structural Contours

S35_008a Rev: A Produced: HZ Reviewed: PD Date: 14/05/2012





LEGEND

- Donaldson Seam Outcrop (Upper & Lower)
- Base of Lower Donaldson Seam (mAHD)
- Model Area
- Freeway
- Principal Road
- Secondary Road
- Lake or River
- Allandale Formation
- Branxton Formation
- Farley Formation
- Greta Coal Measures
- Lochinvar Formation
- Mulbring Siltstone
- Muree Sandstone
- Narrabeen Group
- Newcastle Coal Measures
- Rutherford Formation
- Tomago Coal Measures
- Alluvium
- Coastal Dunes
- Dunes

N

2,000 0 2,000 4,000

Metres

APPROX SCALE 1:150,000 @ A4

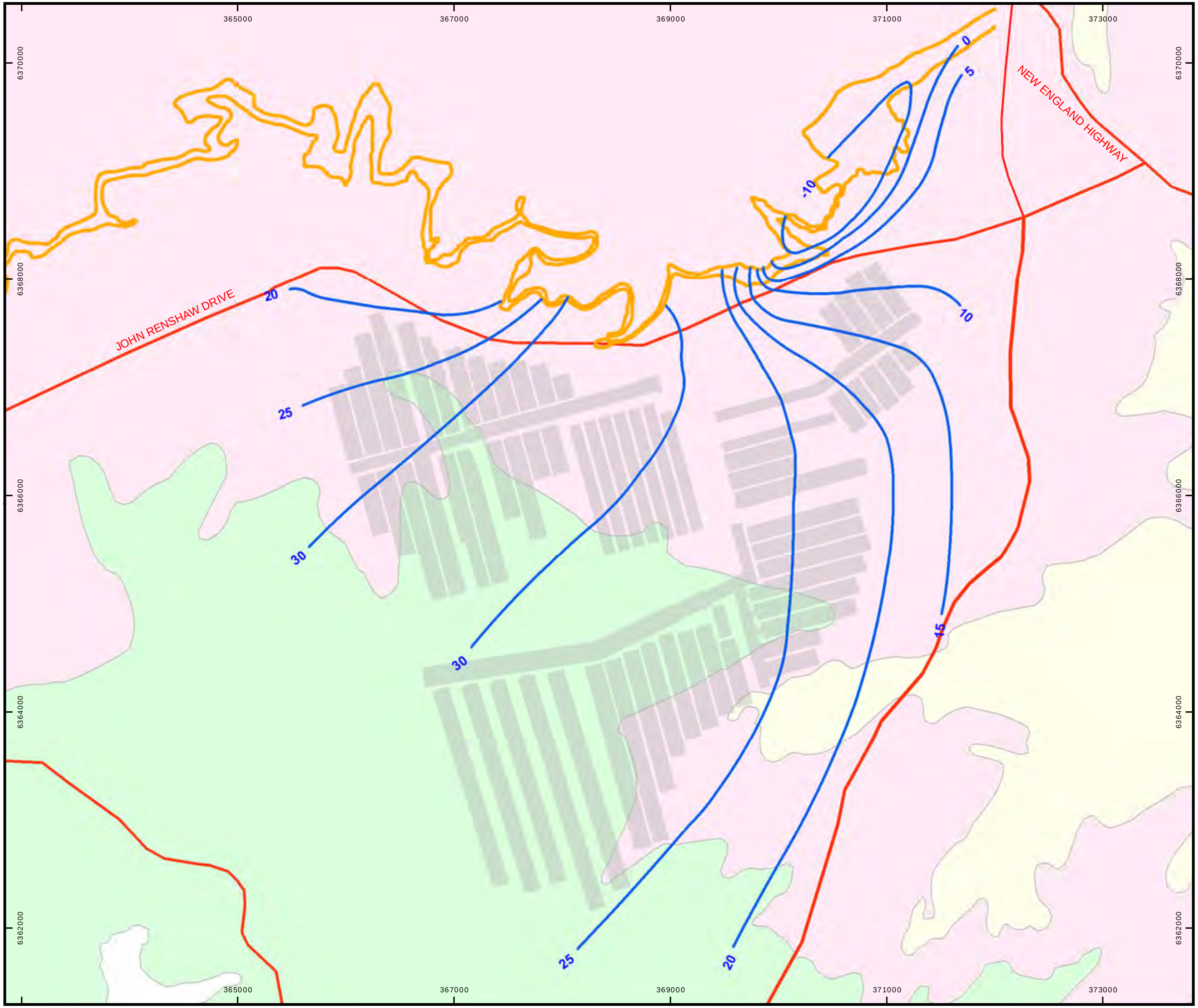
GDA 1994 MGA Zone 56

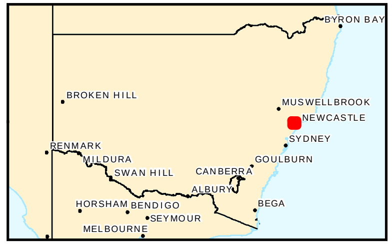
Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Please verify the accuracy of all information prior to use.

RPS Aquaterra

FIGURE 4.7

Lower Donaldson Seam Geology Structural Contours





LEGEND

- Groundwater Contours (mAHD)
- Abel Underground Mine Plan- Upper Donaldson
- Donaldson Seam Outcrop (Upper & Lower)
- Model Area
- Freeway
- Principal Road
- Secondary Road
- Newcastle Coal Measures
- Tomago Coal Measures
- Alluvium

N

500 0 500 1,000

Metres

APPROX SCALE 1:50,000 @ A4

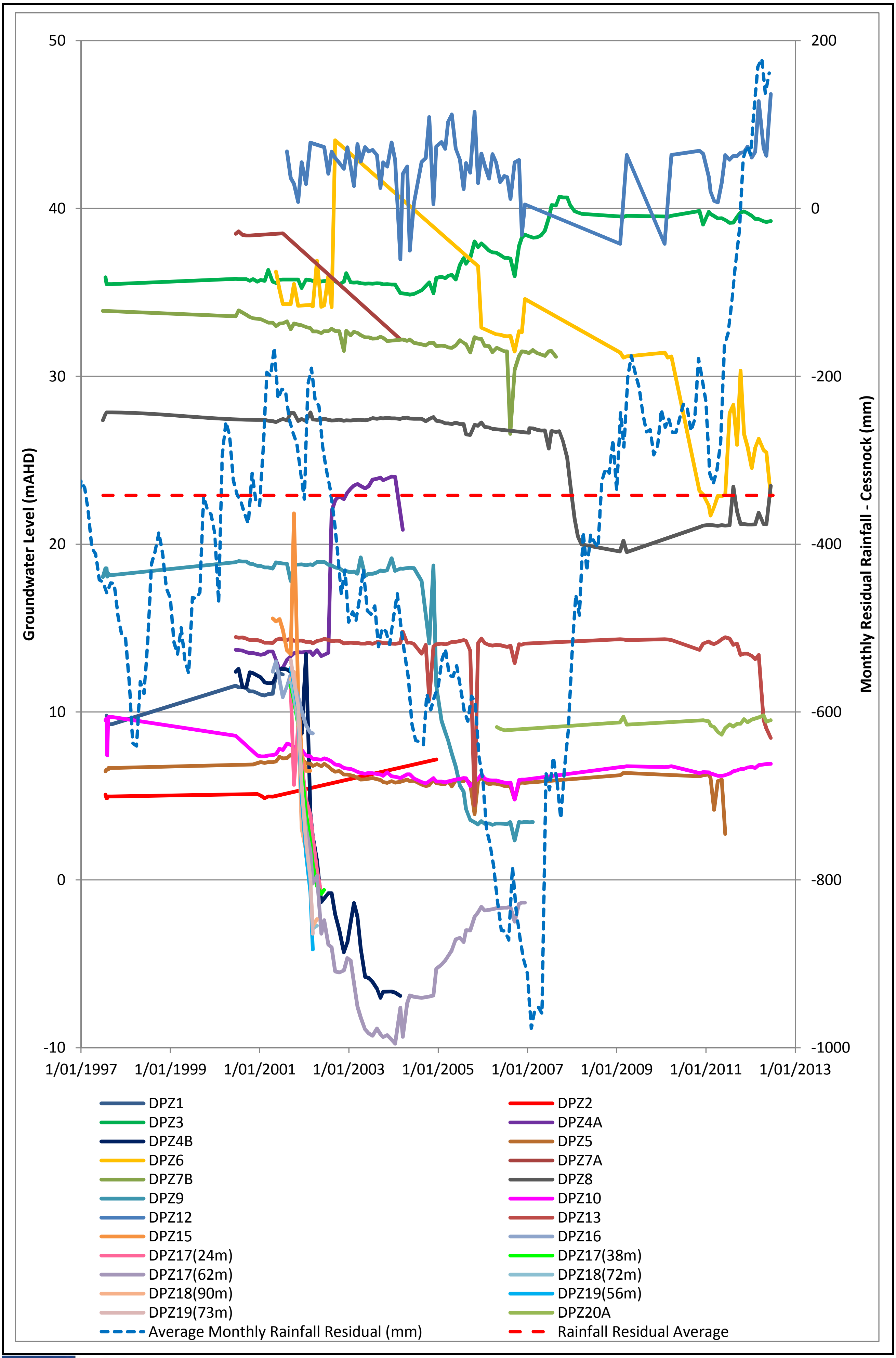
GDA 1994 MGA Zone 56

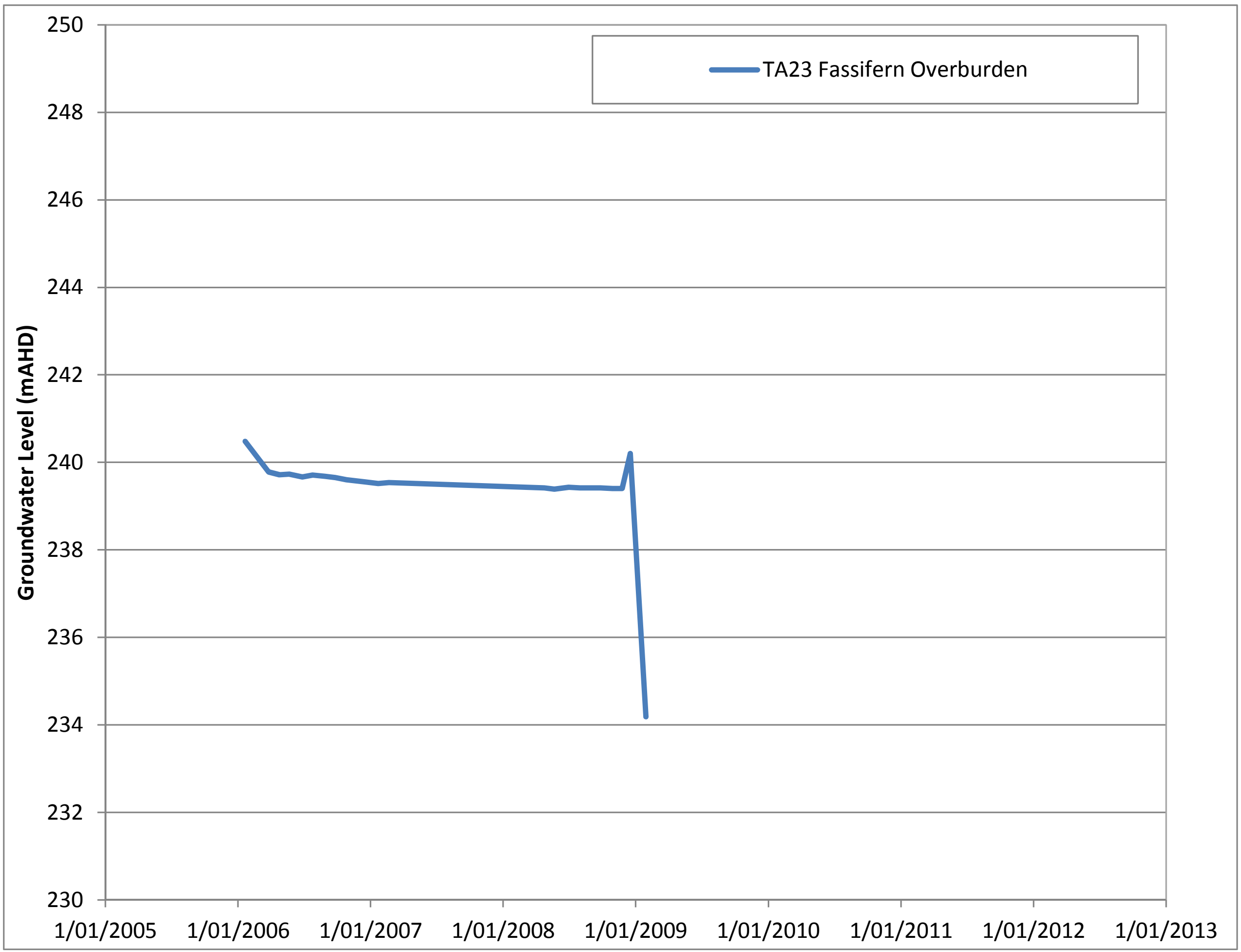
RPS Aquaterra

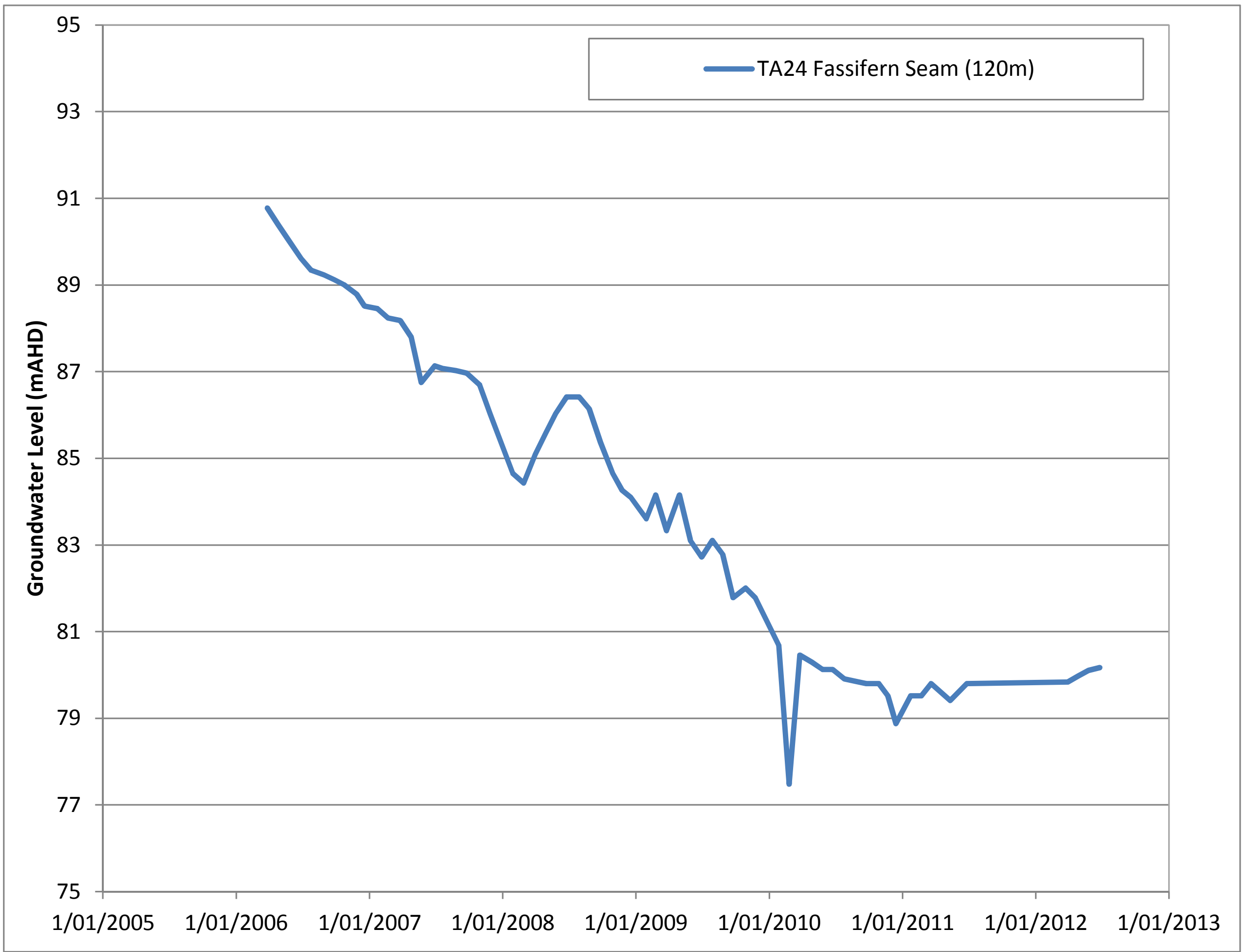
FIGURE 4.8

Interpreted Groundwater Contours for Donaldson Seam

S64D_015 Rev: A Produced: HZ Reviewed: KB Date: 10/08/2012


50
40
30
20
10
0
-10
200
0
-200
-400
-600
-800
-1000
Groundwater Level (mAHD)
Monthly Residual Rainfall - Cessnock (mm)
1/01/1997
1/01/1999
1/01/2001
1/01/2003
1/01/2005
1/01/2007
1/01/2009
1/01/2011
1/01/2013
DPZ1
DPZ2
DPZ3
DPZ4A
DPZ4B
DPZ5
DPZ6
DPZ7A
DPZ7B
DPZ8
DPZ9
DPZ10
DPZ12
DPZ13
DPZ15
DPZ16
DPZ17(24m)
DPZ17(38m)
DPZ17(62m)
DPZ18(72m)
DPZ18(90m)
DPZ19(56m)
DPZ19(73m)
DPZ20A
Average Monthly Rainfall Residual (mm)
Rainfall Residual Average

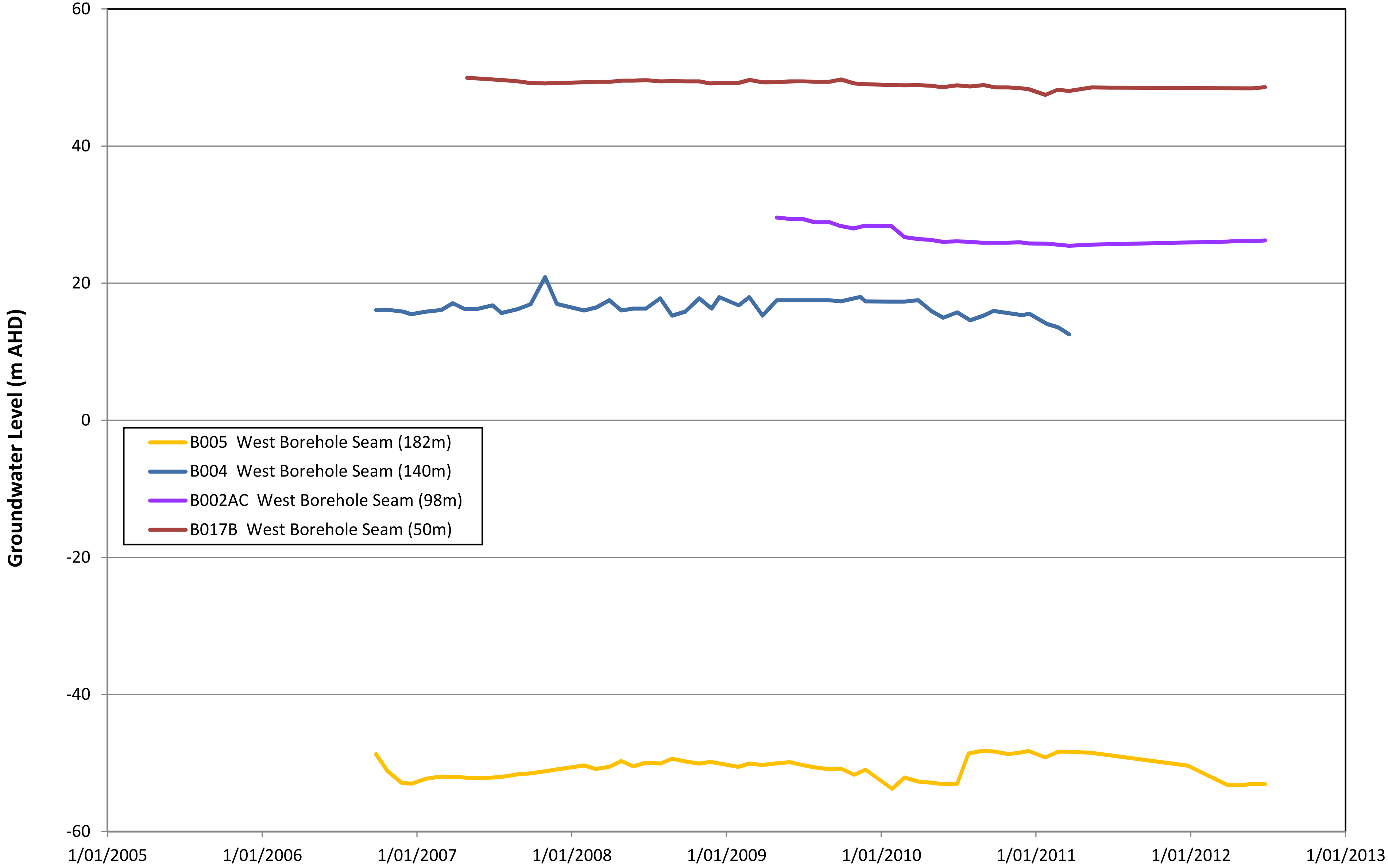




RPS Aquaterra

TA23 and TA24 Hydrographs FIGURE 4.10

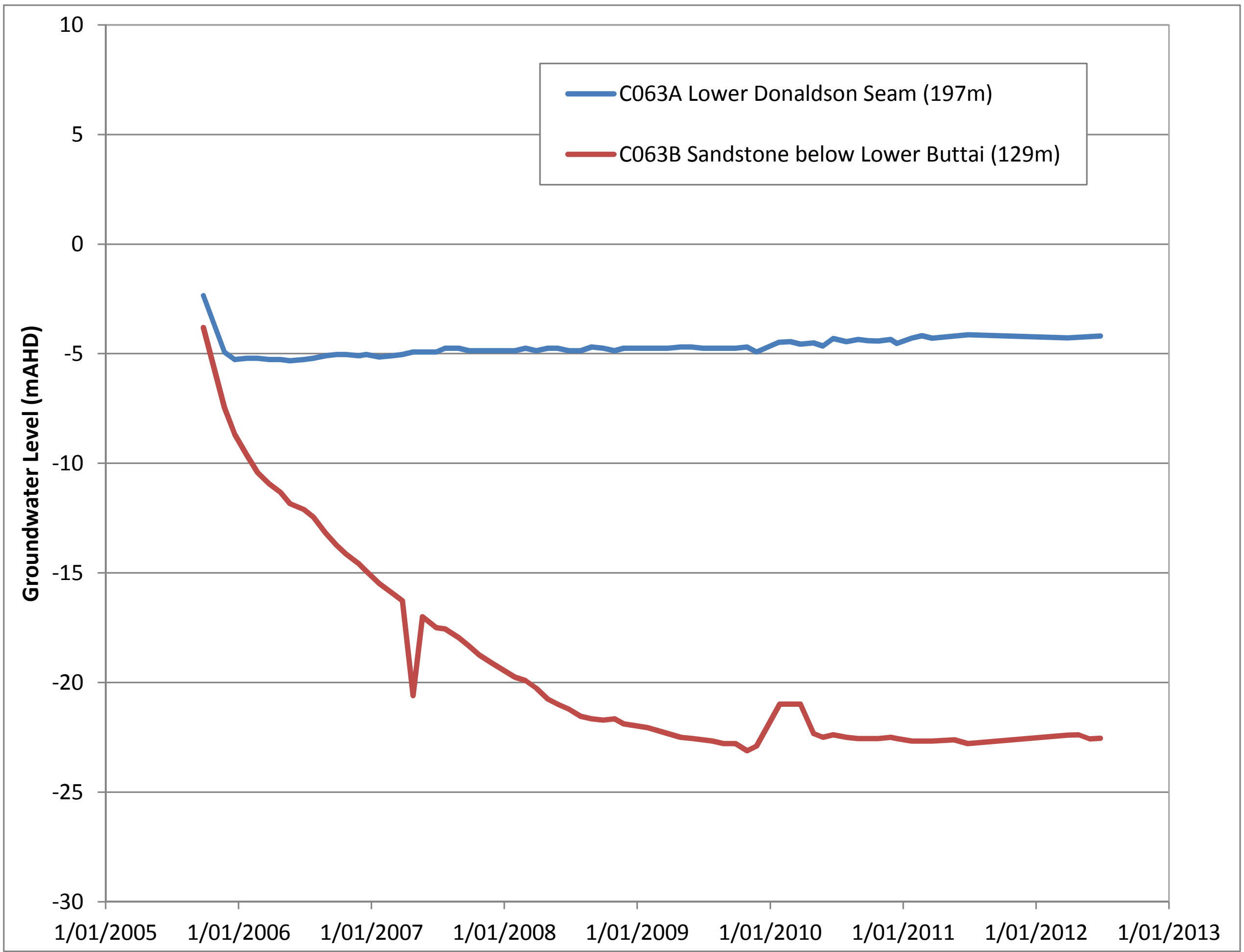
F:\Jobs\S64DD\300\Bore_information\[022_Donaldson_borehole_inventory_KB.xlsx]Fig_4.10TA

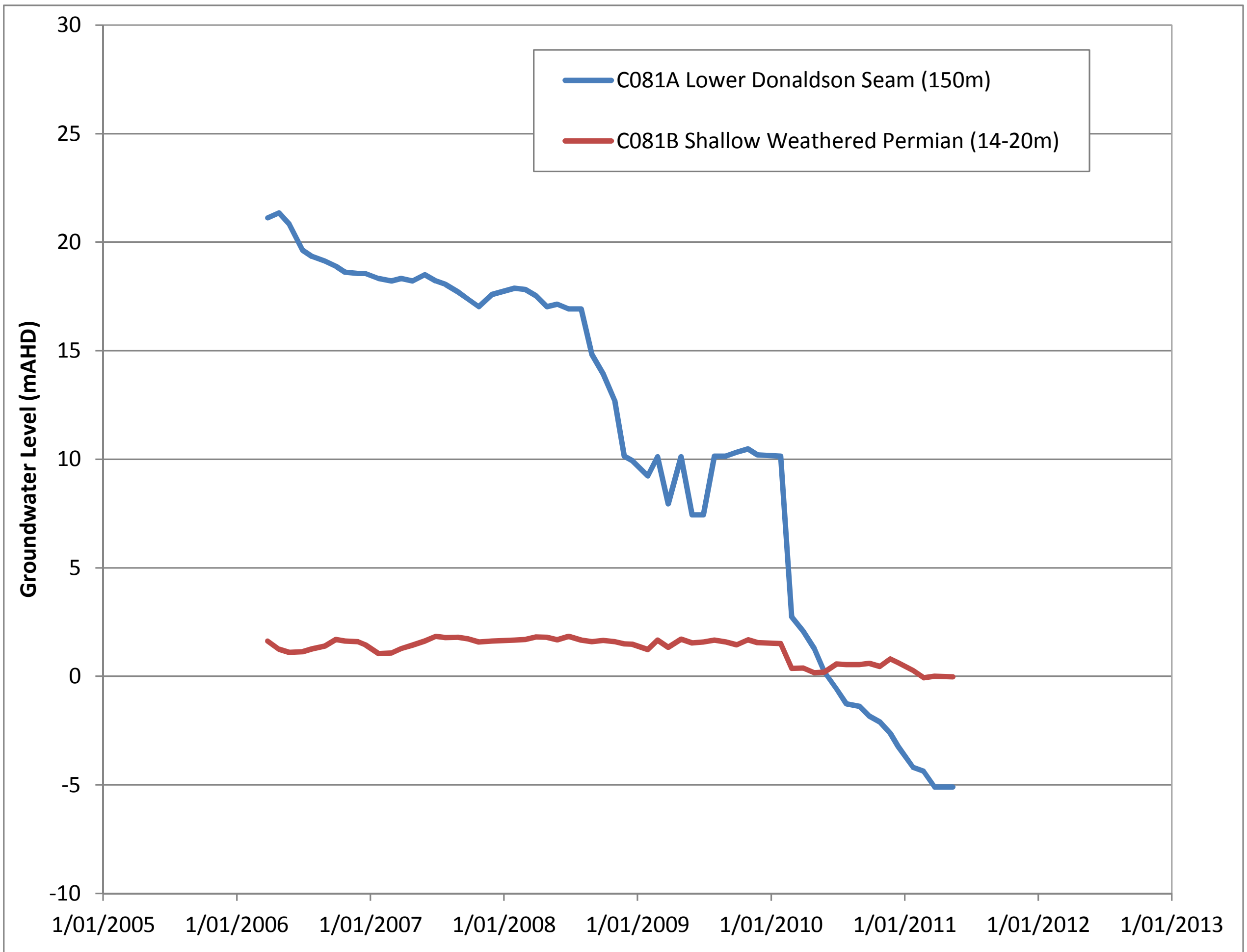


RPS Aquaterra

West Borehole Seam Hydrographs FIGURE 4.11

F:\Jobs\S64DD\300\Bore_information\[022_Donaldson_borehole_inventory_KB.xlsx]Fig_4.11

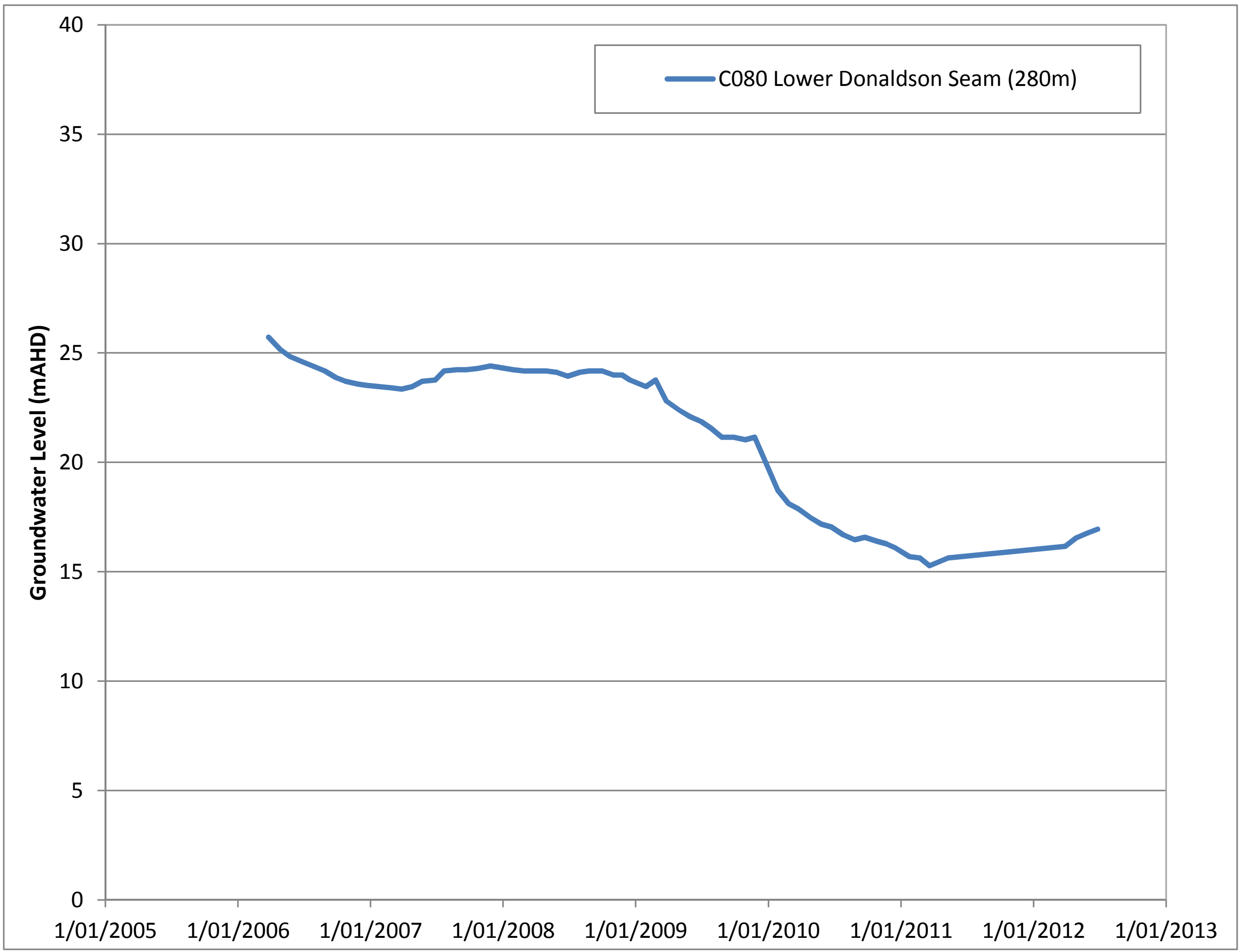


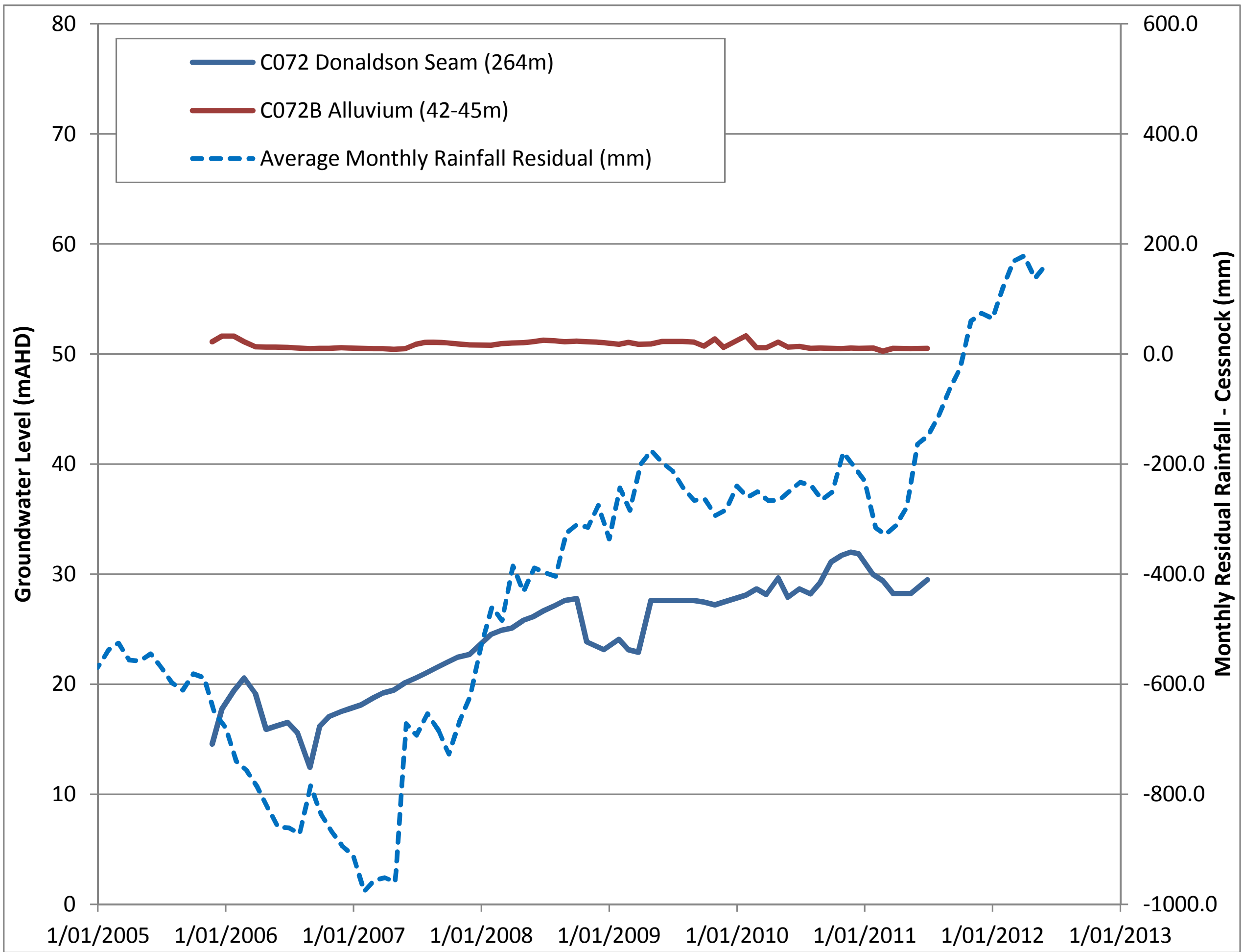


RPS Aquaterra

C063A, C063B, C081A and C081B Hydrographs FIGURE 4.12

F:\Jobs\S64DD\300\Bore_information\[022_Donaldson_borehole_inventory_KB.xlsx]Fig_4.12

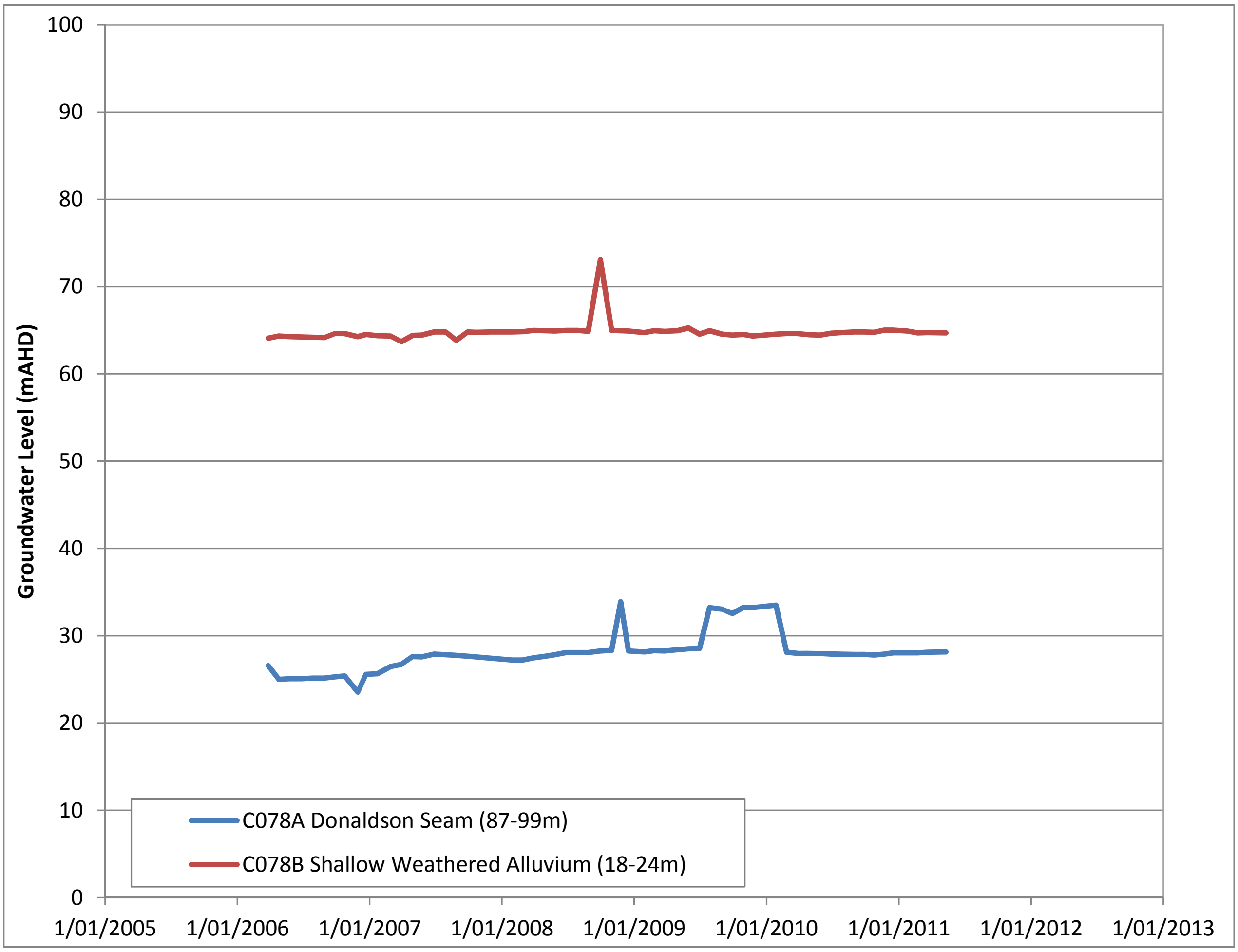


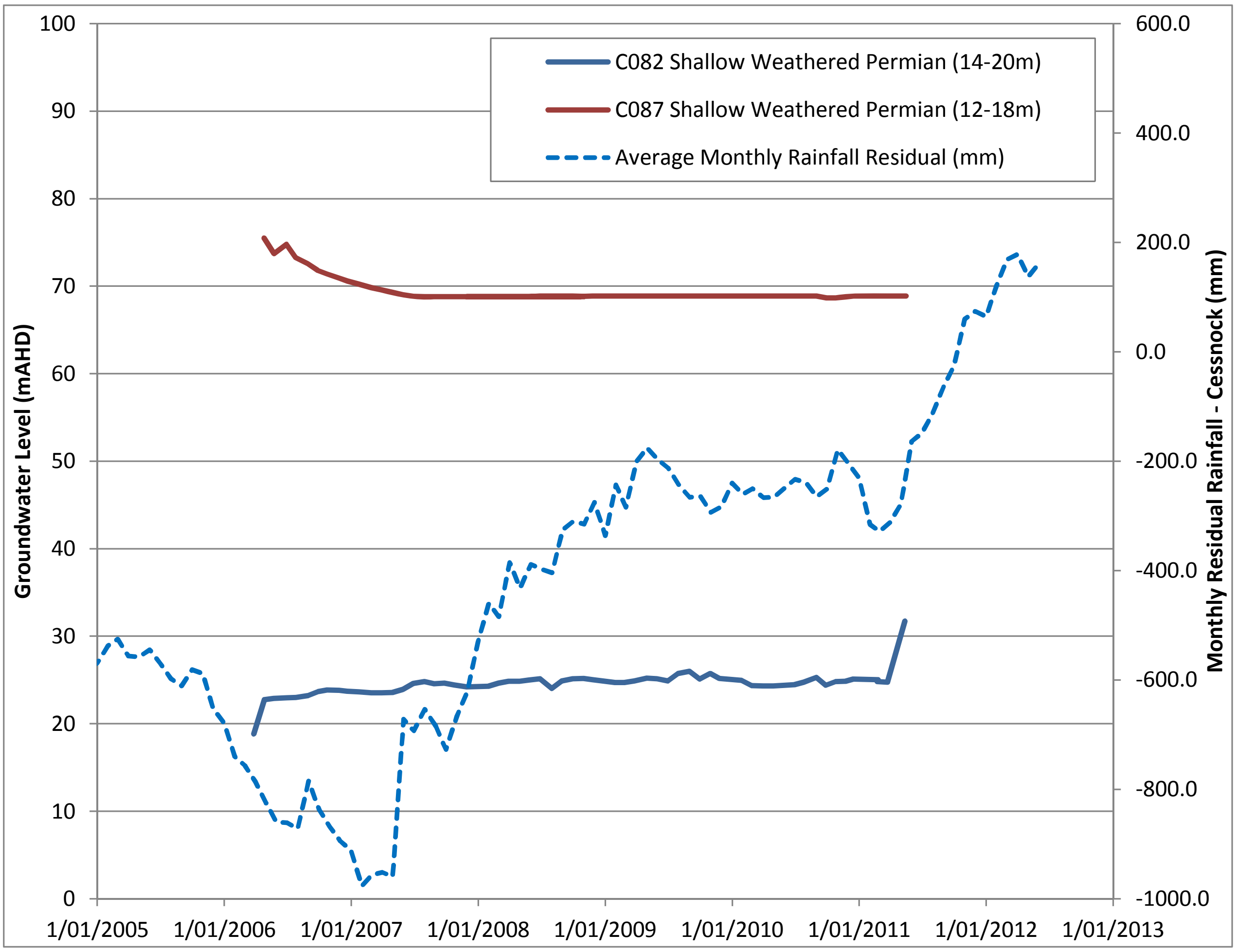


RPS Aquaterra

C080, C072 and C072B Hydrographs FIGURE 4.13

F:\Jobs\S64DD\300\Bore_information\[022_Donaldson_borehole_inventory_KB.xlsx]Fig_4.13

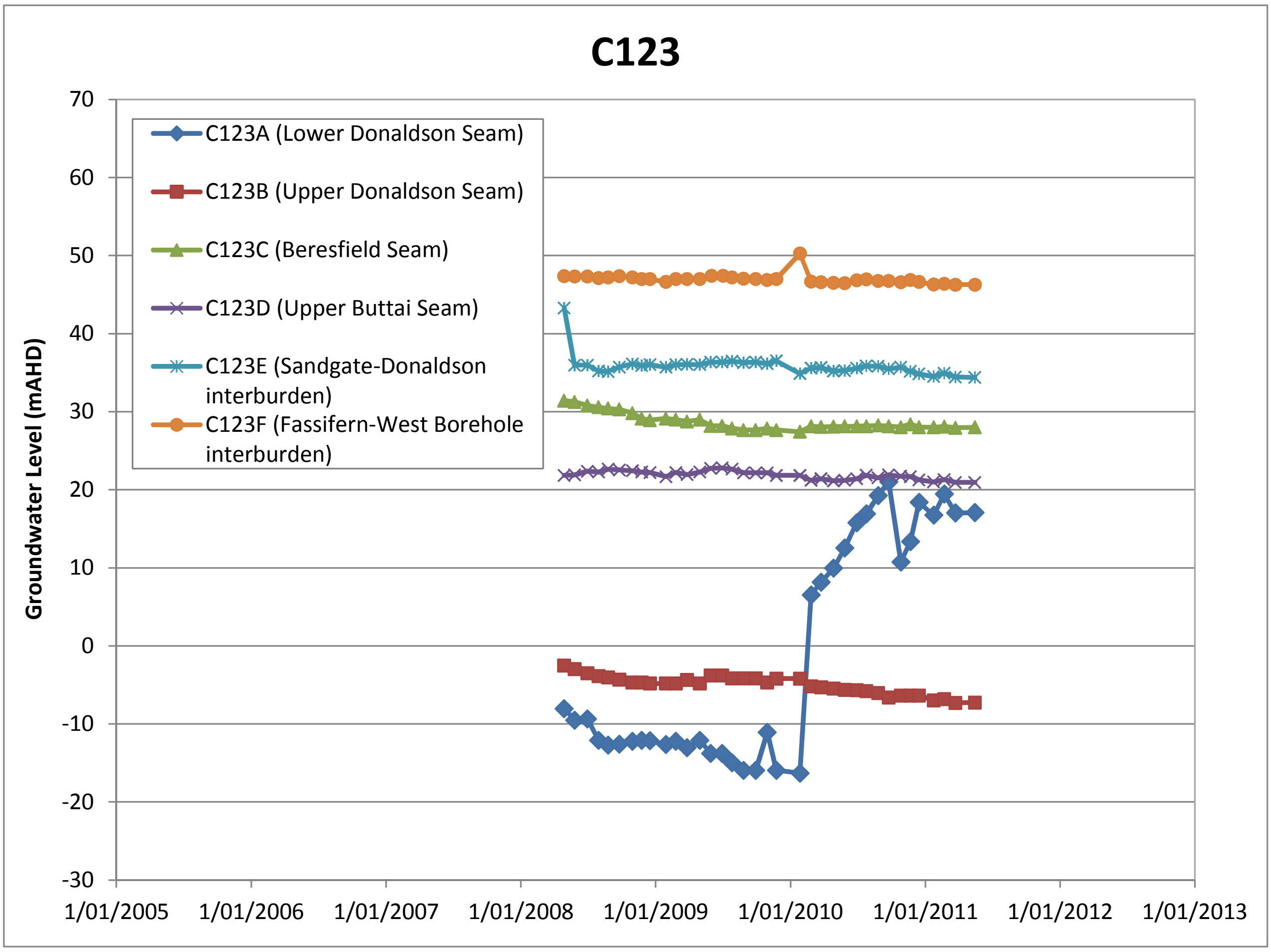


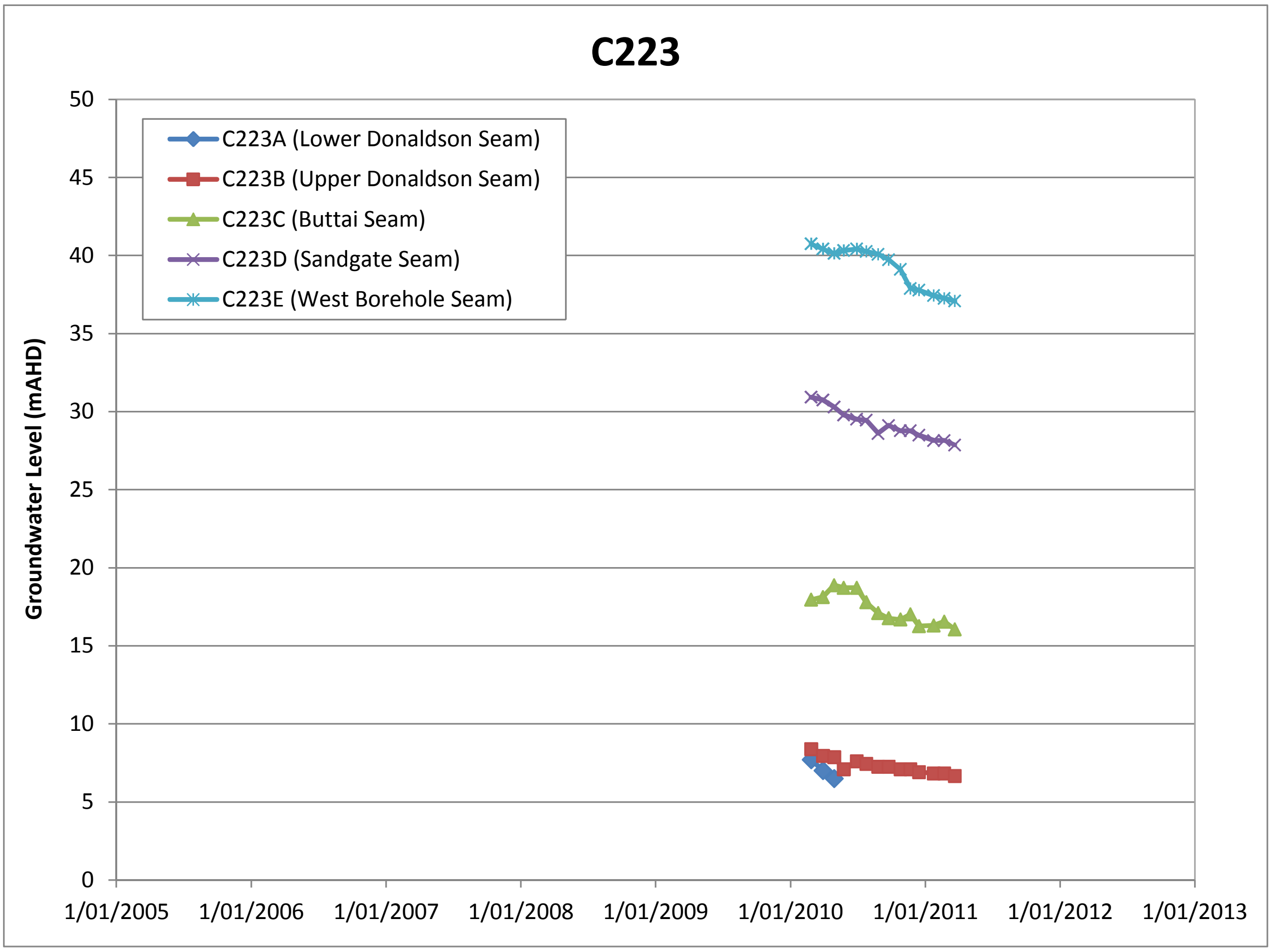


RPS Aquaterra

C078A, C078B, C082 and C087 Hydrographs FIGURE 4.14

F:\Jobs\S64DD\300\Bore_information\[022_Donaldson_borehole_inventory_KB.xlsx]Fig_4.14

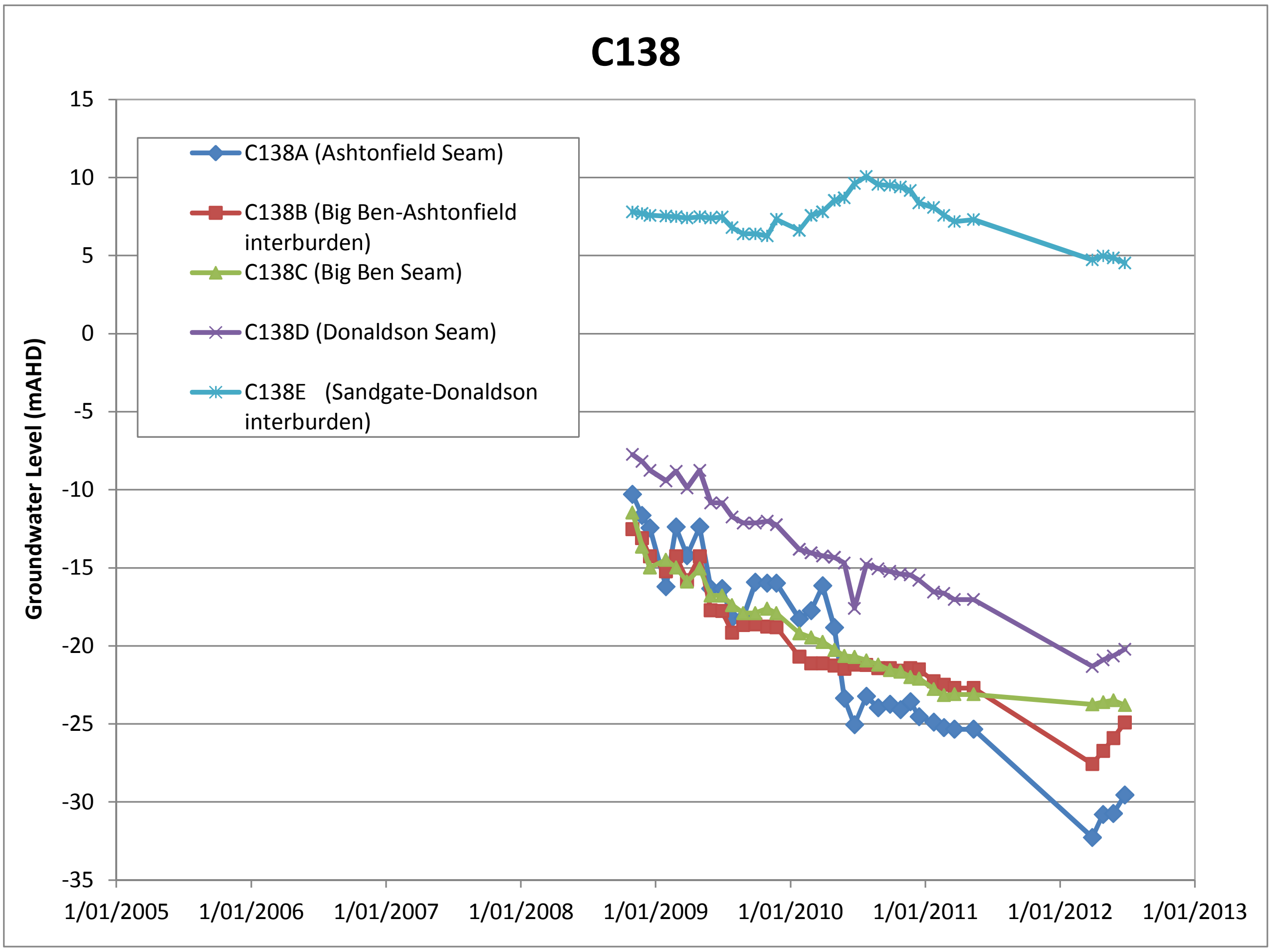


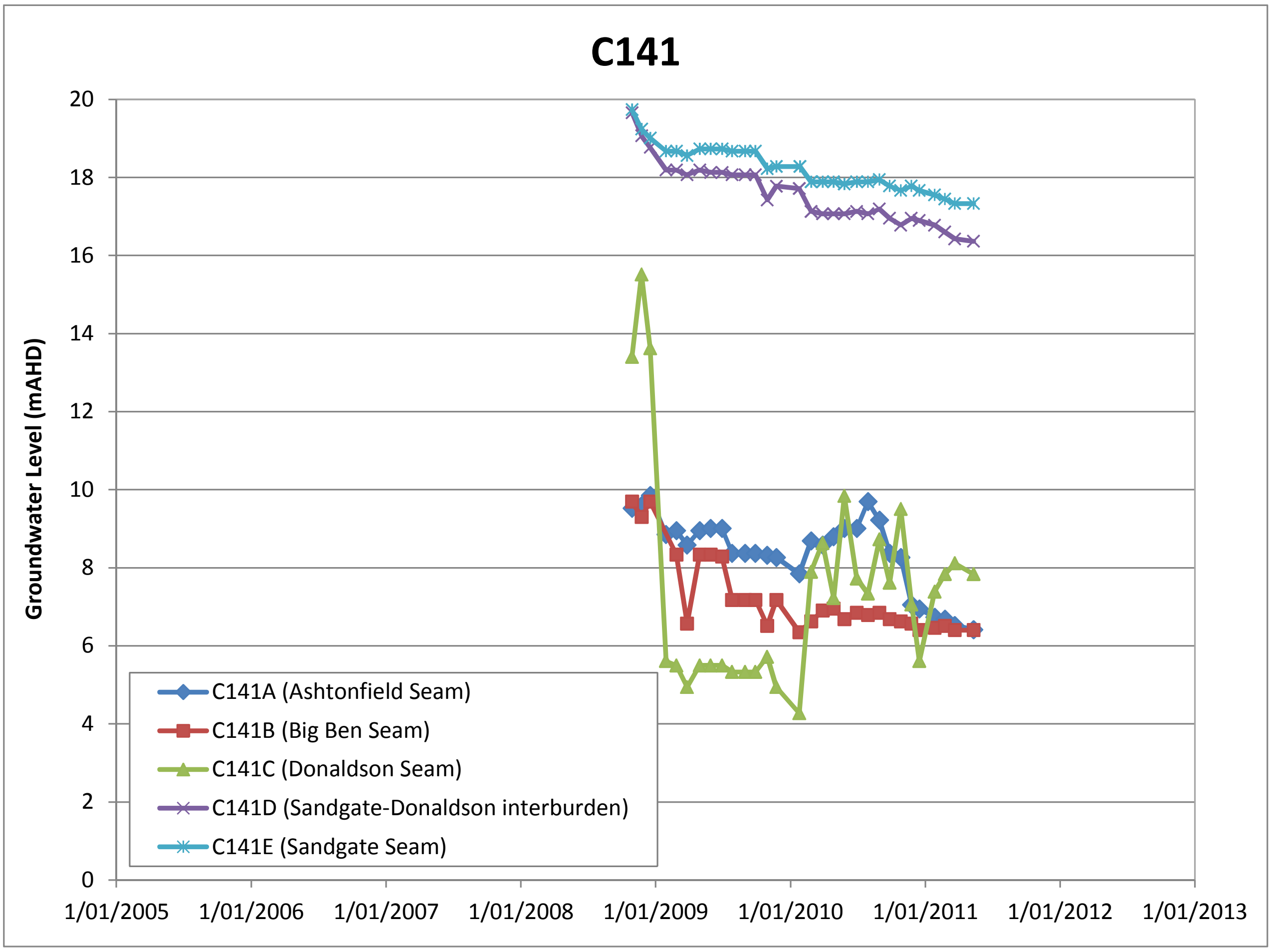


RPS Aquaterra

C123 AND C223 HYDROGRAPHS FIGURE 4.15

F:\Jobs\S64DD\300\Bore_information\[022_Donaldson_borehole_inventory_KB.xlsx]Fig_4.15

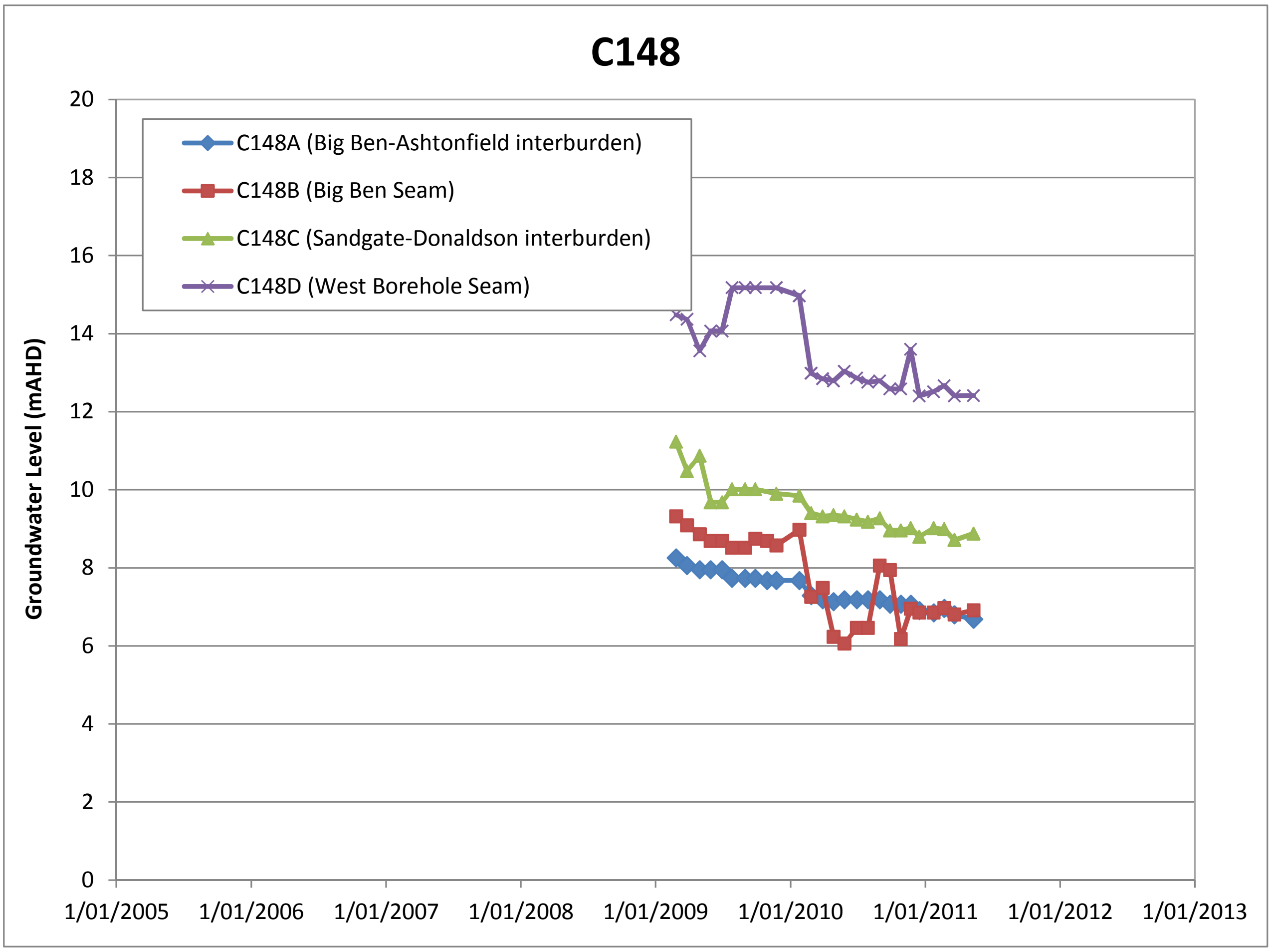


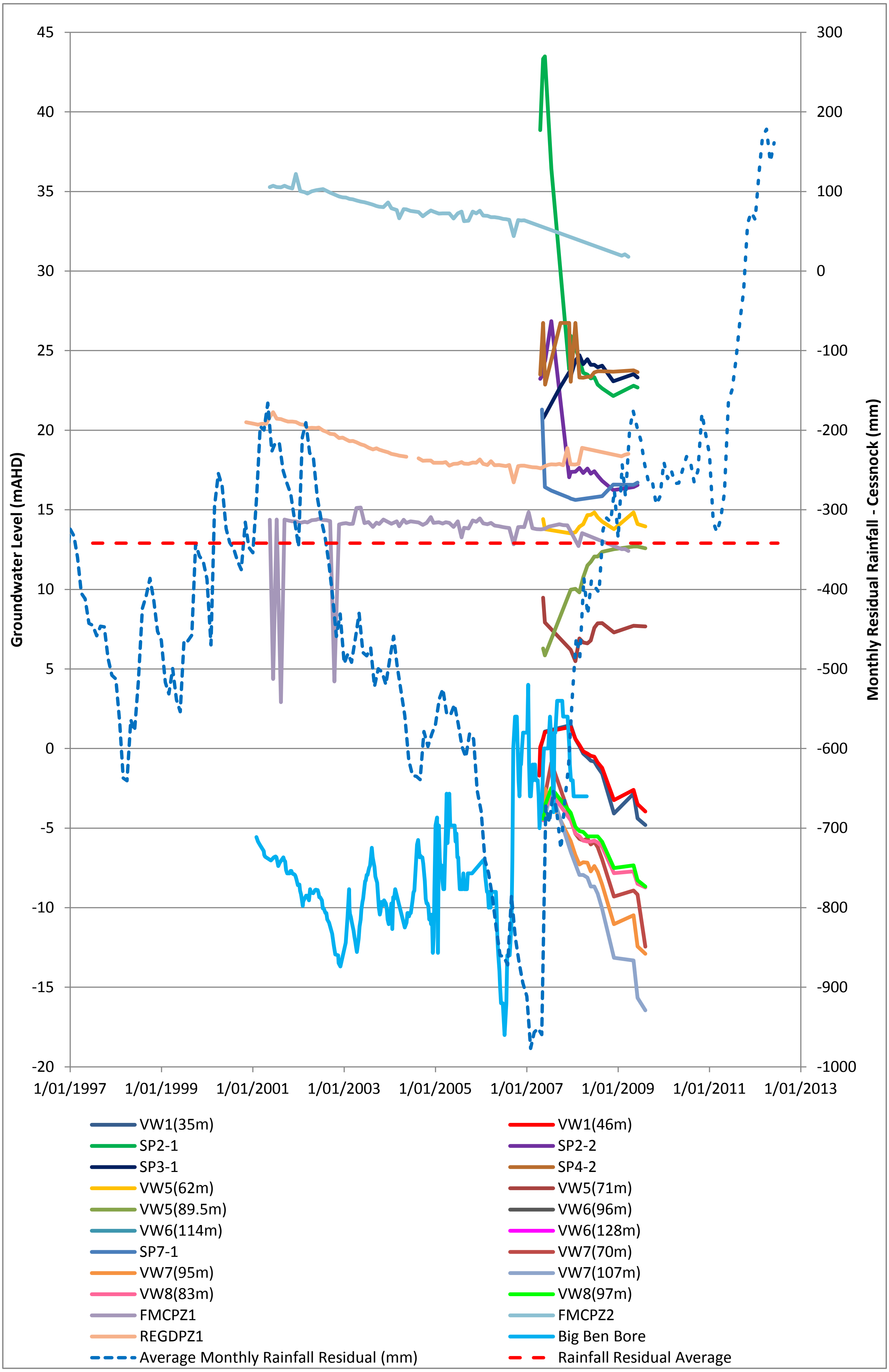


RPS Aquaterra

C138 AND C141 HYDROGRAPHS FIGURE 4.16

F:\Jobs\S64DD\300\Bore_information\[022_Donaldson_borehole_inventory_KB.xlsx]Fig_4.16

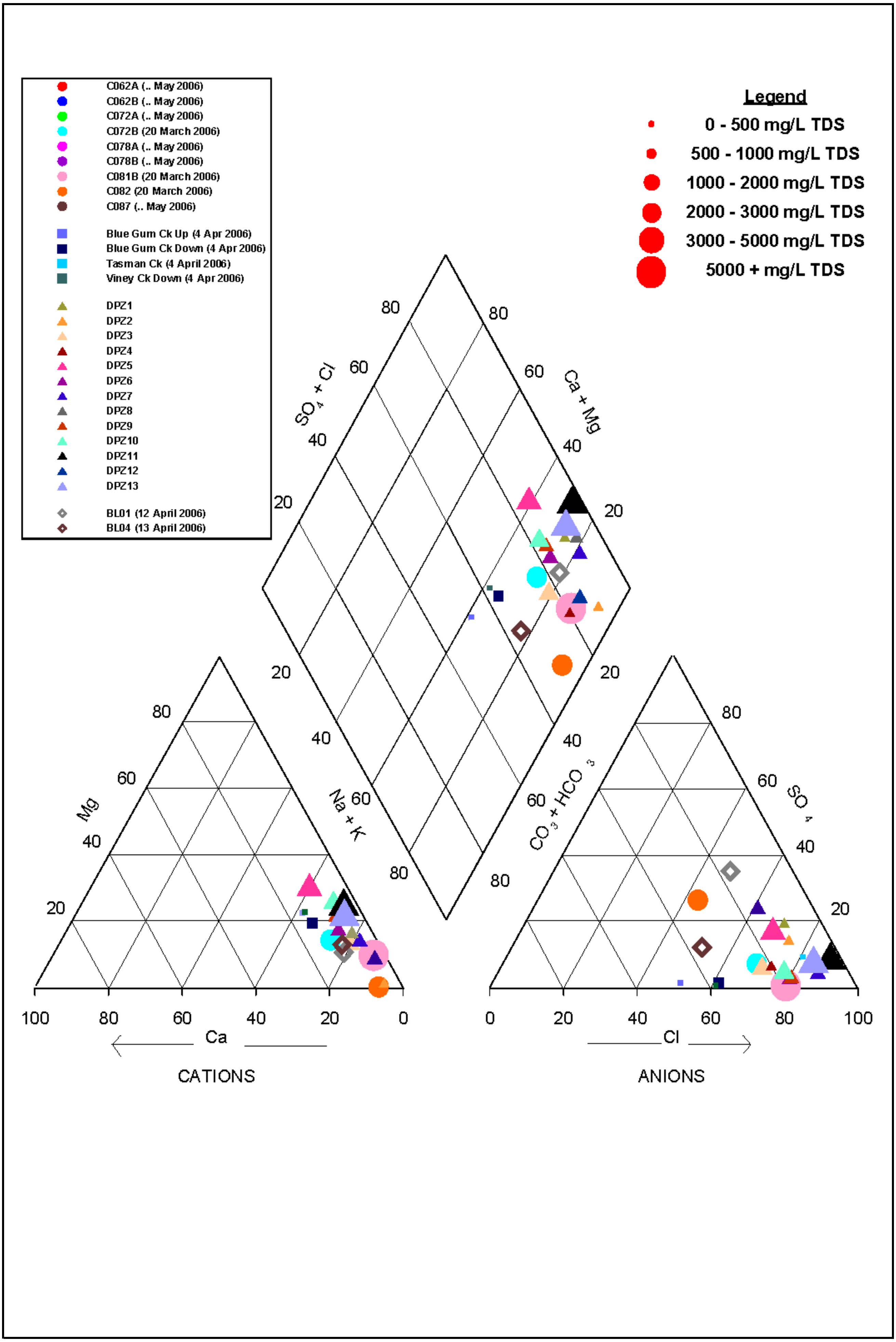

C148
Groundwater Level (mAHD)
20
18
16
14
12
10
8
6
4
2
0
1/01/2005
1/01/2006
1/01/2007
1/01/2008
1/01/2009
1/01/2010
1/01/2011
1/01/2012
1/01/2013
C148A (Big Ben-Ashtonfield interburden)
C148B (Big Ben Seam)
C148C (Sandgate-Donaldson interburden)
C148D (West Borehole Seam)

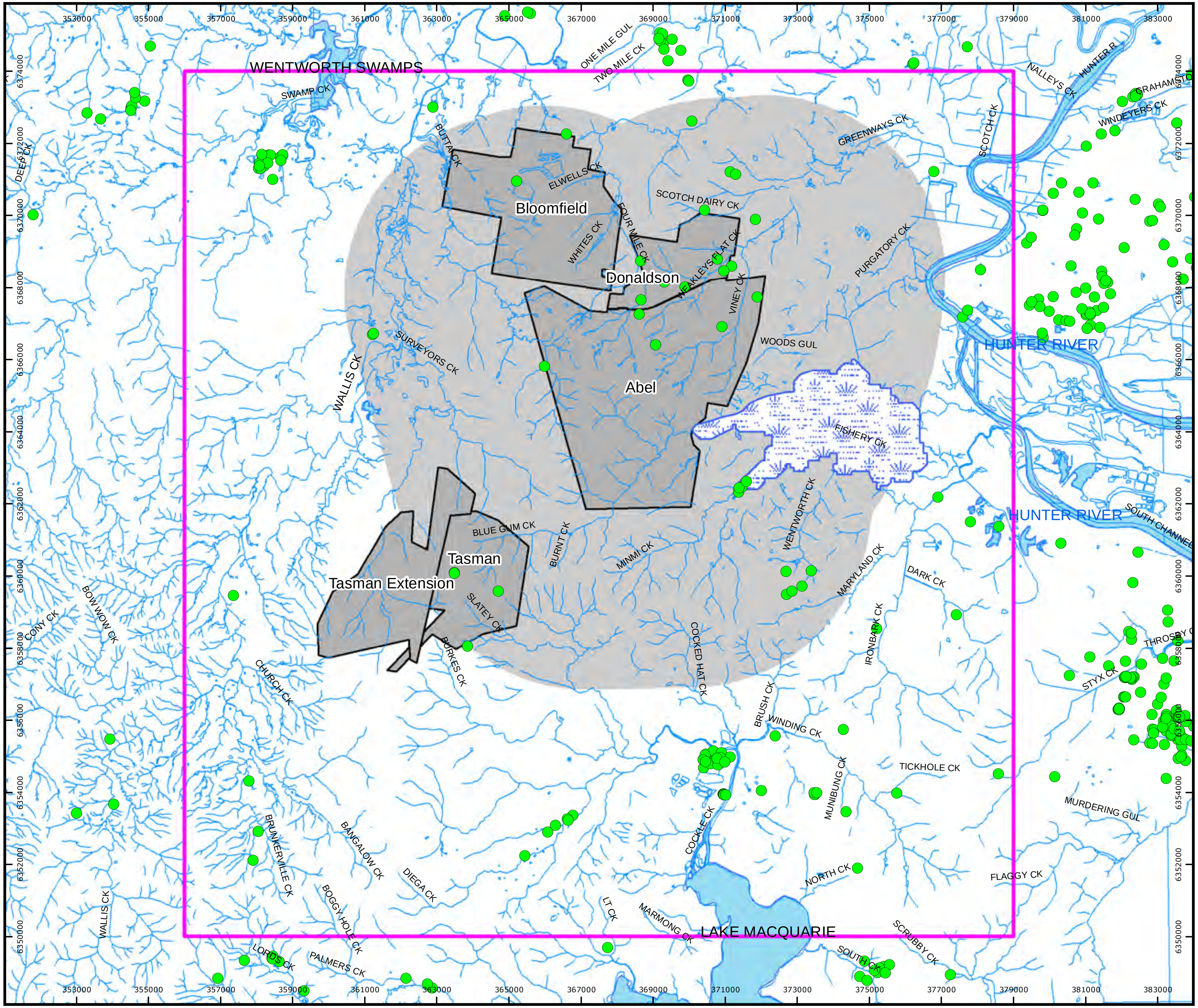


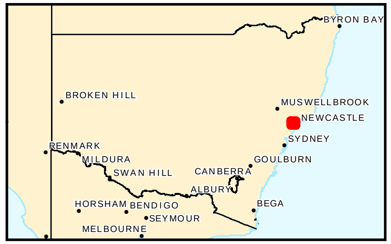
RPS Aquaterra

Bloomfield Groundwater Monitoring Hydrographs FIGURE 4.18

F:\Jobs\S64DD\300\Bore_information\[022_Donaldson_borehole_inventory_KB.xlsx]Fig_4.18


C062A (.. May 2006)
C062B (.. May 2006)
C072A (.. May 2006)
C072B (20 March 2006)
C078A (.. May 2006)
C078B (.. May 2006)
C081B (20 March 2006)
C082 (20 March 2006)
C087 (.. May 2006)
Blue Gum Ck Up (4 Apr 2006)
Blue Gum Ck Down (4 Apr 2006)
Tasman Ck (4 April 2006)
Viney Ck Down (4 Apr 2006)
DPZ1
DPZ2
DPZ3
DPZ4
DPZ5
DPZ6
DPZ7
DPZ8
DPZ9
DPZ10
DPZ11
DPZ12
DPZ13
BL01 (12 April 2006)
BL04 (13 April 2006)
Legend
0 - 500 mg/L TDS
500 - 1000 mg/L TDS
1000 - 2000 mg/L TDS
2000 - 3000 mg/L TDS
3000 - 5000 mg/L TDS
5000 + mg/L TDS
SO4 + Cl
Ca + Mg
CO3 + HCO3
Na + K
Mg
Ca
Cl
SO4
CATIONS
ANIONS
0
20
40
60
80
100





LEGEND

- Registered Bores
- Hexham Swamp
- Model Area
- Rivers or Creeks
- 5 km Radius from Abel
- Mine Lease

2,000 0 2,000 4,000

Metres

APPROX SCALE 1:150,000 @ A4

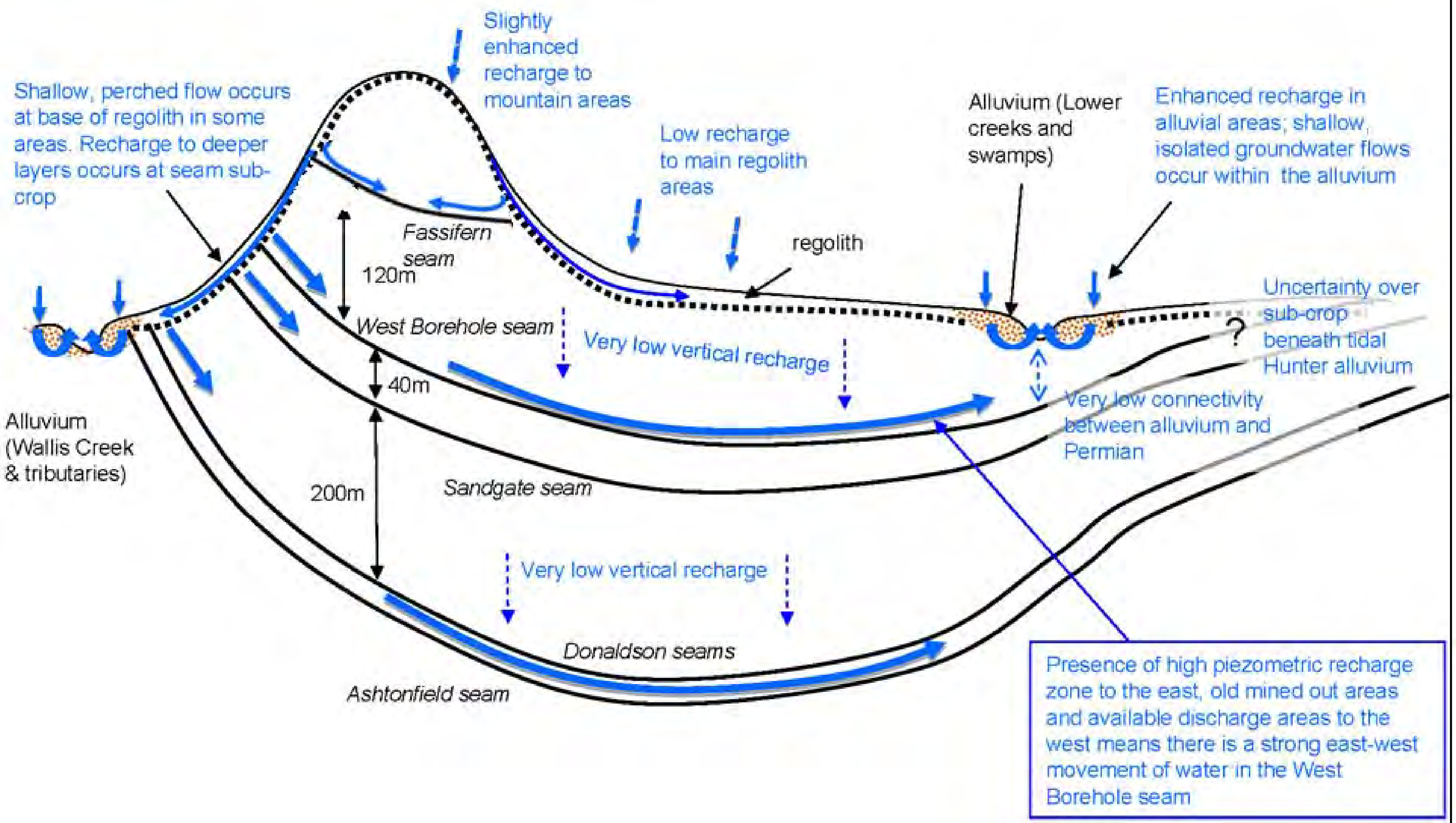
GDA 1994 MGA Zone 56

RPS Aquaterra

FIGURE 4.20

Registered Bores

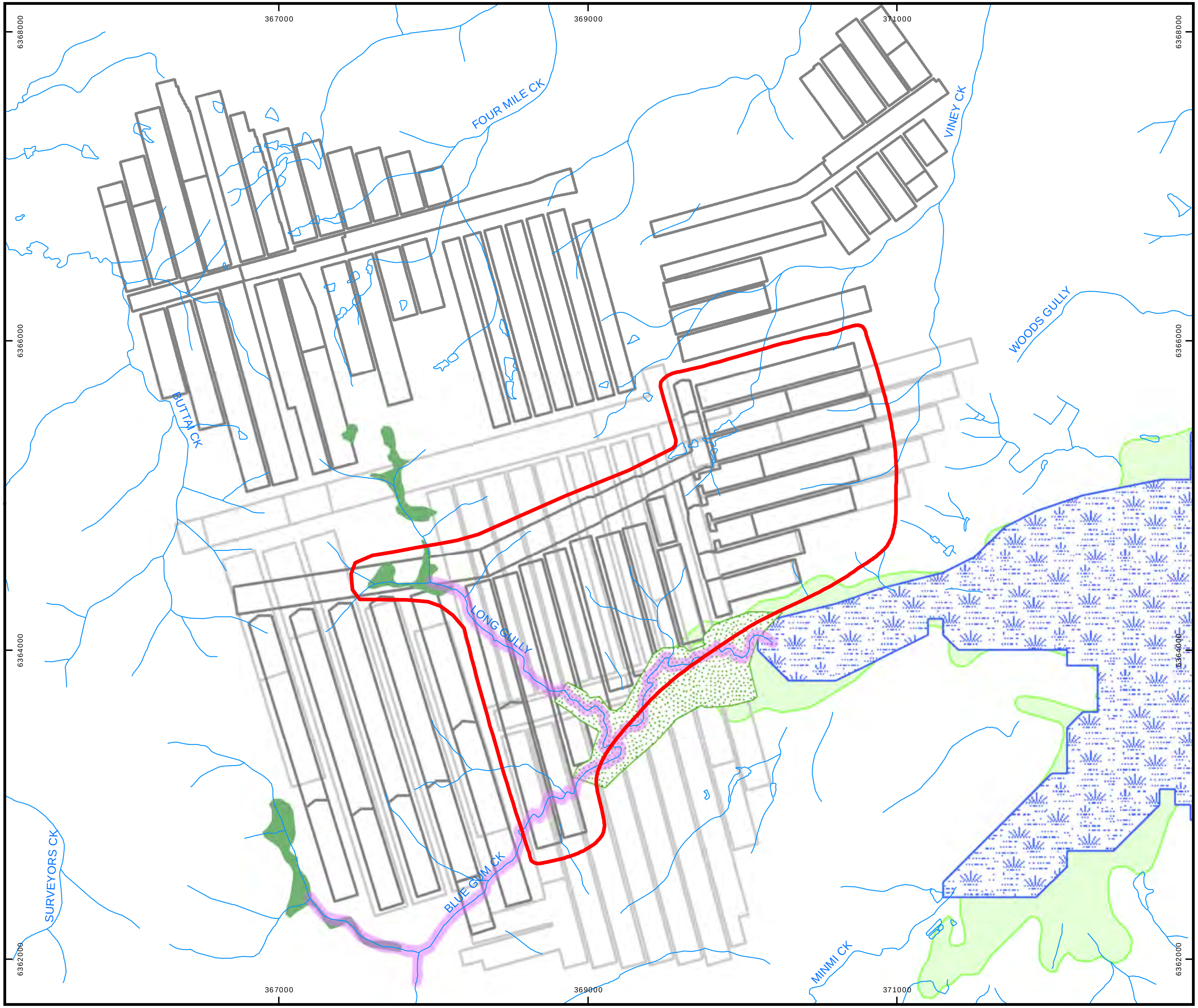
S64_007 Rev: A Produced: HZ Reviewed: KB Date: 03/09/2012

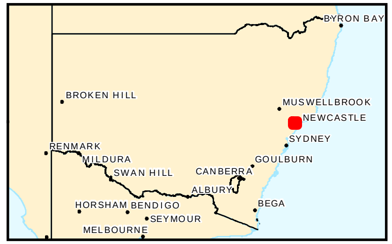


RPS Aquaterra

FIGURE 5.1

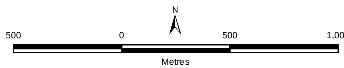
Conceptual Model Cross Section





LEGEND

- Upper Donaldson First Workings Only
- River or Creek
- Protection Zone
- Rainforest
- Alluvium- Blue Gum
- Alluvium
- Hexham Swamp
- Abel Upper Donaldson Mine Plan
- Abel Lower Donaldson Mine Plan



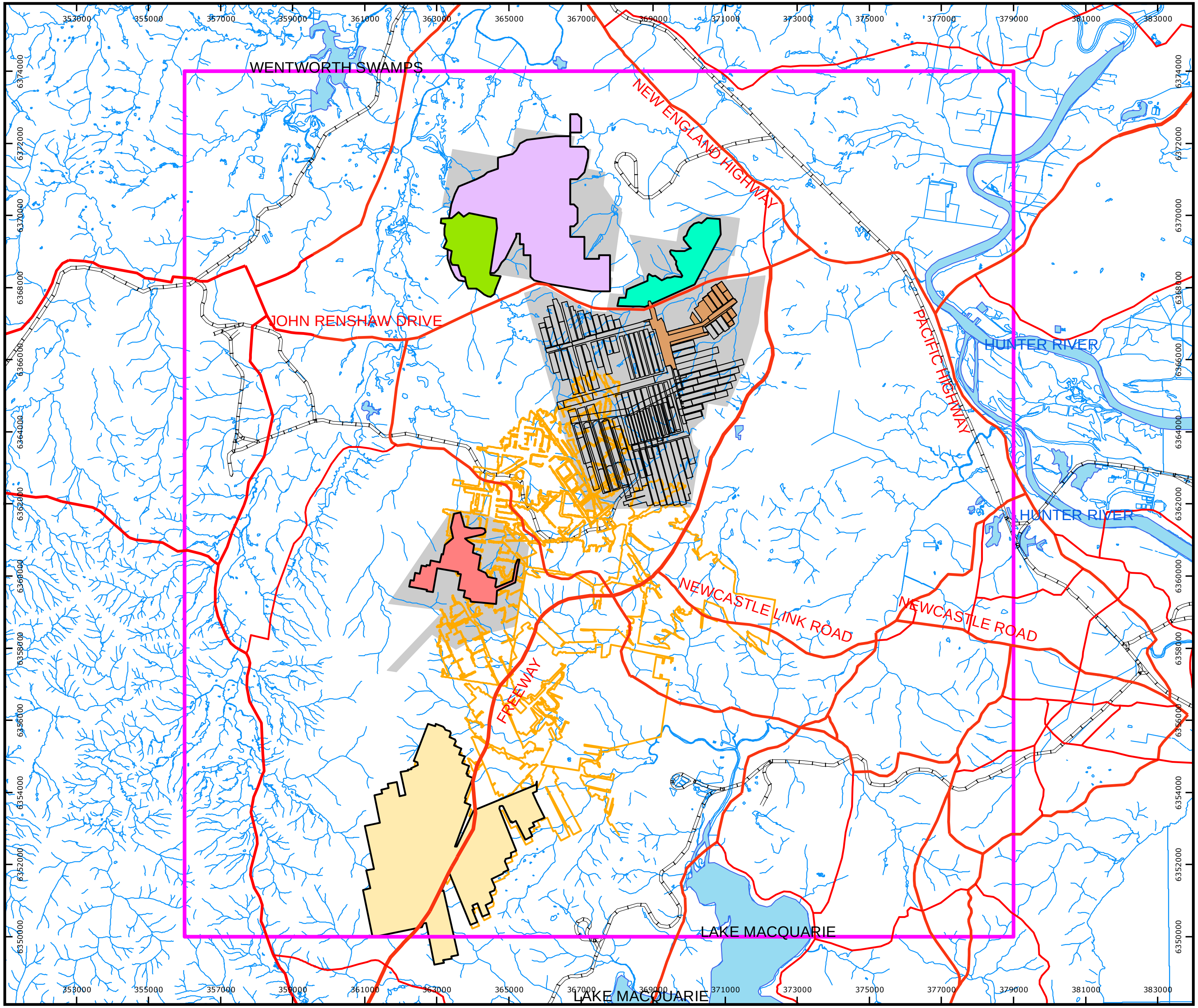
APPROX SCALE 1:35,000 @ A4

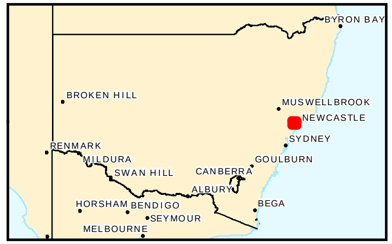
GDA 1994 MGA Zone 56

RPS Aquaterra

FIGURE 5.2

Subsidence Control Zones





LEGEND

- Abel Underground Mine Plan
- Model Area
- Mine Lease
- West Wallsend Underground Mine
- Current Abel Underground Mine
- Current Donaldson Open Cut Mine
- Current Bloomfield Open Cut Mine
- Historical Bloomfield Mine Workings
- Current Tasman Underground Mine
- Historical West Borehole Workings
- Railway
- River or Creek

N

2,000 0 2,000 4,000

Metres

APPROX SCALE 1:150,000 @ A4

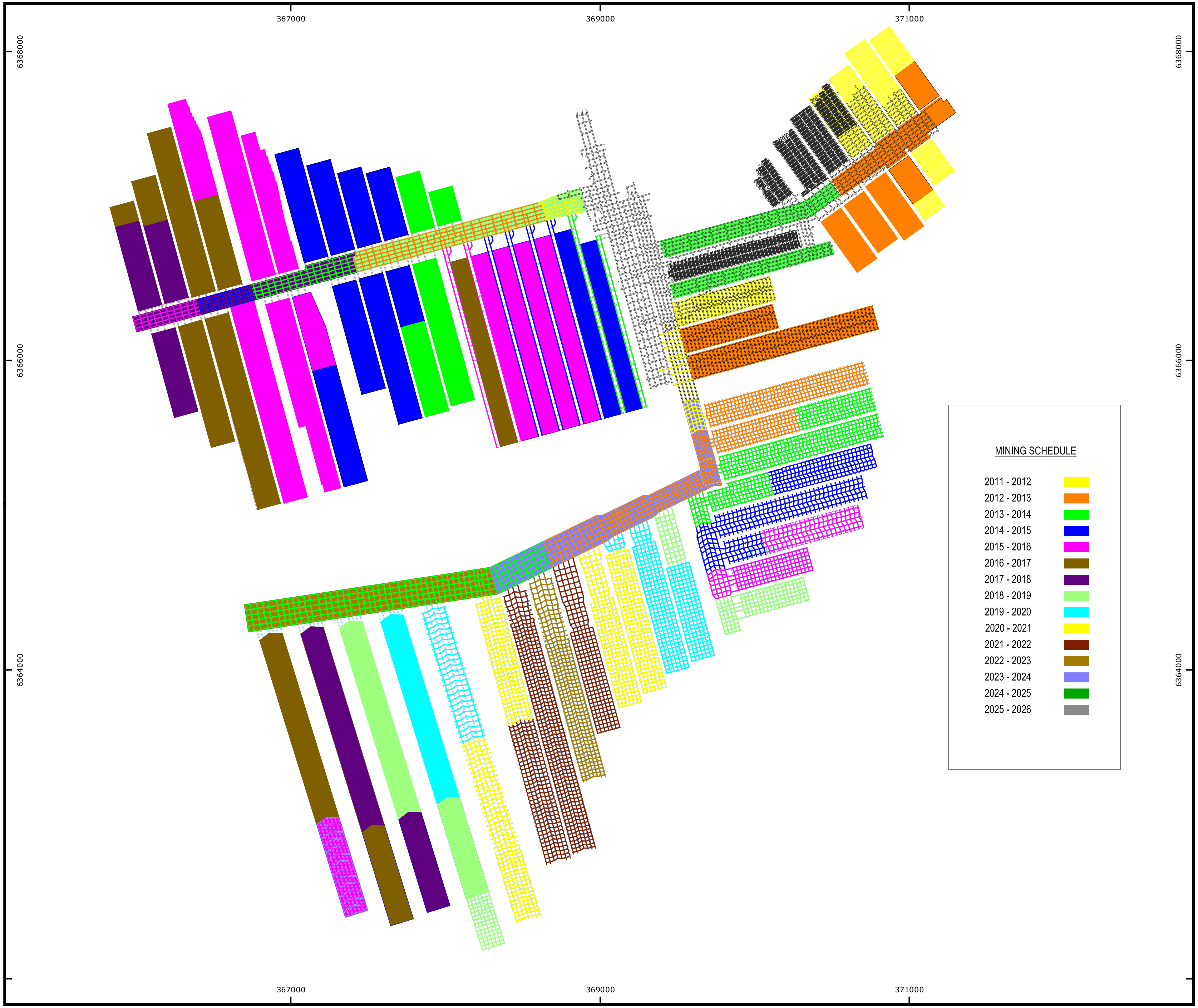
GDA 1994 MGA Zone 56

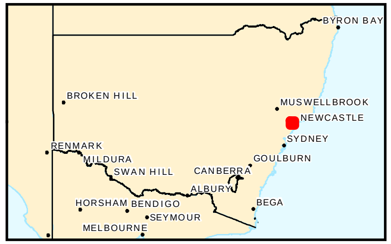
RPS Aquaterra

FIGURE 5.3

Historical And Active Mine Areas

S64_008 Rev: A Produced: HZ Reviewed: KB Date: 10/04/2012





N

500 0 500 1,000

Metres

APPROX SCALE 1:35,000 @ A4

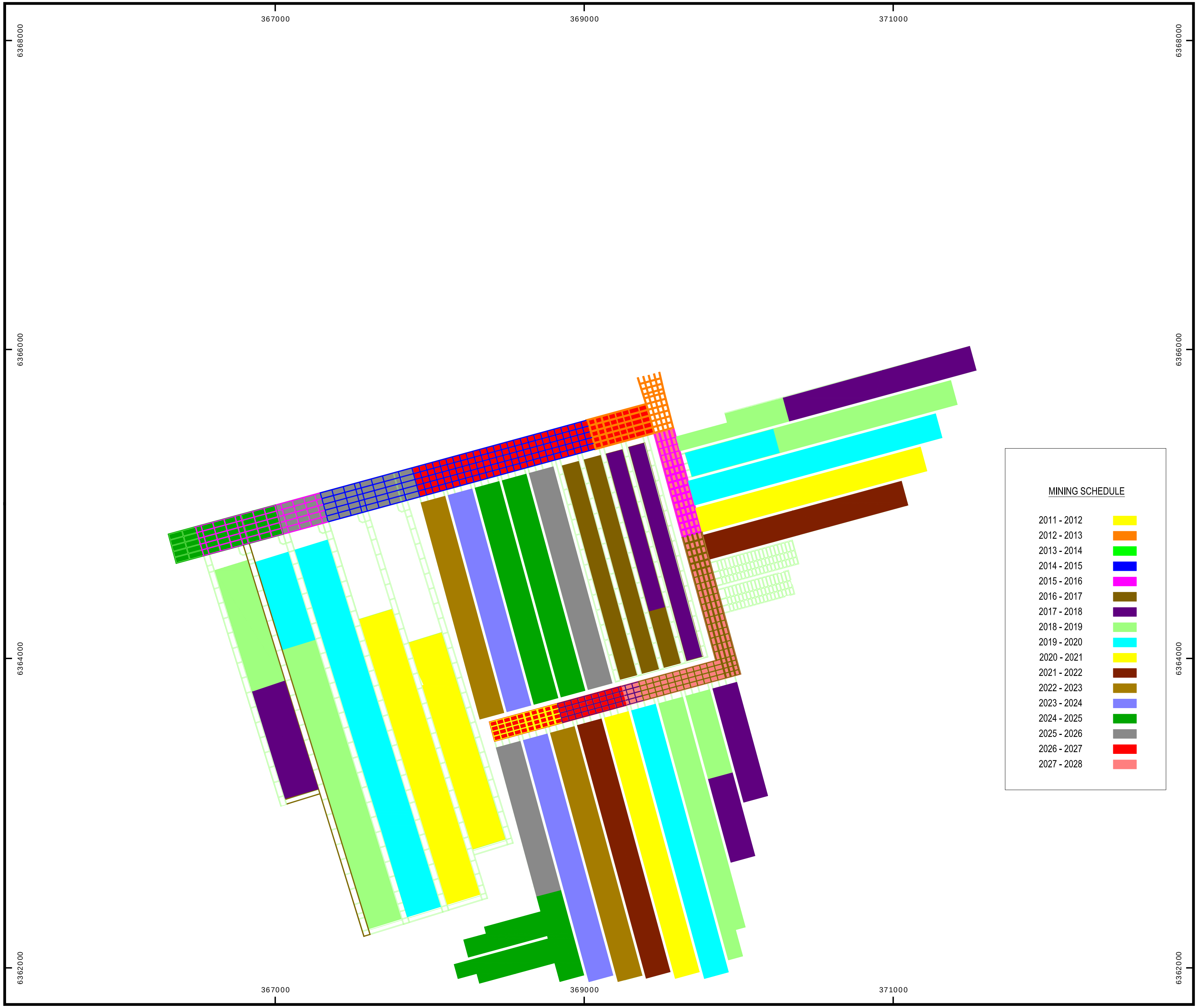
GDA 1994 MGA Zone 56

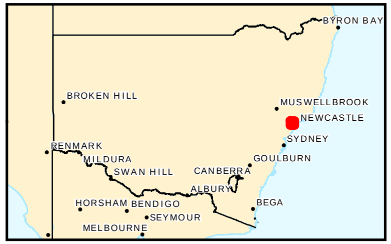
RPS Aquaterra

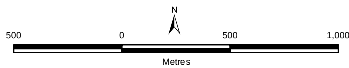
FIGURE 6.1

Abel Underground Mining Schedule
Upper Donaldson Seam

S64_012 Rev: A Produced: HZ Reviewed: KB Date: 22/06/2012







APPROX SCALE 1:35,000 @ A4

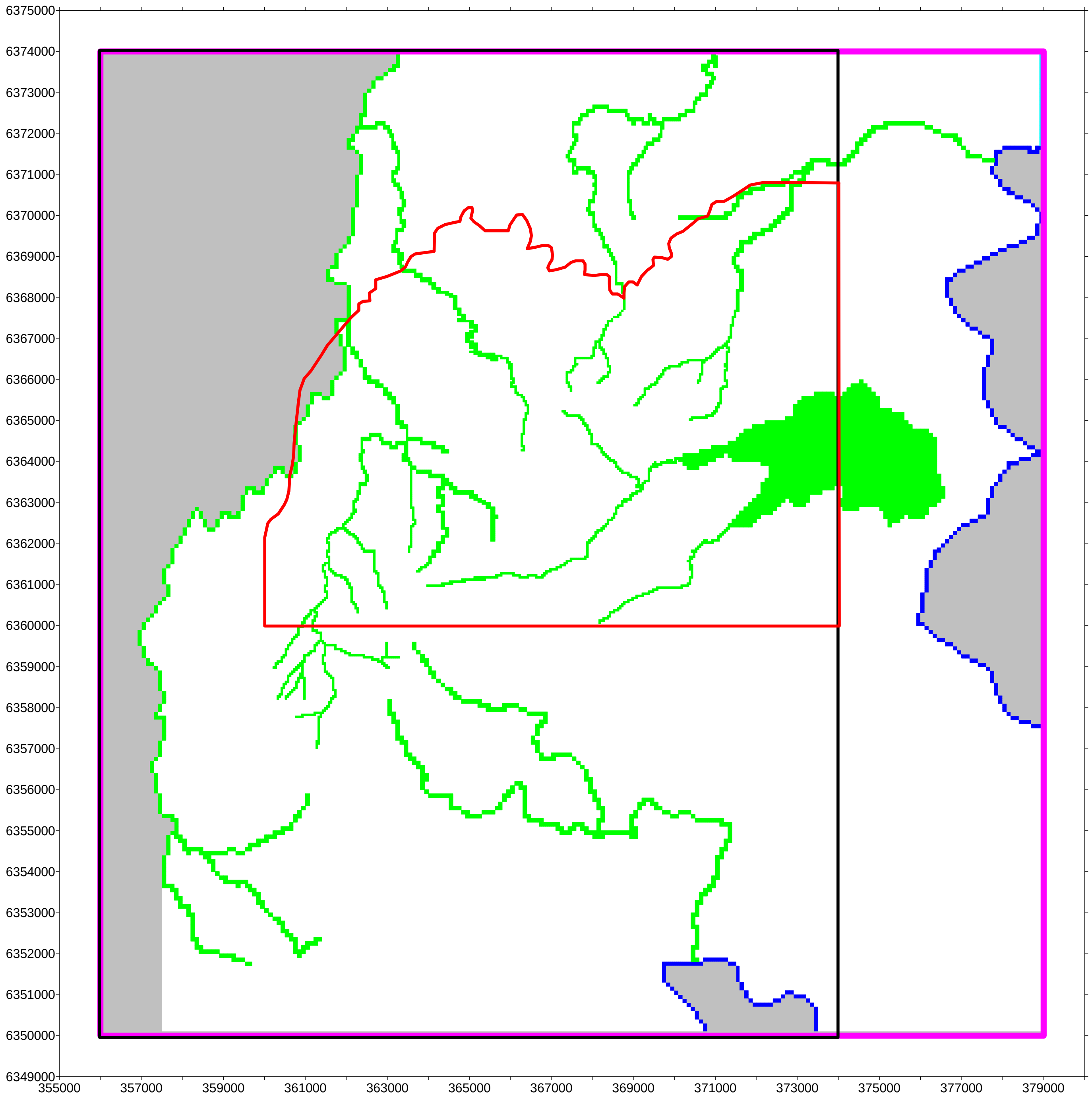
GDA 1994 MGA Zone 56

RPS Aquaterra

FIGURE 6.2

Abel Underground Mining Schedule
Lower Donaldson Seam

S64_013 Rev: A Produced: HZ Reviewed: KB Date: 22/06/2012



LEGEND

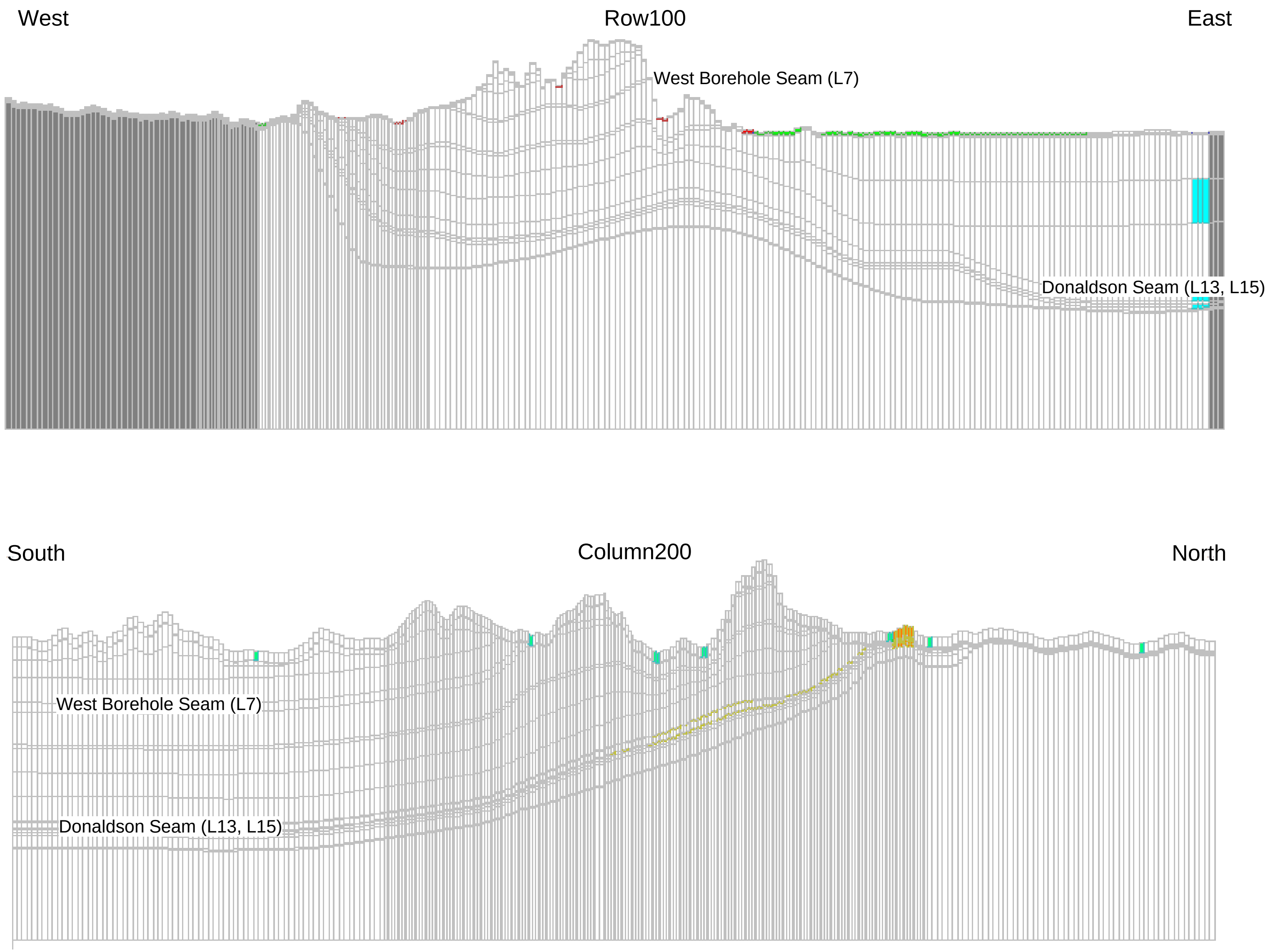
- Rivers or Creeks
- No Flow
- General Head Boundary
- Current Model Boundary
- Abel Bloomfield Model Boundary
- Donaldson Regional Model Boundary

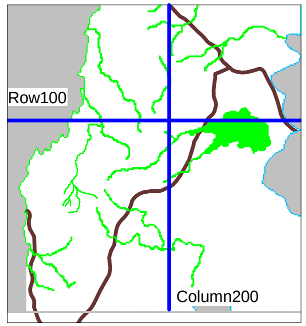
RPS Aquaterra

FIGURE 7.1

Model Domain
Model Boundaries

S64_008 Rev: A Produced: HZ Reviewed: KB Date: 10/08/2012





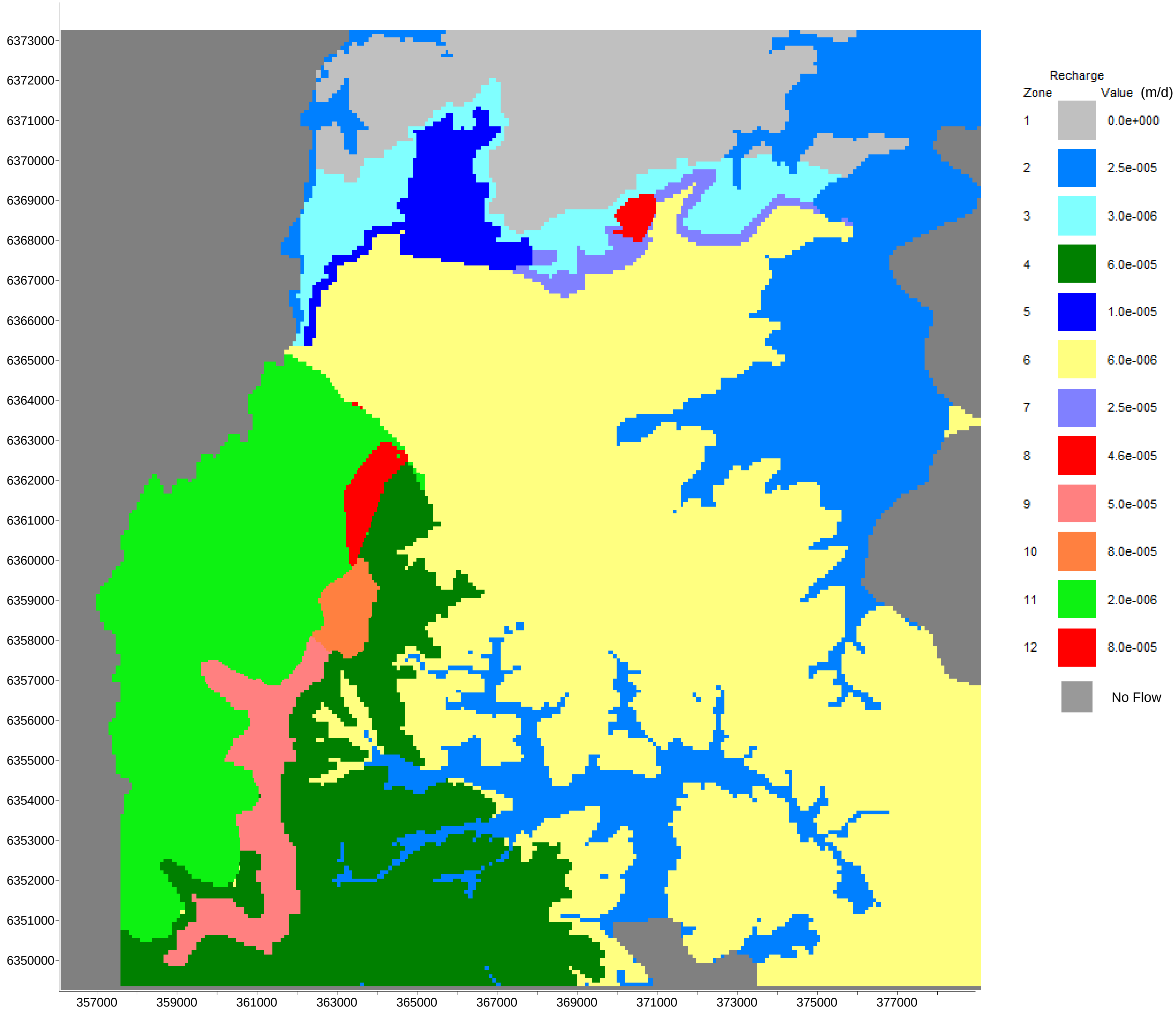
LEGEND

- Drains
- Rivers or Creeks
- No Flow
- General Head Boundary
- Main Road

RPS Aquaterra

FIGURE 7.2

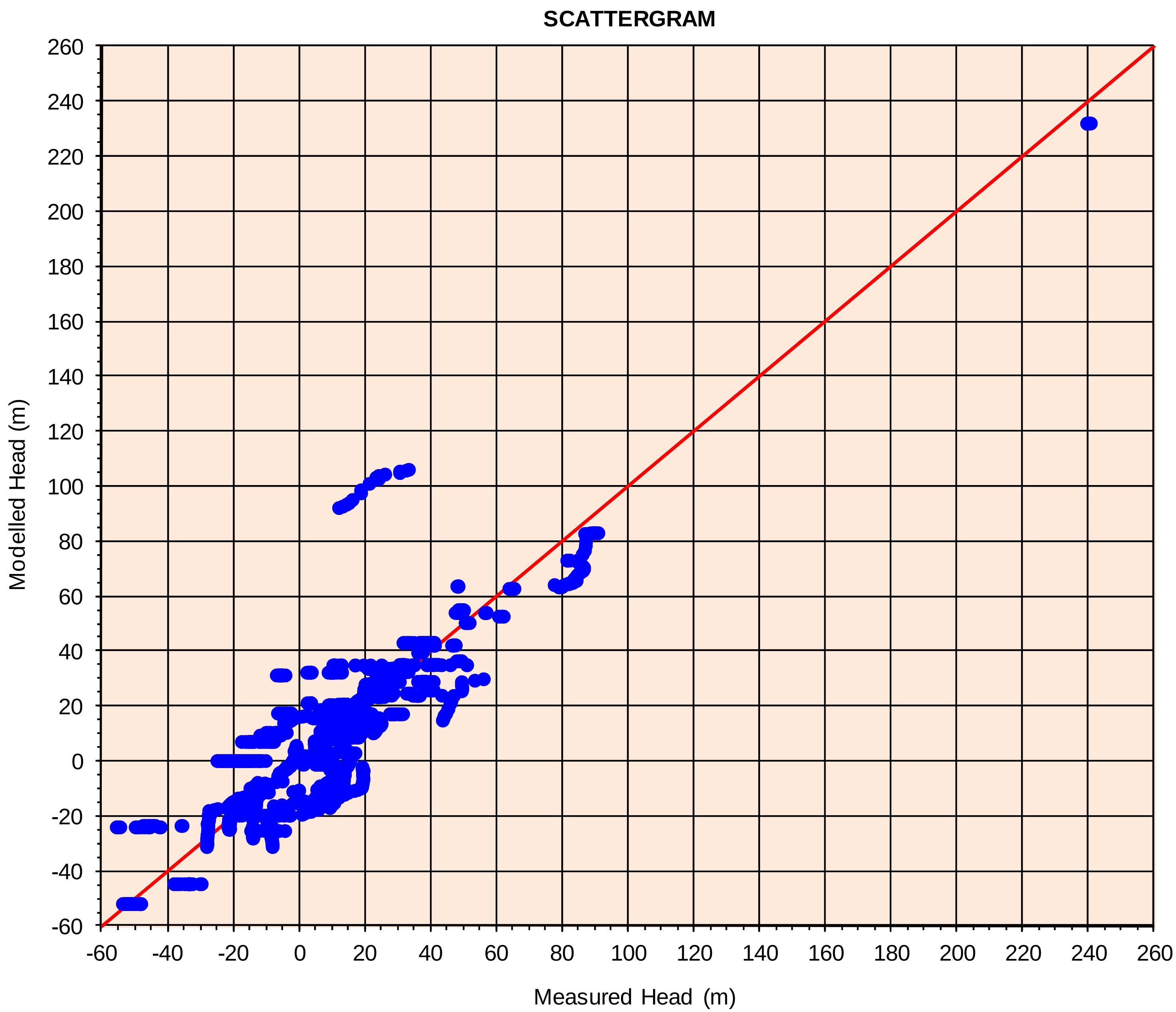
Model Cross Section



RPS Aquaterra

FIGURE 7.3

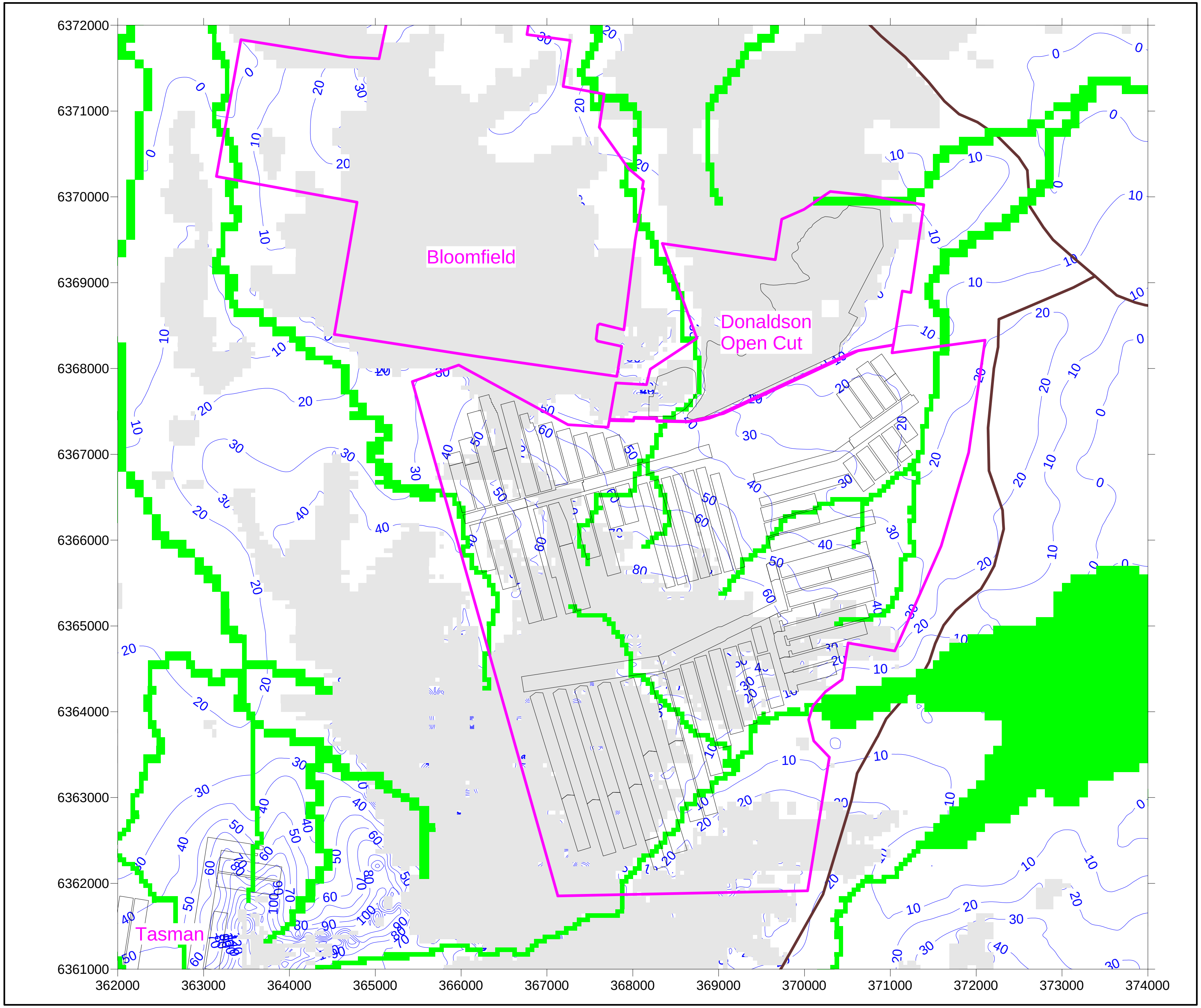
Model Recharge Zones



RPS Aquaterra

CALIBRATION SCATTER DIAGRAM OF MEASURED VERSUS MODELLED POTENTIOMETRIC HEAD FIGURE 7.4

f:\jobs\s64dd\600\650_figure\fig_7.4.docx



LEGEND

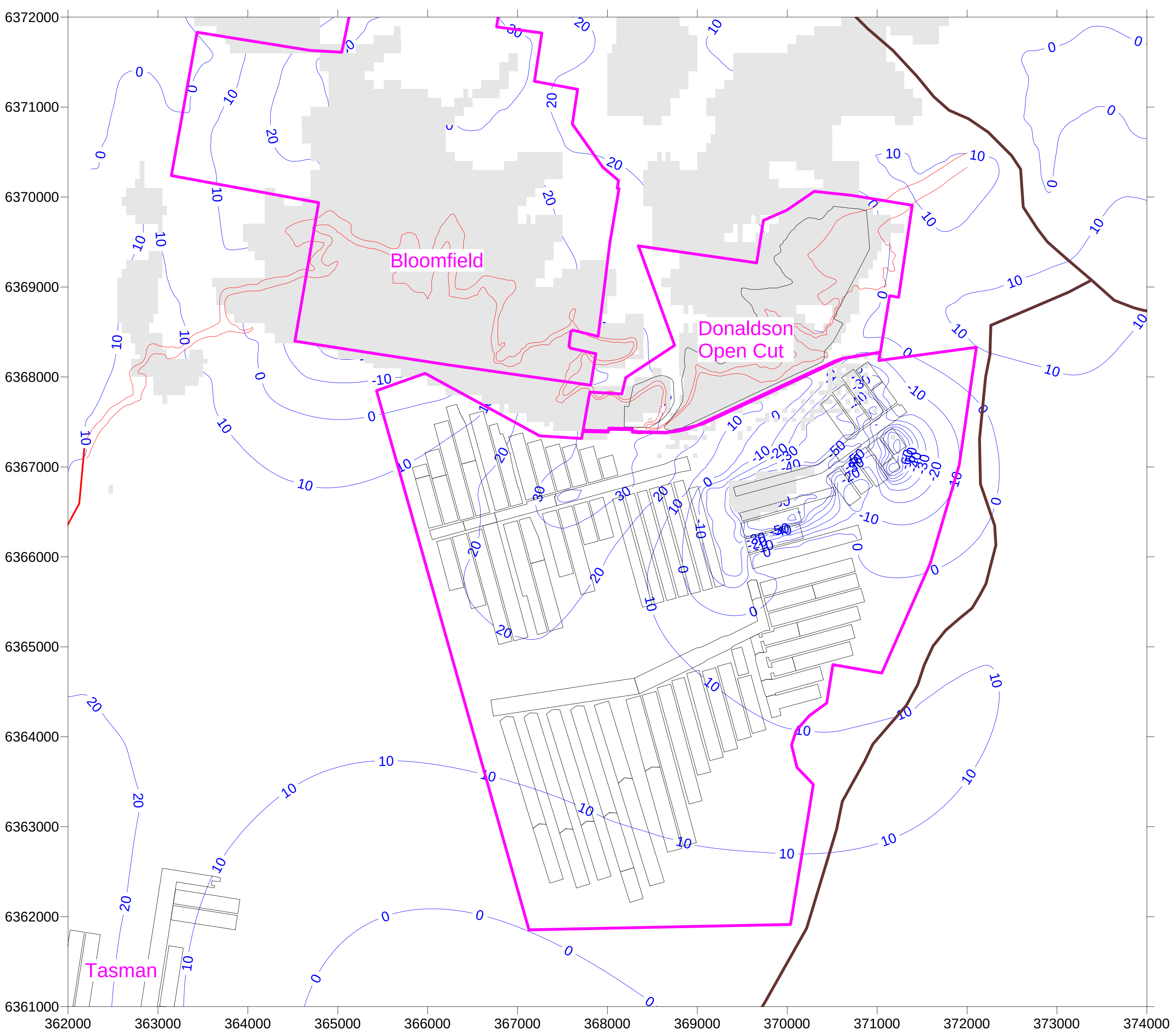
- Mine Lease
- River or Lake
- Mine Plan
- Main Road
- Dry Cells
- Groundwater Levels (mAHD)

N

RPS Aquaterra

FIGURE 7.5

Calibrated Groundwater Level in Alluvium / Colluvium / Regolith (Layer 1) prior to the Modification



LEGEND

- Mine Lease
- Mine Plan
- Main Road
- Dry Cells
- Groundwater Levels (mAHD)
- Boundary of Donaldson Seam

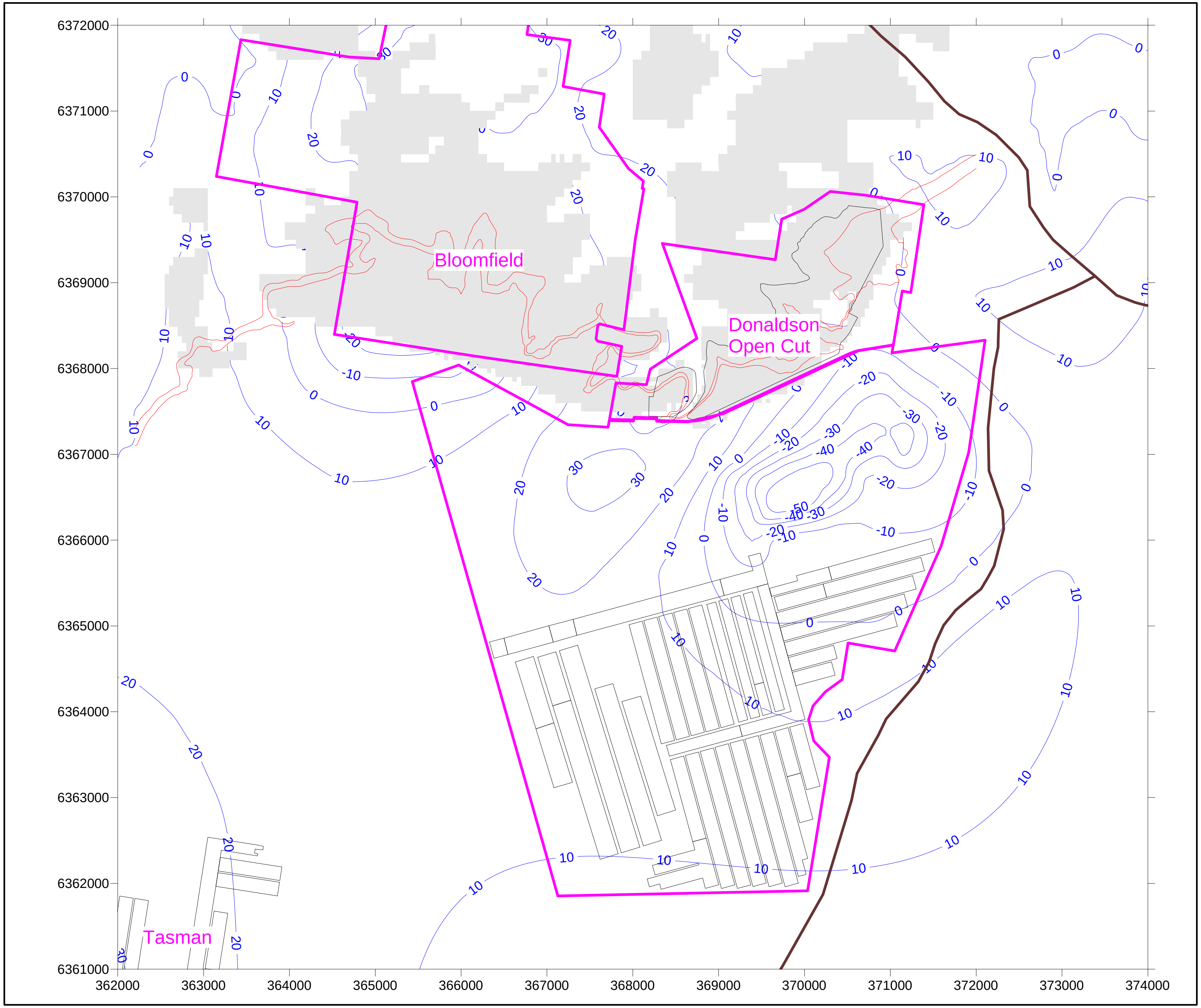
N

RPS Aquaterra

FIGURE 7.6

Calibrated Groundwater Level in Upper Donaldson Seam (Layer 13) prior to the Modification

S64_005 Rev: A Produced: HZ Reviewed: KB Date: 22/08/2012



LEGEND

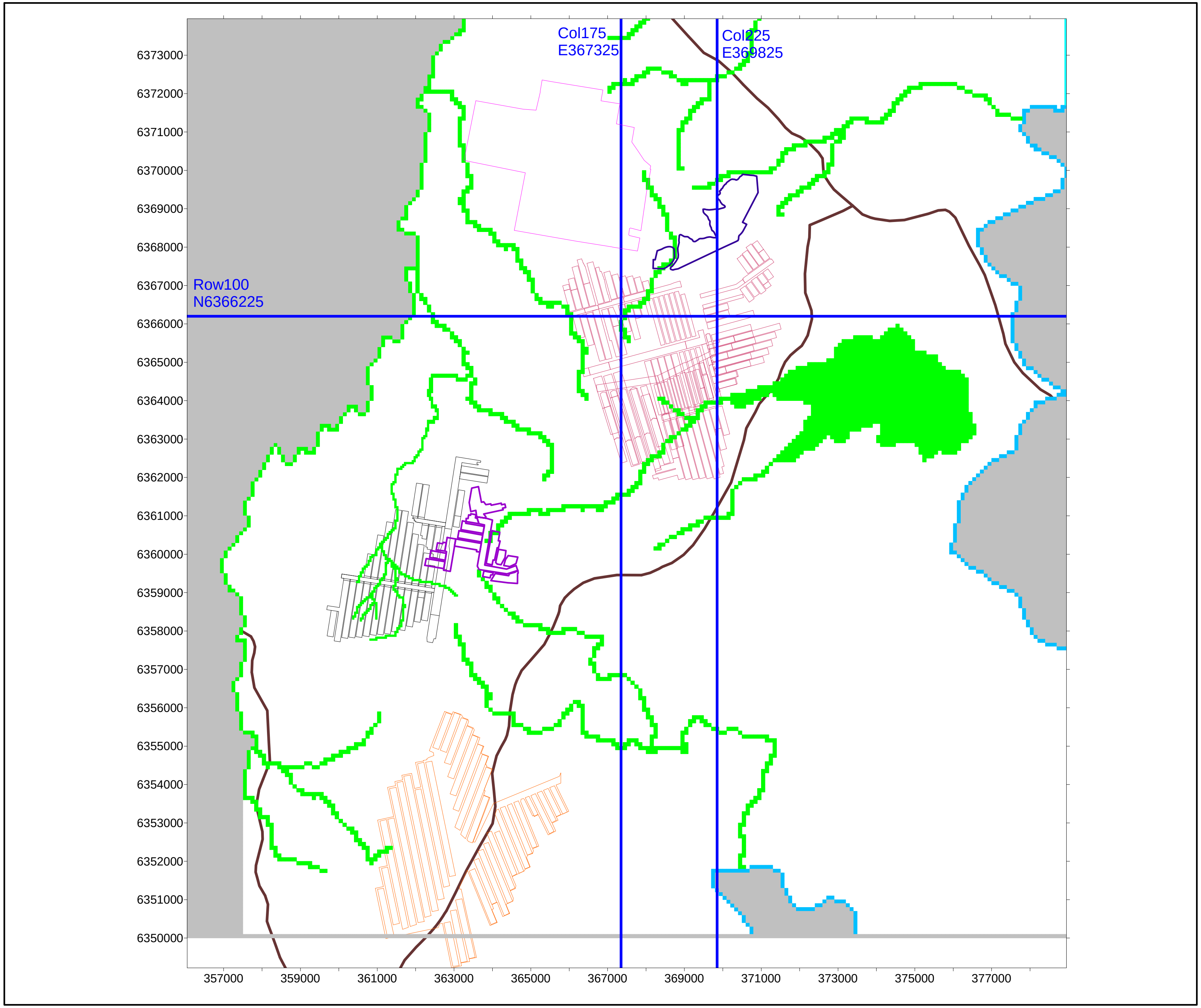
- Mine Lease
- Mine Plan
- Main Road
- Dry Cells
- Groundwater Levels (mAHD)
- Boundary of Donaldson Seam

RPS Aquaterra

FIGURE 7.7

Calibrated Groundwater Level in Lower Donaldson Seam (Layer 15) prior to the Modification

S64_011 Rev: A Produced: HZ Reviewed: KB Date: 22/08/2012



LEGEND

- Rivers or Creeks
- No Flow
- General Head Boundary
- Main Road
- Tasman Extension Mine Plan
- Current Tasman Mine
- Abel Mine Plan
- West Wallsend Mine Plan
- Donaldson Open Cut Area
- Bloomfield Open Cut Area

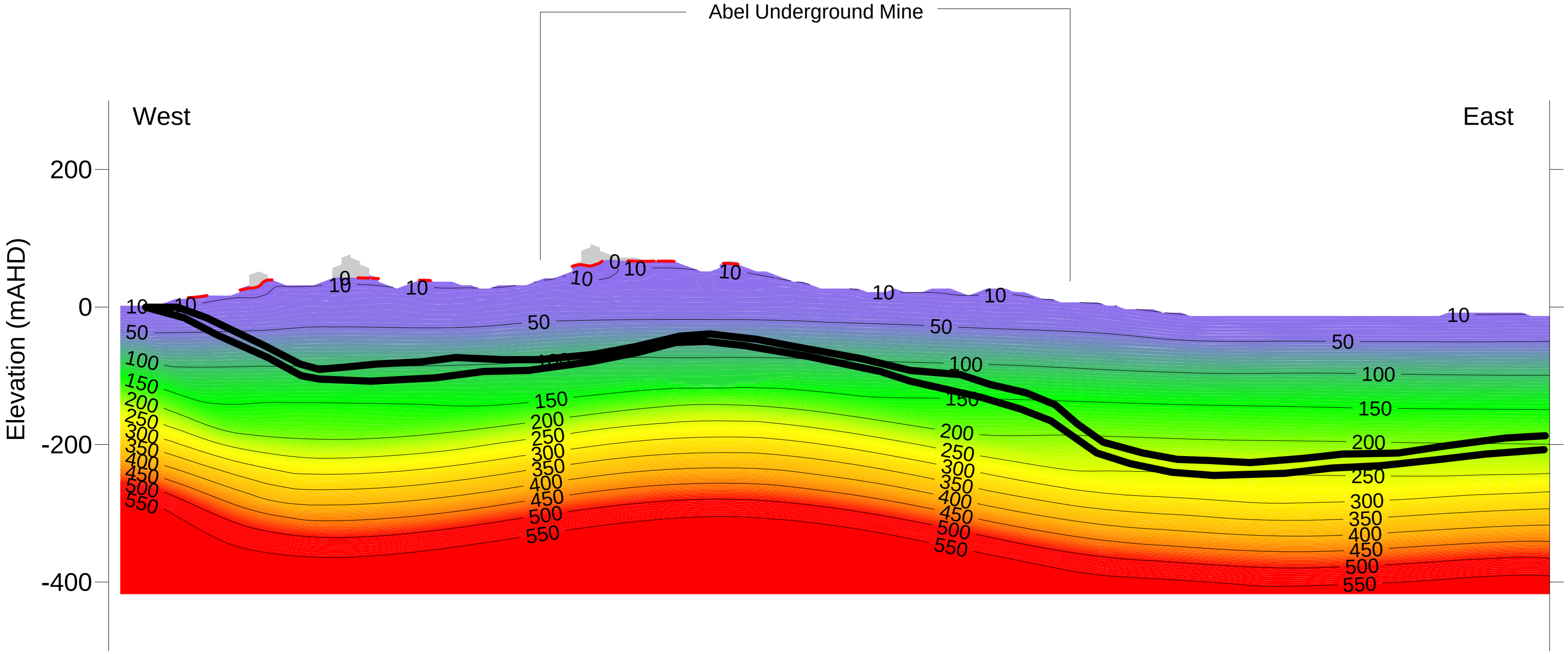
N

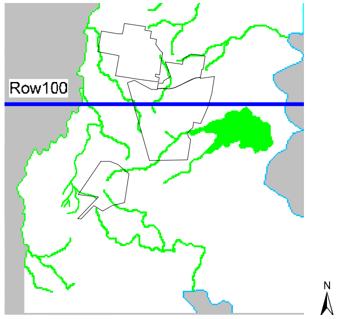
RPS Aquaterra

FIGURE 7.8

Groundwater Model Area Showing Location of Pressure Head Cross-Sections

S64_012 Rev: A Produced: HZ Reviewed: KB Date: 22/08/2012





LEGEND

Inset

Rivers or Creeks

No Flow

General Head Boundary

Cross Section

Water Pressure Head (m)

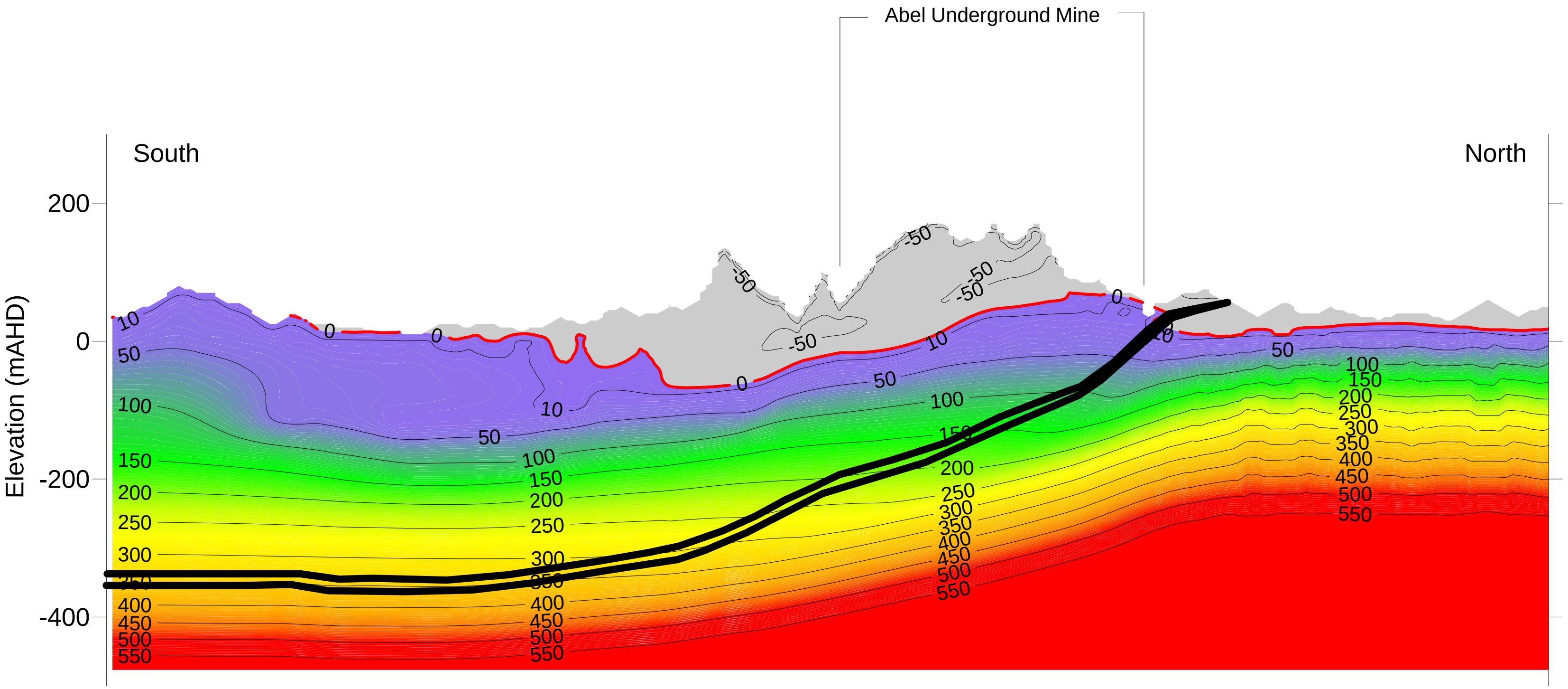
Donaldson Seam

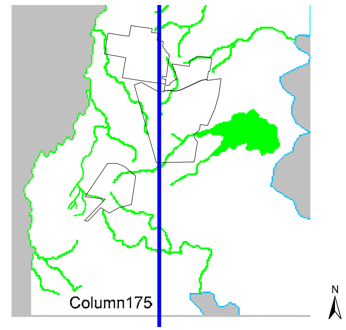
Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Please verify the accuracy of all information prior to use.

RPS Aquaterra

FIGURE 7.9

Steady State Water Pressure Head
Along Northing 6366225 (Row 100)





LEGEND

Inset

- Rivers or Creeks
- No Flow
- General Head Boundary

Cross Section

- Water Pressure Head (m)
- Donaldson Seam

RPS Aquaterra

FIGURE 7.10

Steady State Water Pressure Head Along Easting 367325 (Column 175)

S64_021 Rev: A Produced: HZ Reviewed: KB Date: 23/08/2012