LIDDELL COAL OPERATIONS

APPENDIX **G**

Groundwater Assessment (SKM, 2013)

APPENDICES

SINCLAIR KNIGHT MERZ

SKM

Liddell Coal Operations Modification 5 to Development Consent DA 305-11-01

GROUNDWATER IMPACT ASSESSMENT

- V05
- April 2013

Liddell Coal Operations
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Executive Summary

Liddell Coal Operations (LCO) is an established open-cut coal mining operation located near Ravensworth in the Upper Hunter Valley region of New South Wales. LCO is seeking modification to its existing development consent DA 305-11-01 to allow for the extension of open cut mining operations beyond the currently approved mining footprint so as maximise coal recovery, including:

- Extension of open cut mining in the South Pit and the Entrance Pit to the south and east, and upon completion of mining in these pits, mining of coal resources under the Mine Infrastructure Area (MIA);
- An additional tailings emplacement within the final void of the South Pit; and
- Ancillary surface disturbances and infrastructure to support new mining areas.

LCO is required to submit an Environmental Assessment (EA) in support of its application to extend open cut mining operations. The EA is intended to address the Director General's Requirements (DGRs) for the proposed extension, including an assessment of the impacts of the proposed extension on local groundwater and surface water resources. The purpose of this Groundwater Impact Assessment report is to address the DGRs and specific issues outlined by NSW Office of Water for the assessment of potential impacts of the proposed mine extension on local groundwater resources.

The methodology for the assessment is based on a framework that recognizes the need to consider both the direct potential impacts of mining operations on local to regional scale groundwater systems, and the potential exposure and response of receptors within a regional context. Risks or threats to groundwater systems emerge from exposure pathways and adverse responses of receptors to potential direct impacts. Accordingly, the impact assessment is presented within the following structure:

- Describe the *Context and Setting* of the proposed operations (**Section 2**);
- Identify *Potential Direct Groundwater Impacts* (**Section 4.1**);
- Identify potential *Receptors* (**Section 4.2**);
- Provide an *Impact Assessment* (**Section 4.3**); and
- Identify *Monitoring and Management* measures and strategies to monitor and, where necessary, mitigate such impacts (**Section 5**).

The potential impacts of mining and related activities on surface water and groundwater systems can be evaluated using numerical groundwater flow models. For this assessment a regional groundwater model for the Jerrys and Glennies Water Sources of the Upper Hunter Valley was developed and interrogated to predict and evaluate the potential impacts of the proposed modification on local and regional groundwater resources (**Section 3**).

The results of the predictive model simulations and groundwater impact assessment provide the following key conclusions:

Impacts to Bowmans Creek alluvial aquifer

- With the exception of the final year of the Entrance Pit progression (year 2022), the magnitude of alluvial losses estimated by the model under the proposed is similar to the leakage rates predicted for current mining operations at LCO. These estimated losses from the alluvium amount to between 150 to 180 ML/year up to 2021, and peak at 270 ML/year for 2022.
- Under the proposed modification, model results predict that the progression of the South Pit has negligible impact on the Bowmans Creek alluvial aquifer in terms of increased leakage or drawdown.
- Estimates of historical baseflow contributions to Bowmans Creek streamflow suggest the peak estimated loss of groundwater flow caused by the proposed modification accounts for approximately 4% to 8% of the estimated baseflow component of streamflow and less than 2% of measured annual streamflow.
- Recent groundwater monitoring data and predictive model results indicate leakage from the alluvial aquifer induced by previous underground mining and current open cut mining activities at LCO are having negligible impact on groundwater levels within the alluvium. As a result the estimated losses in groundwater flow under the proposed modification are unlikely to have a significant impact on streamflow in Bowmans Creek or on water levels within the associated alluvial aquifer.
- Historical monitoring of groundwater within the Bowmans Creek alluvium suggests minimal impact of mining operations on groundwater quality, and model simulations provide no indication that the proposed modification will alter the hydrogeologic regime in a manner that would adversely affect groundwater quality.
- Predicted drawdown within the Bowmans Creek alluvial aquifer is expected to be negligible (less than 0.25 m) relative to current water levels up to 2019. When estimated leakage rates peak at the end of mining, drawdown is predicted to peak at less than one meter relative to current water levels. This peak drawdown estimate falls below the minimal impact criteria for aquifer interference activities as defined in the NSW Aquifer Interference Policy (2012).

Impacts to hard rock aquifers

- Estimated total groundwater extraction from the regional hard rock aquifer, determined as the sum of pit inflows and dewatering requirements, needed to accommodate the proposed modification peaks at less than 4,000 ML/year. LCO currently holds extraction licenses totalling 27,000 ML/year for this water source.
- Post mining equilibrium simulations predict the Entrance Pit final void will act as a sink and the South Pit will act as a source for groundwater flow from and to the regional hard rock aquifer. Predicted increases in salinity in the South Pit final void (G&A, 2013) result in potential long term impacts to groundwater quality in the hard rock aquifer due to leakage of increasingly saline water from the South Pit final void when water levels in the void are above approximately 65 m AHD.

The following table summarizes the groundwater impacts assessment for the proposed modification based on the predictive model simulations and other relevant data.

Potential Receptor	Direct Impact	Discussion
Bowmans Creek alluvium (including groundwater dependent ecosystems)	Groundwater quantity	• Predicted leakage rates as a result of the proposed modification are estimated to peak at approximately 270 ML/year at the end of mining. LCO currently holds groundwater licence allocations of 142 ML/year for this water source. • Model simulations predict a peak drawdown within the alluvial aquifer of less than one meter as a result of the proposed modification. This estimated peak drawdown falls below the minimal impact criteria for aquifer interference activities as specified in the Aquifer Interference Policy (NSW, 2012). • Post mining equilibrium simulations further indicate that alluvial groundwater levels will return to current (2013) levels within 50 years following the end of mining.
	Groundwater quality	• Historical monitoring data suggests minimal impacts on groundwater quality in the Bowmans Creek alluvial aquifer due to current and historical mining operations at LCO. • Model simulations provide no indication that the proposed modification will alter the hydrogeologic regime in a manner that would adversely affect groundwater quality within the Bowmans Creek alluvium.
	Surface Water – Groundwater Interaction	• Estimates of baseflow contributions to Bowmans Creek streamflow suggest the predicted peak annual leakage rate caused by the proposed modification accounts for approximately 4% to 8% of the estimated baseflow component of streamflow and less than 2% of measured annual streamflow. • The estimated leakage rates are unlikely to have a significant impact on streamflow in Bowmans Creek or on water levels within the associated alluvial aquifer.
	Aquifer Impact	• The proposed open cut extensions do not intercept the Bowmans Creek alluvial system.
Neighbouring mining operations	Groundwater quantity	• Neighbouring mining operations require depressurisation and dewatering of the coal seams for their own mining purposes, indicating these operations would not be adversely impacted by the predicted depressurisation of the hard rock aquifer caused by the LCO modification. • Water levels in the final voids are predicted to equilibrate levels at which the Entrance Pit is predicted to be a sink while the South Pit is predicted to act as a source of groundwater to the hard rock aquifer.
	Groundwater quality	• Following cessation of mining activities, G&A (2013) predicts salinity in the South Pit final void will increase continuously over time (G&A, 2013), resulting in the potential for long term impacts to groundwater quality in the hard rock aquifer due to leakage of increasingly saline water from the South Pit final void when water levels are above approximately 65 m AHD.
	Surface Water – Groundwater Interaction	• Model predictions and monitoring data indicate the proposed modification is unlikely to have a significant impact on streamflow in Bowmans Creek or on water levels within the associated alluvial aquifer.
	Aquifer Impact	• The depressurisation of the hard rock aquifer caused by the LCO modification is not expected to adversely impact neighbouring mining operations

Based upon the impact assessment and predictive model results, an adaptive management strategy is proposed for the monitoring and (if necessary) mitigation of any potential impacts to the Bowmans Creek alluvial system. Key aspects of the management strategy include:

- Review, update, and implement the current Water Management Plan and Groundwater Monitoring Program for LCO under the proposed modification;
- Supplementation of the existing monitoring network with locations targeting areas predicted by the model for potential alluvial drawdown as a result of the proposed modification;
- Continue to update, refine and re-validate the groundwater model with additional site and monitoring data as it is collected;
- If updated model results continue to predict future groundwater losses from the Bowmans Creek alluvial aquifer in excess of LCO's license allocations for the Jerrys Water Source, LCO should pursue additional licences to cover the estimated losses; and
- If and where necessary, initiate adjustment of mining and/or dewatering plans to mitigate actual or predicted impacts on the alluvial system.

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1. Introduction

1.1 Background

Sinclair Knight Merz Pty Ltd (SKM) has been engaged by Liddell Coal Operations (LCO) Pty Ltd to carry out a Groundwater Impact Assessment for the LCO Development Consent Modification 5 Environmental Assessment (EA). LCO is an established open-cut coal mining operation located near Ravensworth in the Upper Hunter Valley region of New South Wales (refer **Figure 1-1**). LCO is managed by LCO Pty Ltd on behalf of the Liddell Joint Venture (LJV). The LJV ownership comprises Enex Liddell Pty Ltd holding 35 per cent; Gaburne Pty Ltd holding 32.5 per cent; and Mitsui Matsushima Pty Limited holding 32.5 per cent. Gaburne Pty Limited is wholly owned by Enex Liddell Pty Limited which is wholly owned by Xstrata Coal Pty Limited (XC). XC is ultimately controlled by GlencoreXstrata plc.

Mining at LCO has been in continuous operation since the 1950s, during which time mining operations have been subject to a number of development consents. In 2001, a development application was lodged with Planning NSW (now the Department of Planning and Infrastructure (DP&I)) to continue operations at the mine. Development Consent DA 305-11-01 was granted by the Minister for Planning on 20 November 2002 for 21 years of continued mining operations at LCO. This DA remains the current development consent for LCO, and has since been modified on four separate occasions. The DA boundary can be seen in **Figure 1-1**.

LCO is now seeking a fifth modification to development consent DA 305-11-01 to allow for the extension of open cut mining operations beyond the currently approved mining footprint so as maximise coal recovery. The proposed expansion of mining is within both the existing development consent DA 305-11-01 boundary and mining lease ML 1597 and can be seen in **Figure 1-2**. The proposed modification shown in **Figure 1-2** primarily includes:

- Extension of open cut mining in the South Pit and the Entrance Pit to the south and east, and upon completion of mining in these pits mining of coal resources under the Mine Infrastructure Area (MIA);
- An additional tailings emplacement within the final void of the South Pit; and
- Ancillary surface disturbances and infrastructure to support new mining areas.

- **Figure 1-1 – Locality Plan**

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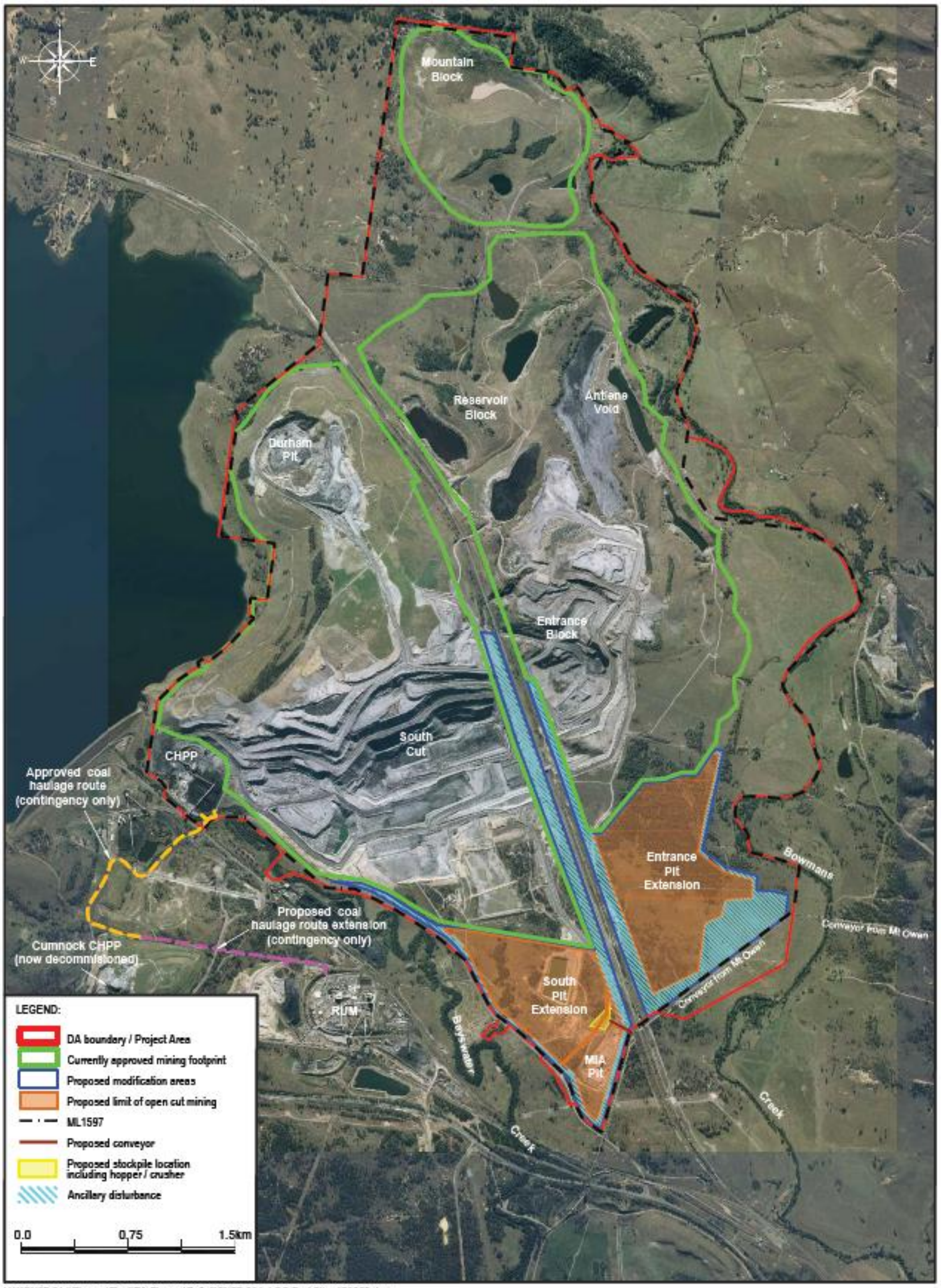
- **Figure 1-2 – Proposed Mine Extension**



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1.2 Purpose of this Report

LCO is required to submit an EA in support of its application to extend open cut mining operations. The EA is intended to address the NSW DP&I's Director General's Requirements (DGRs) for the proposed extension. A key component of the DGRs is an assessment of the impacts of the proposed extension on local groundwater and surface water resources, including any specific impacts designated by the NSW Office of Water.

The purpose of this Groundwater Impact Assessment report is to address the DGRs and specific issues outlined by NSW Office of Water for the assessment of potential impacts of the proposed mine extension on local groundwater resources. The key groundwater issues highlighted in the DGRs and addressed in this report are summarized in **Table 1-1**.

Table 1-1 – DGRs Addressed in This Report

Director-General's Requirement	Relevant Section of Report
General Requirements	
▪ A detailed assessment of the key issues specified below, and any other significant issues identified in the risk assessment, which includes:	
– A description of the existing environment;	Section 2
– An assessment of the potential impacts of all stages of the modification, including any cumulative impacts associated with the concurrent operation of the modification with any other existing or approved mining or gas production operations in the region, taking into consideration any relevant policies, guidelines, plans and statutory provisions; and	Section 3 and 4
– A description of the measures that would be implemented to avoid, minimise, mitigate and/or offset the potential impacts of the modification, including detailed contingency plans for managing any significant risks to the environment;	Section 5
▪ A statement of commitments, outlining all the proposed environmental management and monitoring measures	Section 5
Key Issues: Soil and Water	
▪ A detailed assessment of the potential impacts of the modification, using appropriate quantitative modelling on:	
– The quantity and quality of both surface and ground water resources, with particular reference to the Hunter River, alluvial groundwater and the evaporative sink extension	Section 4.1.1 and 4.1.2
– Ground and surface water users, both in the vicinity of and downstream of the modification	Section 4.2 and 4.3
▪ A comparison of these impact predictions against those associated with the existing mine plan, including detailed explanations for any differences	Section 3.3 and 4.3

In addition to these issues, NSW Office of Water highlighted specific assessment requirements in their letter dated 28 June 2012 relating to the potential impacts of the proposed mine extension on the surface water and alluvial groundwater system of Bowmans Creek, which forms part of the eastern boundary of DA 305-11-01 (refer **Figure 1-1**). The issues highlighted by NSW Office of Water and addressed in this report are summarized in **Table 1-2**.

- **Table 1-2 – NSW Office of Water Requirements Addressed**

NSW Office of Water Issue	Relevant Section of Report
▪ Interference with either alluvial or surface waters associated with Bowmans Creek requires, as a minimum, accounting in accordance with the *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009* (WSPHUAWS)	Section 1.5 and 3.3
▪ Provide mapping of the Bowmans Creek alluvial boundary, with additional information regarding the development of the alluvial groundwater system, and the nature, integrity and risks posed by the open cut mining proposal to the alluvial system. This requires the following information to be presented:	
– Mapping of the lateral and vertical alluvial materials, and identification of saturated layers within the alluvium	Figure 2-10 and Appendix B
– Transects across the Bowmans Creek floodplain from within the extension footprint to the break of slope forming the lower cadastre to the east side of Bowmans Creek	Appendix B
– Identification of alluvial terraces and other geomorphic features both within the floodplain and in the inset channel to Bowmans Creek	Section 2.6
– Ranges and time series groundwater level and quality data, and interpreted groundwater hydraulic gradients and conductivities	Section 2.6
– Formation of an adequate baseline of alluvial groundwaters, including absolute and relative groundwater levels, triangulated groundwater gradients across the Bowmans Creek floodplain	Section 2.6 and Appendix B
▪ An adequate understanding of the importance of the Bowmans Creek portion of the Jerrys Water Source, and the accounting mechanisms related to the provisions of the Water Management Act 2000 and the WSPHUAWS	Sections 1.5, 3.3 and 4.1
▪ Detailed assessment of the history of impacts to Bowmans Creek, present actions by Liddell Operations and risks associated with further interaction with the flooded underground mine workings	Section 2.6 and 4.1

Information describing the Bowmans Creek surface water and alluvial groundwater system is presented in this report (refer **Section 2.6**), along with an assessment of the potential impacts of the proposed mine extension (refer **Section 4.3**) on groundwater resources. Impacts on surface water resources are addressed in a separate report by Gilberts & Associates (G&A, 2013).

1.3 Scope of Work

In order to address the DGR and NSW Office of Water requirements outlined above, SKM has undertaken the following scope of works for the Groundwater Impact Assessment.

- Review of applicable legislative and statutory requirements for the proposal, including the NSW *Water Management Act 2000* and its Water Sharing Plans (WSPs), the Strategic Regional Land Use Plan (SRLUP) for the Hunter Valley, and the NSW Government's Aquifer Interference Policy
- Review of DGRs and consultation with NSW Office of Water in relation to the proposed mine extension and its potential impacts on the Bowmans Creek surface water and alluvial groundwater system
- Review and assimilation of existing geological and hydrogeological information for LCO and the surrounding area, including regional and local stratigraphy and lithology, surface water and groundwater flow systems, and groundwater and surface water quality data
- Review and assimilation of the impacts of historical mining activities on local aquifer systems
- Review of groundwater monitoring data for the area of interest and consideration of future monitoring needs
- Development of a conceptual hydrogeological model for the site and surrounding area
- Development of a numerical groundwater flow model for the region that accounts for existing mining activities both at the site and in the regional area
- Interrogation of the numerical groundwater model to understand groundwater flow regimes, mass balances and surface water – groundwater interactions under the existing and proposed mining conditions
- Assessment of the potential effects of the proposed mine extension on surface water and groundwater resources, identification of potential receptors to such impacts, and assessment of the resulting impacts to the identified receptors
- Identification of potential mitigation measures and monitoring systems to mediate these impacts

1.4 Assessment Methodology

To understand the level of potential impact posed to groundwater systems as a result of mine and supporting infrastructure development, it is necessary to consider how operations such as dewatering, water supply development, mine waste management, supporting infrastructure (such as water treatment facilities, landfills and fuel storages) and linear infrastructure development (e.g. roads and pipelines) might change the 'natural' groundwater regime and so impact upon groundwater systems and potential users of groundwater. Potential direct groundwater impacts relate to the physical impacts of *water affecting activities* at the mine and its supporting infrastructure on groundwater systems. Four categories of potential direct impacts have been identified by Brereton and Moran (2008). They are:

- *Groundwater quantity* – including consideration of changes to groundwater levels / pressures and flux

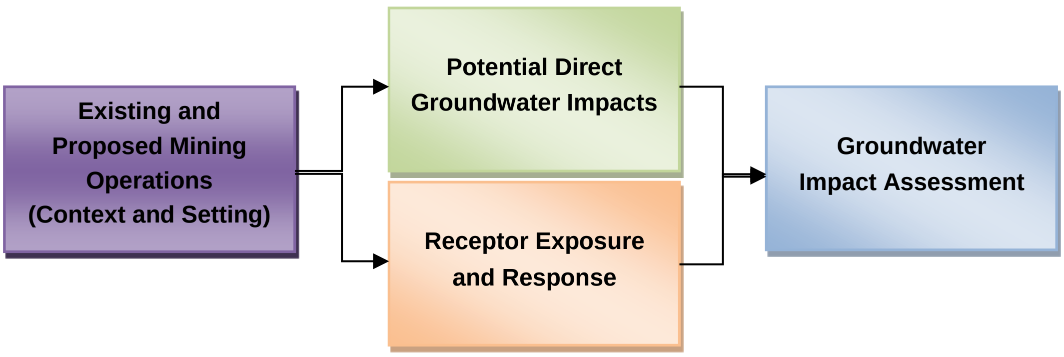
- *Groundwater quality* – including consideration of salinity and concentrations of other important water quality constituents (such as metals, pH, nutrients and radionuclides)
- *Groundwater – surface water interactions* – including consideration of changes to the level of interaction between groundwater and surface water systems (such as stream baseflow)
- *Physical disruption of aquifers* – including consideration of whether or not there will be permanent disruption of a groundwater system by mining, and to what extent

In order to fully assess the risks arising from potential direct impacts to groundwater systems, the exposure and response of potential receptors to these impacts must also be evaluated. The term receptor is used here to include environmental, social and cultural, and economic users of groundwater resources. Examples of typical groundwater receptors that may be impacted by a mining operation include:

- *Environmental*: groundwater dependent ecosystems such as aquatic ecosystems that are maintained to some extent by baseflow, and terrestrial vegetation that utilises groundwater to meet some or all of its water requirements
- *Economic*: including agricultural and aquacultural activities that rely on groundwater for irrigation or stock watering, and other mining operations that utilise groundwater to meet all or some of their mine water requirements
- *Social and cultural*: including recreational use of water resources, as well as domestic, urban and rural water supply and spiritual connections for Traditional Owners.

Groundwater impact assessments for mining operations need to consider both the direct potential impacts on local to regional scale groundwater systems and the potential exposure and response of receptors within a regional context (**Figure 1-3**). Risks or threats emerge from exposure pathways (where they exist) and adverse responses of receptors to potential direct impacts on groundwater systems.

- **Figure 1-3 – Groundwater Impact Assessment Framework (Howe et al., 2010)**



The Groundwater Impact Assessment presented in this report follows the structure outlined in **Figure 1-3** and is summarised below:

- *Context and Setting* (**Section** 2): Placing the current mine operations and proposed extension into a regional context, including identifying hydrogeologic flow regimes, interactions between groundwater flow systems, climatic factors and preliminary identification of potential groundwater receptors (environment, social, economic) that might be impacted by the proposed mine extension.
- *Potential Direct Groundwater Impacts* (**Section 4.1**): Identifies potential direct impacts to the groundwater system arising from the proposed mine extension.
- *Receptor Exposure and Response* (**Section 4.2**): Provides an understanding of the receiving environment that will potentially be affected by direct impacts, and clearly identifies those receptors that are exposed to these potential impacts.
- *Impact Assessment* (**Section 4.3**): Provides an evaluation of the degree to which potential direct impacts will affect the receptors identified, both spatially and temporally.

1.5 Legislative Framework

1.5.1 *Water Management Act 2000*

The objective of the NSW *Water Management Act 2000* is the sustainable and integrated management of the state's water for the benefit of both present and future generations. The act recognises the need to allocate and provide water for the environmental health of our rivers and groundwater systems, while also providing licence holders with more secure access to water and greater opportunities to trade water through the separation of water licences from land. The main tool within the Act for managing the State's water resources are Water Sharing Plans (WSPs). These plans protect the health of our rivers and groundwater while also providing water users with perpetual access licences, equitable conditions, and increased opportunities to trade water through separation of land and water.

Under the WSPs distinct water sources are identified as the primary unit of water management and are used to define and limit surface and groundwater allocations for a given area. The WSP relevant to operations at LCO is the *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009*, which includes unregulated rivers and creeks, highly connected alluvial groundwater, and tidal pool areas within the Hunter region. In total the Hunter Unregulated and Alluvial WSP covers 39 different water sources, nine of which are further sub-divided into management zones (DWE, 2009). The Hunter Unregulated and Alluvial WSP commenced in August 2009.

Bowmans Creek and its associated alluvial aquifer is located within the Jerrys Management Zone of the Hunter Unregulated and Alluvial WSP. The Jerrys Management Zone and Appletree Flat Management Zone are used to manage separate areas of the Jerrys Water Source. Water sharing rules for Jerrys Water Source are governed by the WSP and include access and trading rules and restrictions on alluvial groundwater bores. According to NSW Office of Water (2012), interference with surface waters or alluvial groundwaters associated with Bowmans Creek requires accounting in accordance with this WSP and an understanding of the importance of Bowmans Creek and its alluvial groundwater to the Jerrys Water Source.

Whilst the WSPs govern the accounting and use of water from a given source, the sustainable allocations specified in the WSPs were estimated through consideration of agricultural, industrial, and stock and domestic use at the time the WSP commenced. No estimation (real or potential) of, or provision for, water use by mining operations was made in the WSP allocations, including impacts on alluvial systems by mining activities. Accordingly water use by mining operations at the time of commencement of the Hunter Unregulated and Alluvial WSP (August 2009) is presumed to have been accounted for in the sustainable allocation, and only additional usage from that time requires water licenses.

1.5.2 NSW Aquifer Interference Policy (2012)

In September 2012, the NSW Government released its Aquifer Interference Policy to objectively define the process by which projects are assessed to determine their potential impacts on aquifers, to clarify the requirements for obtaining water licenses for aquifer interference activities, and to define the considerations for assessing potential impacts on key water-dependent assets. The policy focuses on mining, coal seam gas exploration and extraction, and other activities that remove water from aquifers for non-water supply purposes.

The *Water Management Act 2000* defines an aquifer interference activity as that which involves 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
- The disposal of water taken from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations

Aquifer interference activities may take water from the source in which they exist as well as connected groundwater and surface water sources. The Aquifer Interference Policy clarifies water licence requirements and details how these potential interference activities will be assessed under relevant planning and approvals processes. The policy provides 'minimal impact considerations' to evaluate potential impacts on groundwater levels, pressures, and quality for different categories of groundwater sources. The policy also includes provisions for water take from a source following the cessation of the aquifer interference activity.

According to the policy, the assessment of impacts on water sources and water dependent ecosystems will be based on the project proponents' ability to demonstrate:

1. The capacity to obtain the necessary licenses to account for the take of water from a given source, or if licenses are unavailable, that the proposed project has been designed to prevent the take of water;
2. That adequate arrangements will be in place to meet the 'minimal impact considerations' defined in the policy; and

3. Proposed remedial actions for impacts greater than those that were predicted as part of the relevant approval.

The ‘minimal impact considerations’ provided in the policy are defined for ‘highly productive’ and ‘less productive’ groundwater sources, both of which are further grouped into categories according to aquifer type (e.g. alluvial, coastal sands, fractured rock, etc). Two levels of ‘minimal impact considerations’ are provided, and if the predicted impacts are less than the Level 1 impact considerations, then the impacts from the project would be considered acceptable. If the predicted impacts are greater than the Level 1 considerations, additional studies would be required to fully assess these impacts.

The alluvial systems of the Hunter River and its tributaries, which includes Bowmans Creek, are listed as Biophysical Strategic Agricultural Land (BSAL) under the NSW Government’s Strategic Regional Land Use Policy. As such, the proposed mine extension for LCO requires an assessment of potential environmental impacts on Bowmans Creek and its alluvial groundwater system.

1.5.3 Water Licensing

LCO currently holds several different licenses to extract groundwater from water sources in the area to accommodate mining operations. These licenses include allocations to extract groundwater from Jerrys Water Source, which is regulated under the Hunter Unregulated and Alluvial WSP (2009), as well as allocations to extract water from deeper regional hardrock aquifers where the targeted coal measures are found. **Table 1-3** provides a summary of the current extraction licenses held by LCO. Current licensing allocations permit LCO to extract a total of 142 ML/year from Jerrys Water Source, which includes Bowmans Creek and its associated alluvial aquifer system, and up to 27,000 ML/year (27 GL/year) from the regional hard rock aquifer.

- **Table 1-3 – Summary of Groundwater Extraction Licences held by LCO**

Name / Licence No.	Licence Holder	Water Source	Type / Use	Alloc. (ML/yr)	Status / Notes
WAL18302	Liddell Southern Tenements P/L	Jerrys Water Source	Irrigation	5	
WAL18304	Enex Foydell P/L	Jerrys Water Source	Irrigation	32	On Glendell land
WAL18318	Enex Foydell P/L	Jerrys Water Source	Irrigation	55	
WAL18320	Enex Foydell P/L	Jerrys Water Source	Irrigation	50	Mt Owen Complex 50 unit share - responsible
Haz 2 / 20BL168060	Liddell Tenements P/L	Hardrock (Coal Measures)	Industrial	5500	Dewatering into Hazeldene workings
Durham 2 & 4	Liddell Tenements P/L	Hardrock (Coal Measures)	Industrial	1000	
8 South 3 & 4	Liddell Tenements P/L	Hardrock (Coal Measures)	Industrial	6000	Dewatering into Hazeldene workings east of Barrier Pit
Durham 1	Liddell Tenements P/L	Hardrock (Coal Measures)	Industrial	6000	Dewatering into Liddell workings
M49	Liddell Southern Tenements P/L	Hardrock (Coal Measures)	Dewatering	2500	
Middle Liddell	Liddell Coal Operations P/L	Hardrock (Coal Measures)	Dewatering	6000	

2. Context Setting

2.1 Regional Mining Activities

LCO is an established open-cut coal mining operation located approximately 25 km northwest of Singleton in the Upper Hunter Valley region of New South Wales. The region surrounding the mine has been subject to extensive underground and open-cut coal mining since the early 20th century which has extensively altered the area's physical features and setting, including the regions surface water and groundwater systems. The location of other mines in the region is shown in **Figure 2-1**, and a summary of these mining operations is provided in the following sections.

2.1.1 Liddell Coal Operations

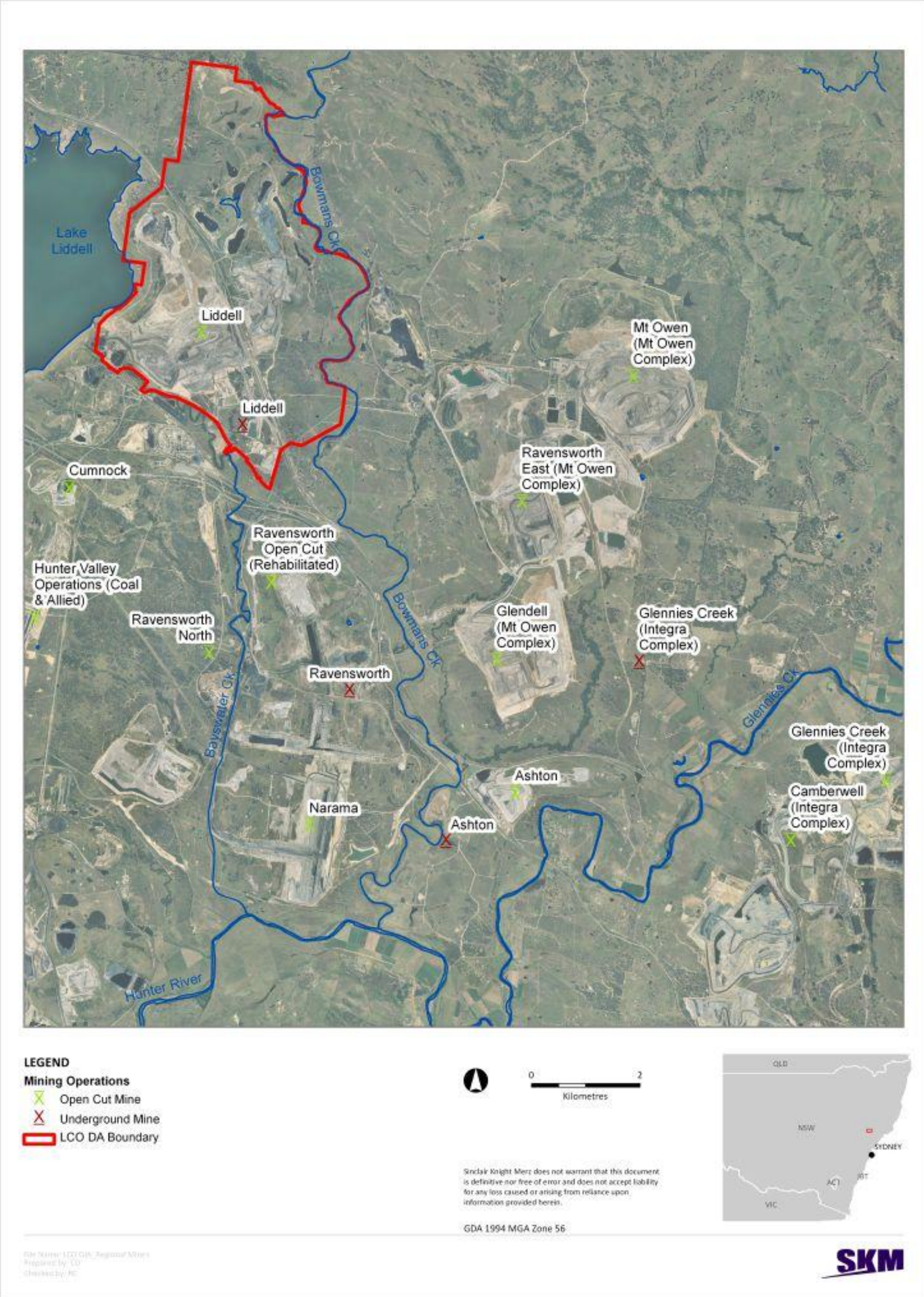
Mining at LCO has been continuous since the 1950s, prior to which operations were intermittent. Underground operations at LCO commenced in 1923 and open cut operations in 1946 (Umwelt, 2001; AECOM, 2012). Open cut operations re-commenced in 1990 to extract coal reserves not previously captured during previous underground operations. In 2002 development consent for DA 305-11-01 was granted for the current mining operations at LCO (consent boundary shown in **Figure 1-1**) to produce up to eight million tonnes per annum (Mtpa) of run-of-mine (ROM) coal (GSS, 2011; AECOM, 2012).

Current mining operations at LCO are undertaken 24 hours per day using excavator and truck / shovel methods with product coal (both semi-soft and thermal) being transported to Newcastle Port by rail for sale to the export market. The coal seams being mined include the Lemington, Pikes Gully, Arties, Liddell and Barrett seams (GSS, 2011). The open cut void is progressing in a south-easterly direction, with the former Liddell underground operations being progressively intercepted by the open cut pits. The water balance for current mining operations results in LCO being a net water producer, with excess water being discharged to surrounding mines in the area or via licensed discharge points (GSS, 2011).

2.1.2 Ravensworth Operations

Located to the south of LCO, the Ravensworth Operations Project received project approval in February 2011 and consolidates the Narama and Ravensworth West open cuts, the Cumnock No. 1 open cut and underground operations, Ravensworth Underground Mine (RUM), the former Ravensworth South and Ravensworth No. 2 mines, and associated surface infrastructure (Umwelt, 2010). The project includes expansion of the existing Ravensworth West open cut mine to the north, known as the Ravensworth North Pit, down to the Barrett seam. As part of the environmental assessment Umwelt (2010) undertook a detailed water balance and determined the project would have a water deficit for extended periods over the project life.

▪ **Figure 2-1 – Regional Mining Operations**



The former Ravensworth No. 2, Ravensworth South and Namara open cut pits historically extracted coal down to the Bayswater seam. These operations have left a continuous synclinal pit shell over a north-south distance of more than 7 km which is now mostly filled with spoils, fly ash and tailings, with the exception of the Narama open pit and ramp. Ravensworth Underground Mine (RUM) is located beneath the old Ravensworth No. 2, Ravensworth South and Narama open cut pits and extracts coal from the Pikes Gully seam via long wall panels in a southwesterly direction. It is understood that current and future long wall mining at RUM will advance into the underlying Liddell and Barrett seams (MER, 2011b).

2.1.3 Mt Owen Complex

The Mt Owen Complex (MOC) is located to the east of Bowmans Creek and includes three adjacent open cut coal mines: Mt Owen, Ravensworth East and Glendell. Mt Owen open cut commenced operations in 1993, Ravensworth East in 2000, and Glendell in 2008. The Mt Owen and Ravensworth East open cut pits currently mine or have previously mined coal seams from the Bayswater down to the Hebden seam at depths of more than 250 m (MER, 2011a). The Glendell pit mines coal from the Bayswater to the Barrett seam to an approximate depth of 200 m, with a proposed northward extension of the pit to target the same seams at similar depths (MER, 2011a). MOC has approval to extract up to 15 Mtpa of ROM thermal and semi-soft coking coals for export to the international market. Predicted water balances for MOC indicate the complex is a net water user under typical conditions (e.g. average rainfall), with water shortages being met via transfers from other XCN operations in the local area whenever possible (XMO, 2011).

2.1.4 Integra Mine Complex

Formed in 2006 through the integration of the former Glennies Creek Colliery and Camberwell Coal Mine, the Integra Mine Complex consists of the former Glennies Creek Open Cut and Underground Coal Mines (now referred to as the Integra North Open Cut and Integra Underground, respectively) and the Integra Open Cut (formerly the Camberwell Coal Mine). The Integra Open Cut includes the former North Pit, where mining occurred between 1991 and 1999 and has since been backfilled, the South Pit, where mining ceased in 2011, and the South Pit (Western Extension) where mining activities commenced in 2011 (RW Corkery, 2011). The Integra Underground Mine currently comprises longwall mining in the Middle Liddell seam, with development works and approval for expansion to the Hebden and Barrett seams (MER, 2011a). Coal from the Integra Mine Complex is handled and processed at the Integra Coal Handling and Preparation Plant prior to transport by rail to Newcastle for export. Sufficient water is typically available from mining operations that Integra acts as a net water producer, having an agreement in place to transfer up to 900 ML/year to Ashton Coal, subject to water availability (Vale, 2011).

2.1.5 Ashton Coal

Ashton Coal open cut and underground operations are located east of Ravensworth and south of Glendell open cut pit. Ashton open cut operations commenced in 2004 and mine coal from the Pikes Gully seam down to the Barrett seam. The underground operations extract longwall panels in the Pikes Gully seam, with future longwall extraction in the Liddell seam planned (MER, 2011a).

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Water balance modelling indicates water demands for mining operations can be met with secure water supply sources (Ashton, 2012).

2.1.6 Hunter Valley Operations

The Hunter Valley Operations (HVO) mining complex is located southwest of LCO and is geographically split by the Hunter River, resulting in mining and processing activities being referred to as HVO North and HVO South though the entire complex is managed by Coal & Allied Operations Pty Ltd as an integrated operation. HVO North comprises active open cut pits West (formerly Howick Pit), North and Carrington Pits, while HVO South includes the Cheshunt, Riverview and Lemington Pits (ERM, 2008). Mining operations at HVO target a number of seams within the Wittingham Coal Measures, producing over 10 Mtpa thermal coal and 1.9 Mtpa semi-soft coking coal in 2011 for export to the international market.

2.2 Climate

Regional climate can be described as temperate, with hot summers and cool winters. The average daily maximum temperature ranges from approximately 39°C in February to 14°C in June. Rainfall data from two nearby weather stations (Jerrys Plains, located approximately 15 km southwest of LCO, and Bowmans Creek, 18 km north) is presented in **Table 2-1**, along with pan evaporation rates recorded at the Scone SCS weather station (approximately 38 km north of LCO). Rainfall at Jerrys Plains averages 645 mm/yr with the highest rainfall occurring between November and February. Rainfall data for Bowmans Creek weather station, located in the upper parts of the Bowmans Creek catchment, shows an annual rainfall some 35% higher than Jerrys Plains at 871 mm/yr. This higher rainfall is likely due to the higher land elevations on the flanks of the Hunter Valley.

- **Table 2-1 – Rainfall and Evaporation Averages (mm) (BOM, 2012)**

Rainfall	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Jerrys Plains	76.7	72.4	58.4	44.5	40.9	48.1	43.5	36.5	42.0	52.2	61.1	67.9	**645**
Bowmans Creek	108.0	95.8	90.7	58.2	60.3	66.9	48.1	46.3	56.3	68.7	84.1	85.0	**871**
Evaporation													
Scone SCS	220	174	155	105	68	48	56	84	117	155	183	220	**1,585**

2.3 Topography

Figure 2-2 presents a topographical map of the region highlighted by two distinct areas: the gently undulating plain associated with the Hunter River Valley, and the steeper, elevated ranges in the north delineating the flank of the valley. Within the valley ground elevations generally range between 50 and 150 m AHD, rising to elevations up to 500 m AHD along the northwest to southeast trending ridgeline of the Hunter Thrust. The Hunter Thrust is associated with outcropping of Carboniferous rocks and marks the northern catchment boundary of the Hunter River Valley.

2.4 Hydrology

Surface water features in the region are predominantly comprised of the Hunter River and its tributaries and local dams and lakes associated with mining and power generation activities. The Hunter River forms the primary surface water drainage system in the region in terms of physical size and flow rate, with its catchment area covering approximately 22,000 square kilometres.

LCO is located within two sub-catchments of the Hunter River catchment, with surface water features in each forming the boundary of the LCO DA area, as shown in **Figure 2-3**. Lake Liddell bounds LCO to the west and is an artificial lake constructed to supply water to several coal-fired power stations in the area. Lake Liddell was created by damming Bayswater Creek and collects runoff from the upper three quarters of the creek's catchment.

Bowmans Creek bounds LCO to the east and drains a catchment area of approximately 250 square kilometres, which is enough to maintain flow under most rainfall conditions (Umwelt, 2006). LCO's proposed extension to the open cut Entrance Pit is in close proximity to Bowmans Creek and its associated alluvial deposits.

Flow duration curves extracted from stream gauges on the Hunter River (station 210126), Bowmans Creek (stations 210042 and 210130), and Bayswater Creek (station 210059), shown in **Figure 2-4**, reflect the relative contribution of these features to surface water drainage in the region. The low median annual flow rate for station 210059 (approximately one ML/day) reflects the impact of Lake Liddell and the significantly altered flow system of Bayswater Creek. The flow rates and duration profile for station 210126 are indicative of the Hunter River as the major surface water feature in the region. The two stream gauges on Bowmans Creek show markedly different flow duration curves, with the gauge located near LCO (station 210042, refer **Figure 2-3**) recording measurable stream flow only 65% of the time, while further downstream near the confluence of the Hunter River data from station 210130 indicates near perennial flow. The stream flow data recorded at station 210042 corresponds with historical observations of intermittent flow in Bowmans Creek in the vicinity of LCO.

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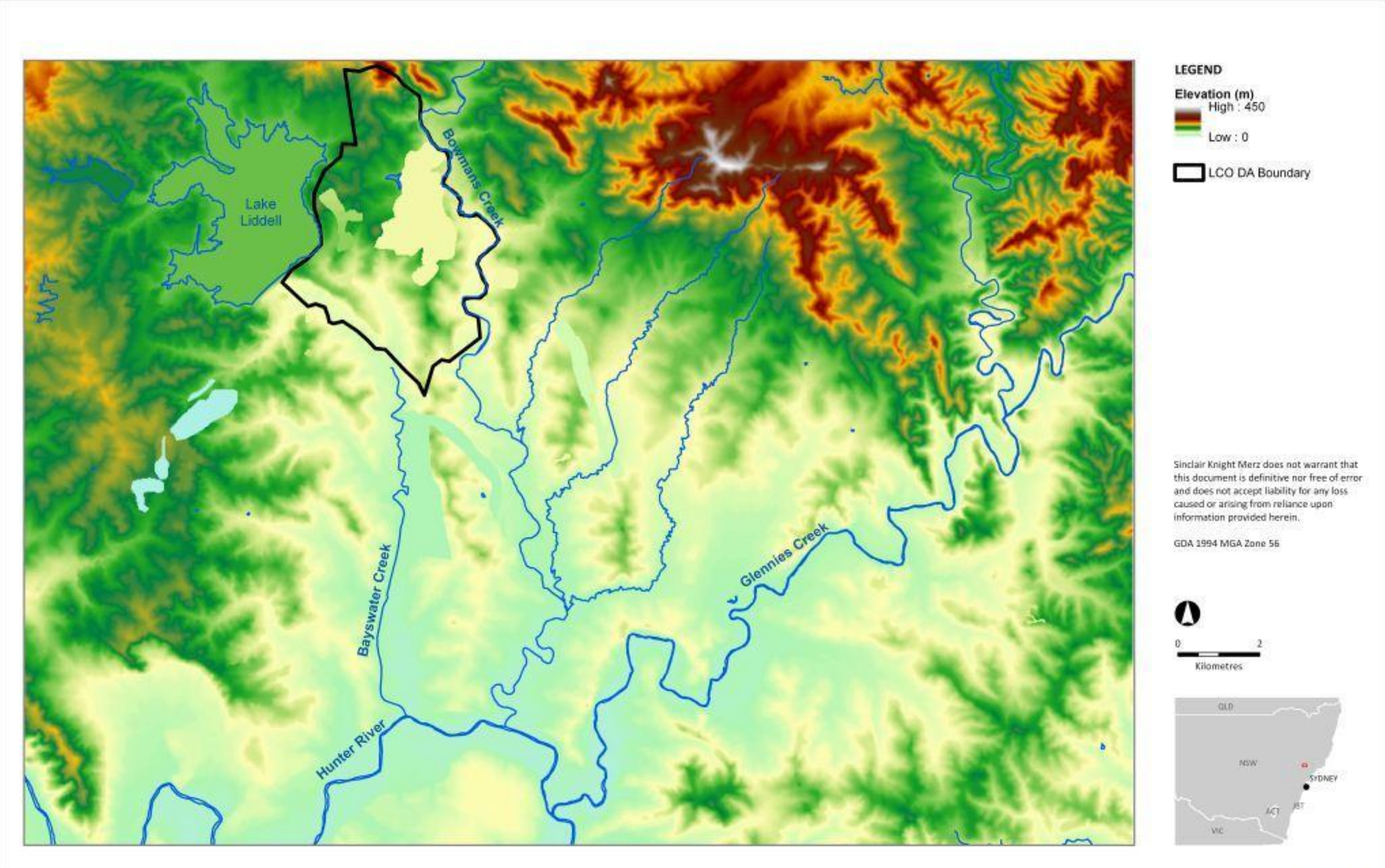
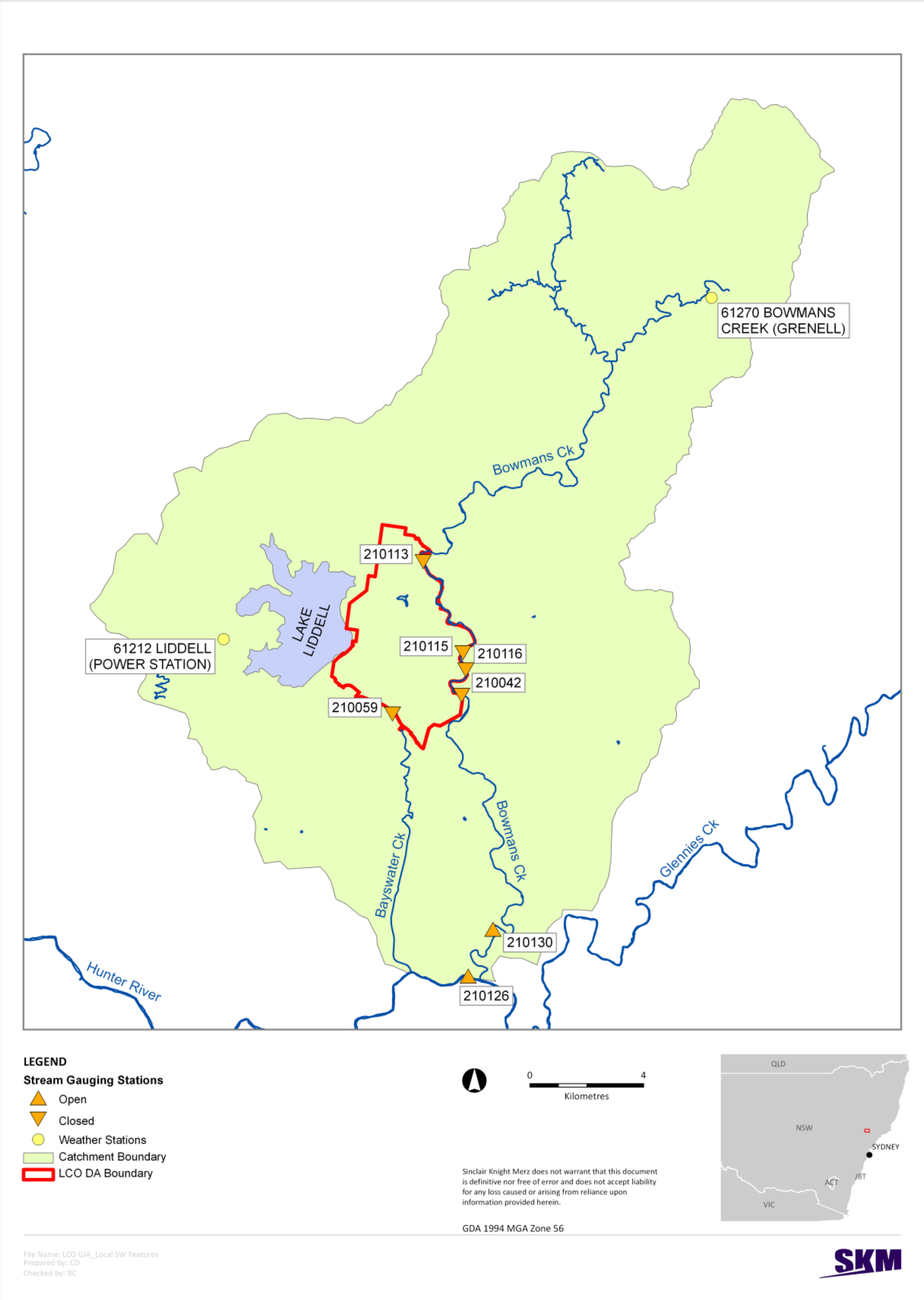
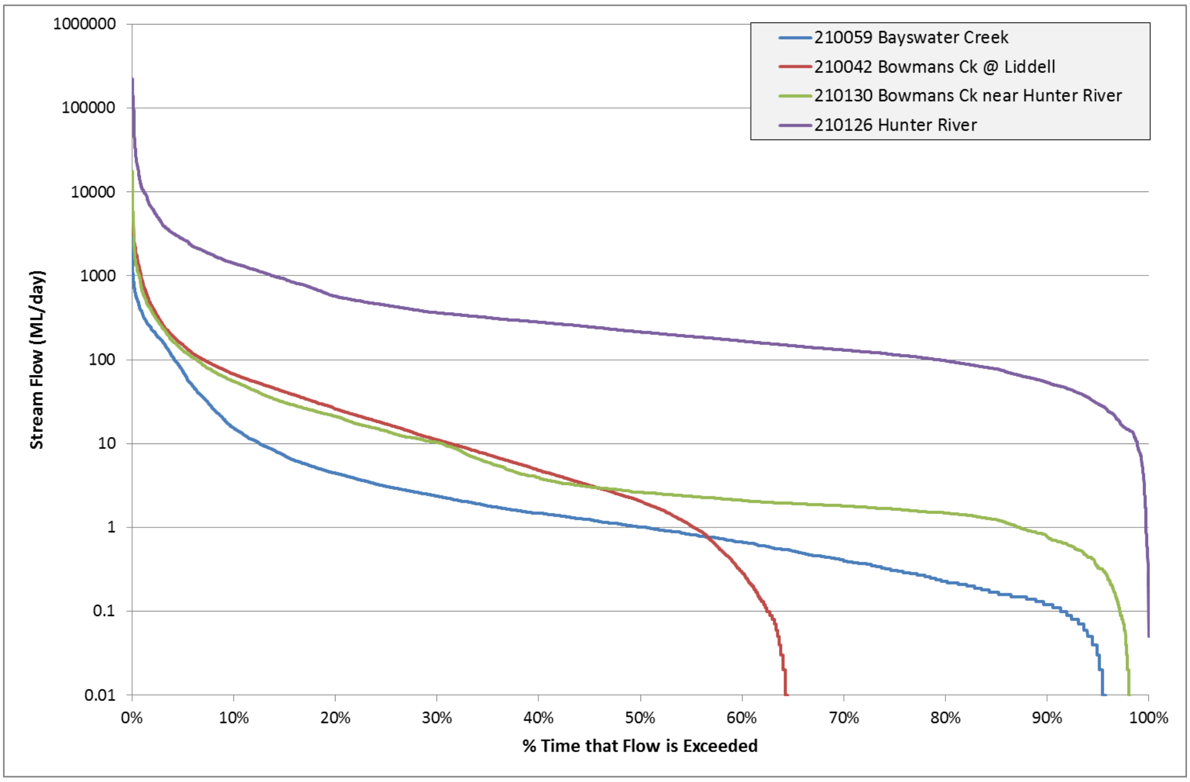
- **Figure 2-2 – Regional Topography and Structural Features**



▪ Figure 2-3 – Local Surface Water Features



- **Figure 2-4 – Flow Duration Curves for Surface Water Features**



In order to evaluate the potential effects of mining activities on groundwater within the Bowmans Creek alluvium, historical streamflow and climactic data can be used to estimate contributions of groundwater baseflow to the creek. SKM's BaseJumper (Murphy et al, 2008) program analyses streamflow data through a digital recursive filter to estimate groundwater contributions to baseflow. **Table 2-2** summarizes the data record for stream gauges along Bowmans Creek, and includes the estimated baseflow component for each of the gauges as determined using BaseJumper. The data provides order of magnitude estimates of the reduction in baseflow required for impacts to streamflow to be seen along Bowmans Creek.

Table 2-2 – Summary of Streamflow Data[1] for Gauges on Bowmans Creek

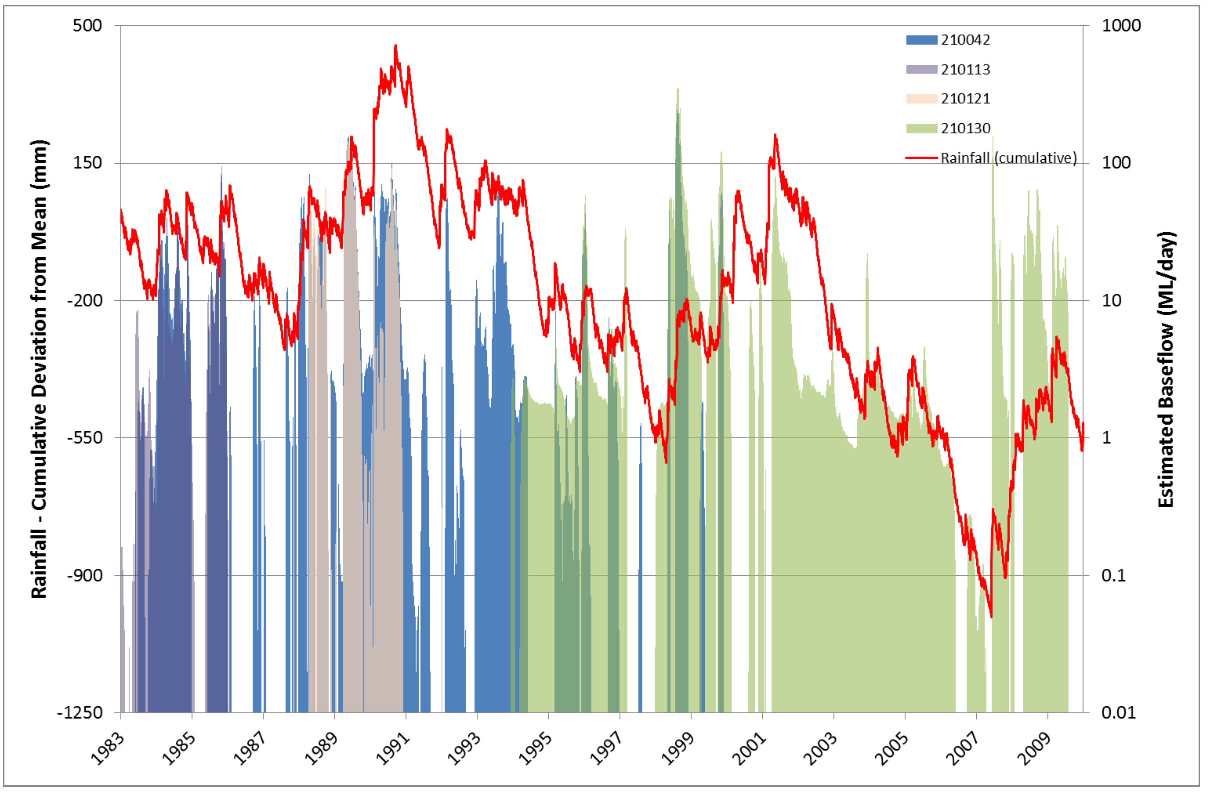
Stream Gauge	210113	210115	210116	210042	210121	210130
Start of Record	2/07/1980	16/12/1981	1/01/1982	23/03/1956	2/04/1988	29/10/1993
End of Record	1/01/1986	1/01/1986	1/01/1986	23/11/1999	3/01/1992	29/07/2009
Number of days over record	2010	1478	1461	15950	1372	5753
Number of years over record	5.5	4.0	4.0	43.7	3.8	15.8
Number of days with data	2010	1478	1461	14869	1372	5130
Number of days missing data	0	0	0	1081	0	623
% missing	0.0%	0.0%	0.0%	6.8%	0.0%	10.8%
Number of days with zero flow	418	60	151	5244	572	97
% of time zero flow	20.8%	4.1%	10.3%	35.3%	41.7%	1.9%
Avg. Streamflow (ML/day)	27.1	35.1	34.6	46.2	72.8	45.2
Avg. Streamflow (ML/year)	9890	12,800	12,600	16,900	26,600	16,500
Est. Baseflow[2] (ML/day)	4.2	7.5	13.7	9.6	16.3	10.8
Est. Baseflow[2] (ML/year)	1530	2740	5000	3500	5950	3940
Pct Streamflow as Baseflow	15.5%	21.3%	39.6%	20.8%	22.4%	23.9%

Notes
1. Streamflow data from NSW Office of Water's PINEENA CM database, http://waterinfo.nsw.gov.au/pinneena/cm.shtml.
2. Baseflow estimated using BaseJumper software analysis package (Murphy et al., 2008)

Table 2-2 shows the estimated annual baseflow for stream gauges most likely to be impacted by current and future mining operations at LCO (e.g. gauges 210115, 210116, 210042, 210121 and 210130) range from 2,740 ML/year to 5,950 ML/year. These baseflow estimates amount to between 15% and 40% of average streamflow rates measured at the stream gauges, though it is noted that the 40% contribution was measured at only one gauge (station 210116) and the estimated baseflow contribution at the adjacent gauge (station 210115) was only 21% over the same period. The data suggest groundwater baseflow likely contributes between 20% and 25% of total streamflow along Bowmans Creek in the vicinity of Liddell.

Figure 2-5 shows baseflow estimates for selected stream gauges along Bowmans Creek together with cumulative rainfall trends since 1983. Downward rainfall trends reflect dry weather periods (i.e. less than annual average), and upward trends indicate wetter than average conditions. The figure shows correlation between rainfall and baseflow estimates, as expected for shallow unconfined alluvial systems with high transmissivity. Trends in baseflow follow comparable trends in rainfall, demonstrating the significant natural climatic impact on flow in Bowmans Creek. **Figure 2-5** also provides an indication of the magnitude of variance in the baseflow estimates, with rates often ranging between one and 100 ML/day (365 to 36,500 ML/year).

▪ **Figure 2-5 – Estimated Baseflow Contributions and Rainfall for Bowmans Creek**



2.5 Geology

LCO is located within the Hunter Coalfield of the Permian and Triassic Sydney Basin. The geology comprises Permian coal measures hosted within an eroded valley that has been infilled with Quaternary to Recent alluvial sediments associated with the Hunter River and its tributaries (Mackie, 2009). To the west and southwest of the Hunter River Valley is steeply incised terrain of the younger Triassic Narrabeen Group, and to the east and northeast are older Carboniferous rocks. The depositional environment is interpreted by a varying cyclic pattern of fluvial to marine deltaic conditions (Mackie, 2009).

The lower elevations of the Hunter Valley sit within an area of gently folded Permian rocks, with the folds generally on a N-S and NNW-SSE axis and plunging gently to the south at 2 to 5 degrees. Structural features in the area include the Muswellbrook Anticline in the west, the Bayswater Syncline, Camberwell Anticline, and Glennies Creek Syncline. To the north and northeast along the flank of the Hunter Valley a series of northwest to southeast trending faults and thrusts, including the minor Hebden Thrust and the major Hunter Thrust, bring older Permian and Carboniferous rocks to the surface. In these thrust areas coal bearing Permian-aged rocks found elsewhere in the valley are not present. **Figure 2-6** shows the geology and the locations of major structural features within the region.

LCO is located above the Bayswater Syncline and Camberwell Anticline. An impervious, north-easterly striking dyke, which has previously affected underground mining, is present in the southeast of the LCO DA area (MER, 2001). Further south the dyke zone is known to become faulted and south of LCO the zone is identified as the Davis Creek fault.

2.5.1 Alluvial Deposits

Quaternary and Recent alluvial sediments are deposited along major and minor surface water drainages in the region. The thickness of these alluvial deposits is variable, with Mackie (2009) reporting a maximum thickness of 18 m in the region.

The alluvial deposits are generally characterised by a succession of three units, grading from a basal coarse grained bed load comprising sand to cobble size deposits, a middle unit comprising finer grained levee deposits, and finally an upper unit comprising floodplain deposits (Beckett, 1987). The basal unit varies in thickness across the region, ranging from zero to 12 m thickness, whilst the middle and upper units are generally between 1 m and 3 m thickness. The sediments within the upper tributaries of Bowmans Creek are expected to have similar lithology, perhaps with a thinner intersection of the basal coarse grained unit.

2.5.2 Permian Coal Measures

The main coal-bearing strata in the region are the Permian aged Wittingham Coal Measures of the Singleton Super Group which are summarized in **Table 2-3**. These strata were deposited at a time when global sea levels and tectonism led to widespread deltaic conditions favourable for the development of coal (Mackie, 2009).

- **Figure 2-6 – Regional Geology and Structural Features**

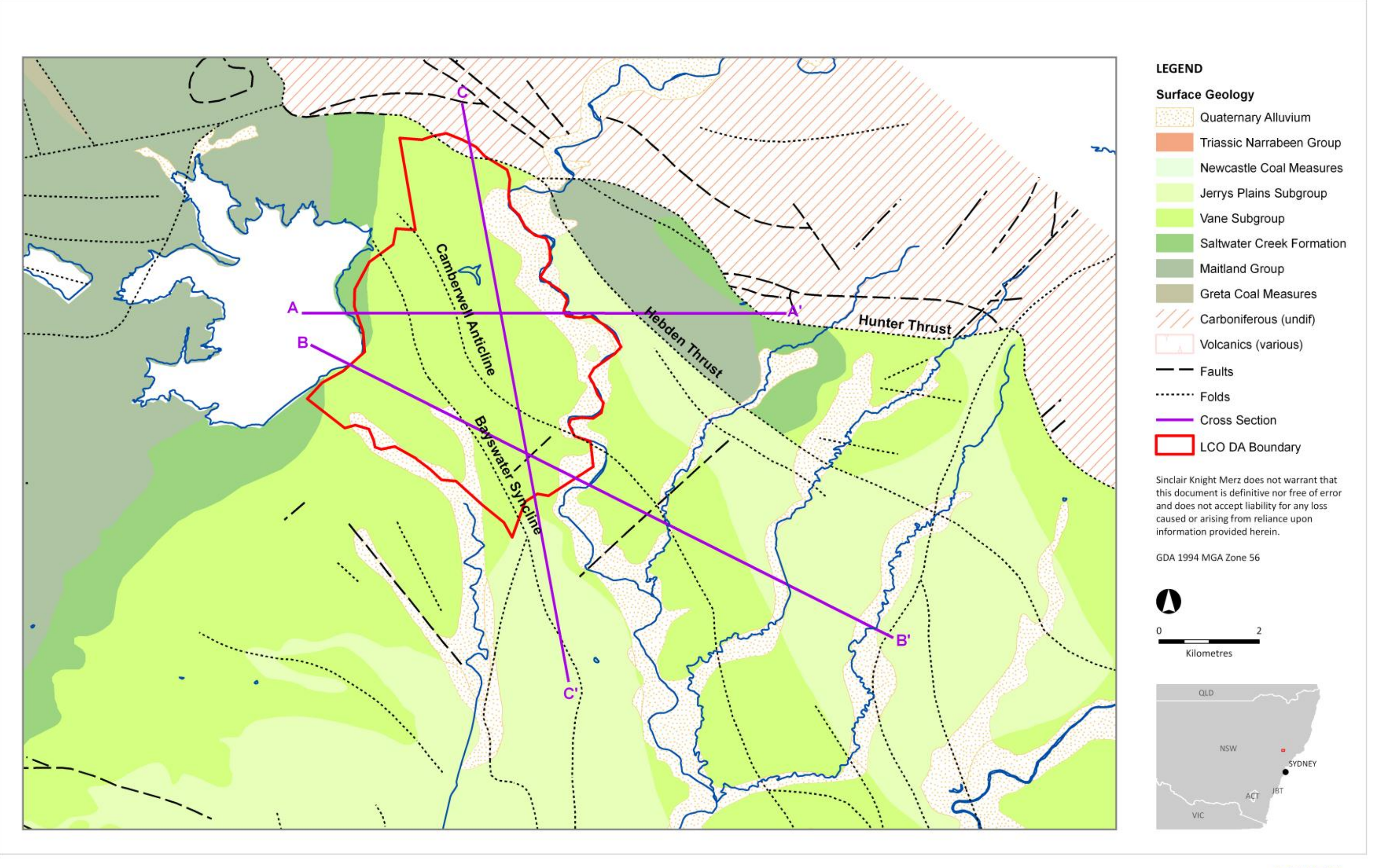


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Table 2-3 – Stratigraphic Table of the Wittingham Coal Measures

Singleton Super Group	**Wittingham Coal Measures**	*Denman Formation (sandstone and siltstone)*		
		Jerrys Plains Subgroup	**Mount Leonard Formation**	Whybrow Seam
			Allthorp Formation (claystone)	
			Malabar Formation	Redbank Creek Seam
				Wambo Seam
				Whynot Seam
				Blakefield Seam
			Saxonvale Member (siltsone and claystone)	
			Mount Ogilvie Formation	Glen Munro Seam
				Woodlands Hill Seam
			Milbrodale Formation (claystone)	
			Mount Thurney Formation	Arrowfield Seam
				Bowfield Seam
				Warkworth Seam
			Fairford Formation (claystone)	
			Burnamwood Formation	Mt Arthur Seam
				Piercefield Seam
				Vaux Seam
				Broonie Seam
				Bayswater Seam
		Archerfield Sandstone		
		Vane SubGroup	*Bulga Formation (sandstone and siltstone)*	
			Foybrook Formation	Lemington Seam
				Pikes Gully Seam
				Arties Seam
				Liddell- Ramrod Creek Seam
				Barrett Seam
				Hebden Seam
		Saltwater Creek Formation (sandstone and siltstone)		

The basal unit of the Wittingham Coal Measures is the Saltwater Creek Formation which comprises siltstones and sandstones and minor coal seams. The Saltwater Creek Formation resides at depth beneath most of the Hunter Valley, however it subcrops approximately 5 km northeast of LCO where it is upthrown between the Hebden and Hunter Thrusts.

Above the Saltwater Creek Formation, the remaining Wittingham Coal Measures can be divided into two coal bearing subgroups, the Vane Subgroup and the Jerrys Plains Subgroup with a marker bed known as the Archerfield Sandstone separating them. These two subgroups comprise up to six primary coal bearing units with each containing multiple seams (refer **Table 2-3**). The coal seams are separated by interburden units comprised of sandstone, siltstone, conglomerate, mudstone and shale.

Stratigraphic cross sections have been developed for LCO, with particular focus on the coal seams of the Wittingham Coal Measures. The locations of the cross sections are shown in **Figure 2-6**, and the cross sections presented in **Figure 2-7** through **Figure 2-9**. As shown in the cross sections the Liddell seam starts as a single seam in the vicinity of LCO (**Figure 2-7**) before splitting into three seams to the south and southeast (**Figure 2-8** and **Figure 2-9**).

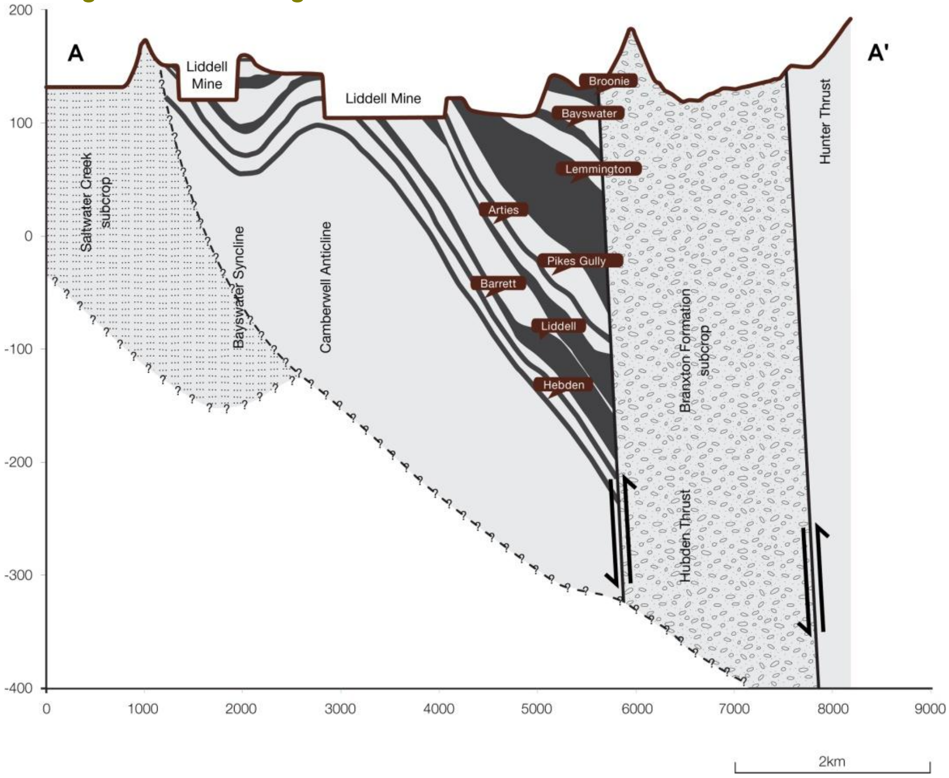
The Foybrook Formation is the basal coal-bearing unit of the Wittingham Coal Measures and forms the main subcropping and outcropping unit in the vicinity of LCO (**Figure 2-7**). **Table 2-4** provides a summary of the thickness of coal seams and interburden strata in the vicinity of LCO, derived from the Xstrata LCO coal exploration drillhole database.

- **Table 2-4 – Thickness of Coal Seams and Interburden Strata at LCO (Source: Xstrata LCO Coal Exploration Drillhole Database)**

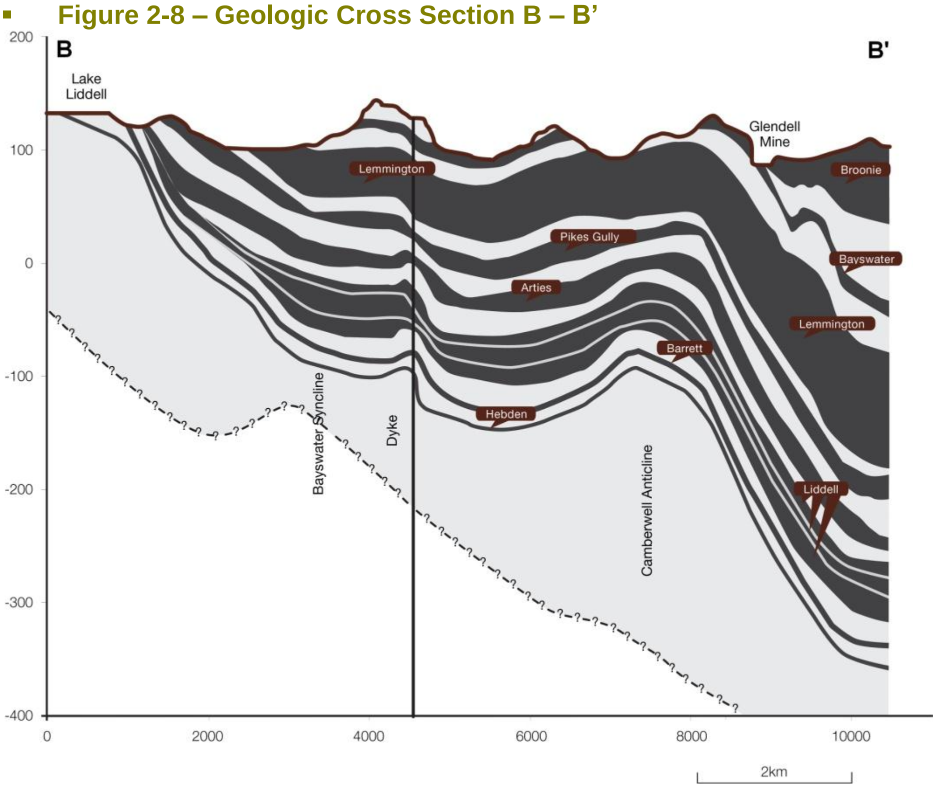
Subgroup	Coal Bearing Unit	Coal Seams	Avg (m)	Min (m)	Max (m)
Jerrys Plains Subgroup	Burnamwood Formation	Broonie Seam	0.3	0	0.7
		Broonie-Bayswater interburden	3.7	0	122
		Bayswater Seam	9.2	0	25
		Bayswater-Lemington interburden	14	0	92
Vane SubGroup	Foybrook Formation	Lemington Seam	53	0	128
		Lemington-Pikes Gully interburden	7.5	0	43
		Pikes Gully Seam	6.0	0	34
		Pikes Gully-Arties interburden	8.3	0	52
		Arties Seam	14	0	42
		Arties- Liddell interburden	8.2	0	36
		Liddell Seam	33	0	81
		Liddell-Barrett interburden	17	0	54
		Barrett Seam	3.5	0	14
		Barrett-Hebden interburden	19	0	50
		Hebden Seam	2.1	0	3.0

Notes:
- Values represent stratigraphic unit thickness, not coal seam thickness
- Average values are skewed by ‘zero’ thickness in database where strata are not present

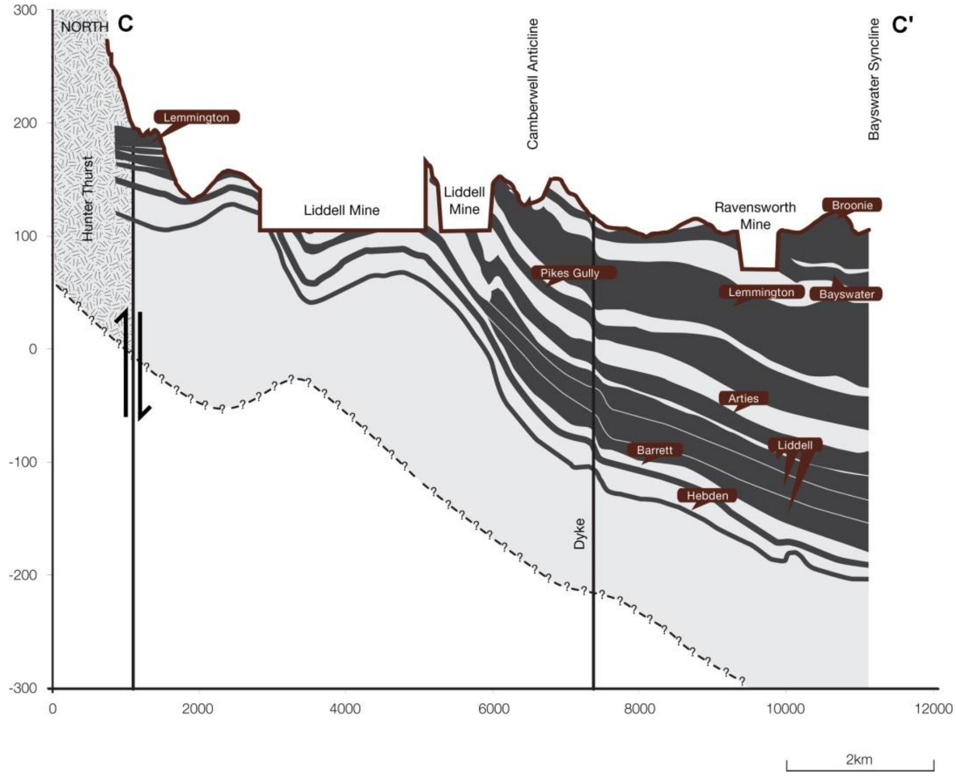
▪ **Figure 2-7 – Geologic Cross Section A – A'**



▪ **Figure 2-8 – Geologic Cross Section B – B'**



- **Figure 2-9 – Geologic Cross Section C – C'**



2.6 Hydrogeology

2.6.1 Aquifer Systems

Previous environmental assessments undertaken in the area (MER, 2001; ERM, 2008; Umwelt, 2006; Umwelt, 2008a; MER, 2011a; Aquaterra, 2009b) provide a consistent description of the local and regional hydrogeological regime being comprised of two distinct aquifer systems:

- Shallow unconfined aquifers of limited extent within the unconsolidated alluvium associated with the Hunter River and its tributaries, and
- A regional hard rock aquifer system associated with the Permian coal measures.

The alluvial aquifers associated with the Hunter River and its tributaries are generally characterized by unconsolidated deposits of silts, sands, and gravels of varying permeability. MER (2011a) describes the morphology of the alluvial deposits as a vertical succession of three distinct units, including basal coarse grained sand and cobble size deposits, finer grained levee deposits, and floodplain deposits. The basal coarse grained sand and gravel unit forms the main aquifer of the alluvium and in places may be confined by the overlying finer grained terrace deposits. These unconsolidated deposits support baseflow to surface water features in the region, with the varying morphology and extent of the deposits leading to complex and variable flow regimes (Aquaterra, 2009a).

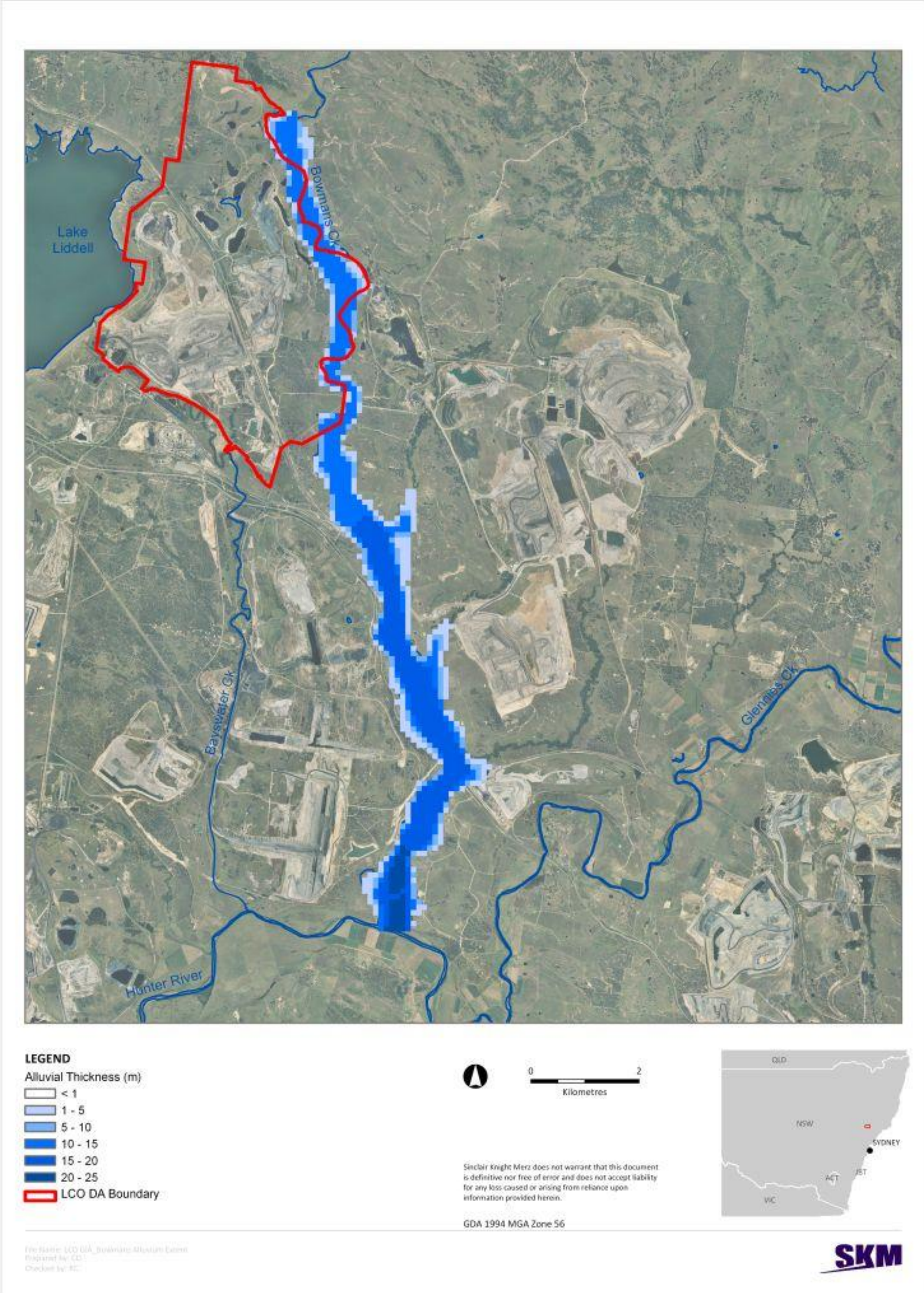
The hard rock aquifer associated with the Permian coal measures exhibits varying levels of groundwater storage and transmission. The most permeable horizons are the coal seams themselves; non-coal interburden strata generally exhibit permeabilities at least one to two orders of magnitude less than the coal seams. Secondary porosity in the non-coal strata may be developed within fractures and joints, however the degree to which this occurs is quite variable and generally unpredictable.

Coal seams typically represent the more permeable hard rock strata through the presence of cleating and jointing, although there is little evidence of structure-related fracturing. Horizontal permeabilities (i.e. parallel to bedding) are generally significantly higher than vertical permeabilities within the coal seams, although subsidence-related cracking may enhance vertical permeabilities of both coal seams and interburden strata in areas of underground workings. Regionally, the coal seam aquifers are generally confined above and below by the interburden strata.

For LCO and its vicinity, the two aquifer systems are present as the localised alluvial aquifers associated with the surface water of Bowmans and Bayswater Creeks, and the regional hard rock aquifer found within the Permian-aged coal seams (the Wittingham Coal Measures) (Umwelt, 2001; Umwelt, 2008a). Of particular relevance for this Groundwater Impact Assessment is the alluvial aquifer associated with Bowmans Creek given the proximity of the proposed mine extension to the Creek (refer **Figure 1-2**) and its classification as BSAL under the Upper Hunter Strategic Regional Land Use Plan.

In an effort to delineate the lateral extent of the alluvial aquifer and to optimise groundwater monitoring locations, Light Detection and Ranging (LiDAR) remote sensing was flown along Bowmans Creek in 2011. Combining LiDAR data with bedrock depth from borehole logs along the creek allows an estimation of the extent and volume of alluvium, as shown in **Figure 2-10**, and can provide an indication of the contribution of alluvial groundwater to stream baseflow. Of particular interest are areas where current operations and the proposed open cut extensions come into close proximity to the alluvial aquifer, potentially impacting the flow of groundwater within the alluvial aquifer system and baseflow contributions to Bowmans Creek.

- **Figure 2-10 – Estimated Extent of Bowmans Creek Alluvial Aquifer**



2.6.2 Registered Bores

A search of NSW Office of Water's PINEENA GW database identified 12 registered groundwater bores within 2 km of the LCO DA boundary. **Figure 2-11** shows the location of these bores, and **Table 2-5** summarises bore information from the database.

Table 2-5 – Registered Groundwater Bores

Work No.	Licence	Owner	Purpose	Date Completed	Depth (m)
GW027690	20BL020923	Liddell Tenements	Irrigation	1/01/1966	6
GW028247	20BL020924	Liddell Tenements	Irrigation	1/01/1962	2
GW080212	20BL168065	Liddell Tenements	Monitoring	31/05/2002	--
GW080245	20BL168066	Liddell Tenements	Monitoring	7/08/2002	--
GW080213	20BL168064	Liddell Tenements	Monitoring	31/05/2002	--
GW080172	20BL168209	Xstrata Mt Owen Pty	Industrial	28/03/2002	--
GW078085	20BL166608	--	Stock	23/06/1997	13
GW080725	20BL168240	--	Mining	10/08/2000	130
GW080176	--	--	Unknown	4/02/2002	--
GW080173	--	--	Unknown	4/02/2002	--
GW035474	20BL028920	Private	Exploration	--	--
GW079793	--	--	Mining	--	3

Source: NSW Office of Water's PINEENA GW database, version 3.2 (October 2010), http://waterinfo.nsw.gov.au/pinneena/gw.shtml

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- **Figure 2-11 – Registered Groundwater Bores**

2.6.3 Hydraulic Properties

The hydraulic properties that govern groundwater storage and flow in the region vary considerably between the unconsolidated alluvial systems and the confined hard rock aquifer system associated with the coal measures. Aquifer testing has been undertaken as part of previous environmental investigations for various mining projects in the region using a variety of techniques, including airlifting, packer tests, and laboratory core tests, with the majority of data collected for hard rock aquifers associated with the coal measures. **Table 2-6** provides a summary of hydraulic conductivity and storativity values reported in previous environmental assessments within the region. Recent slug test data collected from LCO monitoring bores targeting the Bowmans Creek alluvial aquifer are also included.

- **Table 2-6 – Range of Hydraulic Properties**

Lithology	Hydraulic Conductivity (K_{xy}; m/day)	Storage[1]	Source
Alluvium	0.5 – 50	--	MER (2001)
	2.4	$S_s = 8.67 \times 10^{-2}$ $S_y = 0.25$	ERM (2008)
	10	$S_s = 1 \times 10^{-5}$ $S_y = 0.05$	MER (2011b)[2]
Alluvium (Hunter River)	50	$S_s = 1 \times 10^{-4}$ $S_y = 0.1$	Aquaterra (2009b)
	14.5	$S_s = 8.67 \times 10^{-2}$ $S_y = 0.25$	ERM (2008)
Alluvium (Bowmans Ck)	$2 \times 10^{-4} – 15$	$S_s = 1 \times 10^{-4}$ $S_y = 0.05$	Aquaterra (2009b)
	1 – 60	--	LCC (2013)[3]
Alluvium (Glennies Ck)	0.04 – 80	--	Aquaterra (2009a)
	0.07 – 180	$S_s = 1 \times 10^{-4}$ $S_y = 0.05$	Aquaterra (2009b)
Coal Seams	$1 \times 10^{-5} – 1 \times 10^{-1}$	--	MER (2001)
	0.052	$S_s = 1.55 \times 10^{-3}$ $S_y = 0.02$	ERM (2008)
	0.04 – 7	--	Aquaterra (2009a)
	0.002 – 0.03	$S_s = 1 \times 10^{-4}$ $S_y = 0.005$	Aquaterra (2009b)
	$1 \times 10^{-4} – 2 \times 10^{-2}$	$S_s = 4 \times 10^{-6}$ $S_y = 0.002 – 0.1$	MER (2011b)[2]
Interburden / Overburden	0.007	$S_s = 2.25 \times 10^{-5} – 0.2$ $S_y = 0.02$	ERM (2008)
	$1 \times 10^{-6} – 8 \times 10^{-3}$	$S_s = 1 \times 10^{-5}$ $S_y = 0.005$	Aquaterra (2009b)
	$4 \times 10^{-6} – 5 \times 10^{-3}$	$S_s = 1 \times 10^{-6}$ $S_y = 3 \times 10^{-4} – 0.001$	MER (2011b)[2]

Notes
1) S_s = Specific Storage or Storativity (1/m); S_y = Specific Yield (dimensionless)
2) Modelled values
3) Calculated from slug test data collected by Larry Cook Consulting (LCC) for LCO monitoring bores ALV1L through ALV8L in March 2013

The range of hydraulic conductivity values reported in **Table 2-6** reflects the properties of the aquifer systems present in the region, with the permeability of the coal measures generally orders of magnitude lower than the alluvial aquifer system. Within the coal measures hydraulic conductivity values are higher for the coal seams compared to the intervening siltstones, shales, and sandstone units (interburden). Due to the laminar nature of the coal measures groundwater flow generally occurs within the stratigraphic layers, and vertical conductivity (K_z) has been reported to be orders of magnitude lower than horizontal hydraulic conductivity (K_{xy}) (ERM, 2008; Aquaterra, 2009b).

Hydraulic conductivity values reported for alluvial aquifers associated with different surface water features in the region reflects the varying morphology and depositional characteristics observed between the Hunter River sediments and its tributaries. Reported hydraulic conductivity values for the Hunter River alluvium are higher than those for the tributaries Bowmans Creek and Glennies Creek (ERM, 2008), with investigations revealing a clear distinction between these alluvial deposits (Aquaterra, 2009b).

In March 2013, Larry Cook Consulting (LCC) undertook slug testing of selected observation bores within LCO's groundwater monitoring network that target the Bowmans Creek alluvial aquifer. Conductivity values determined from the slug test data ranged from 1 to 60 m/day, in agreement with previous environmental assessments (refer **Table 2-6**). The monitoring bores tested were installed by Mackie Environmental Research (MER) in 2001, and well completion details indicate the screened section of these alluvial bores targets the basal sand and gravel unit of the alluvium (MER, 2001). However the indicative stratigraphic log presented also indicates the sand and gravel unit extends below the bottom of the well screen and to the shallow bedrock (overburden) unit, with pebble diameters in this layer being larger than the screened section (MER, 2001). The hydraulic conductivity values determined therefore are considered to represent minimum ranges for the alluvial system.

2.6.4 Groundwater Levels and Flow Patterns

Groundwater level data for LCO is available from the existing groundwater monitoring network shown in **Figure 2-12**. The monitoring network targets both the Bowmans Creek alluvial aquifer and the hard rock aquifer of the coal measures. Piezometers targeting the alluvium are paired and monitor both the alluvial aquifer and the underlying shallow bedrock strata (where the bore name suffix L = alluvium (**L**arge diameter casing) and S = shallow bedrock or overburden (**S**mall diameter casing)).

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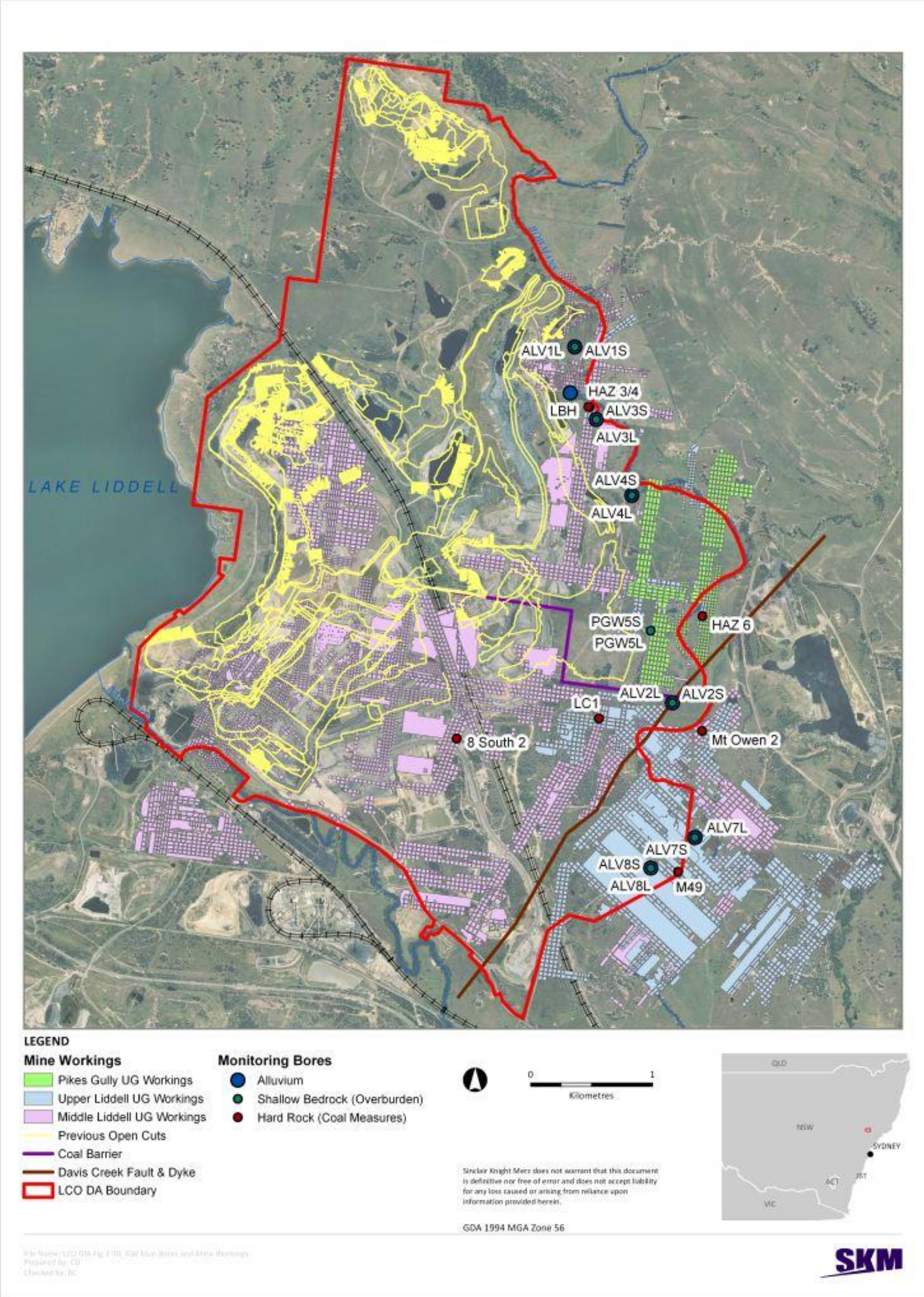
- **Figure 2-12 – Groundwater Monitoring Locations, Mine Workings and Structural Features at LCO**



Hydrographs for piezometers targeting the alluvium and shallow bedrock are displayed in **Figure 2-13**. Groundwater elevations at these bores decrease with distance along Bowmans Creek, and the similar water level responses observed in the paired bores indicates these two units are hydraulically connected. **Figure 2-13** indicates groundwater levels generally decreased from 2001 to 2006 before rebounding to 2001 levels following the June 2007 floods. Since then groundwater levels have remained fairly stable. In 2009 consultants Geoterra undertook an analysis of groundwater depths at LCO and determined that there was negligible impact on the alluvial aquifer as a result of mine dewatering of the open cut pits (CBE, 2010).

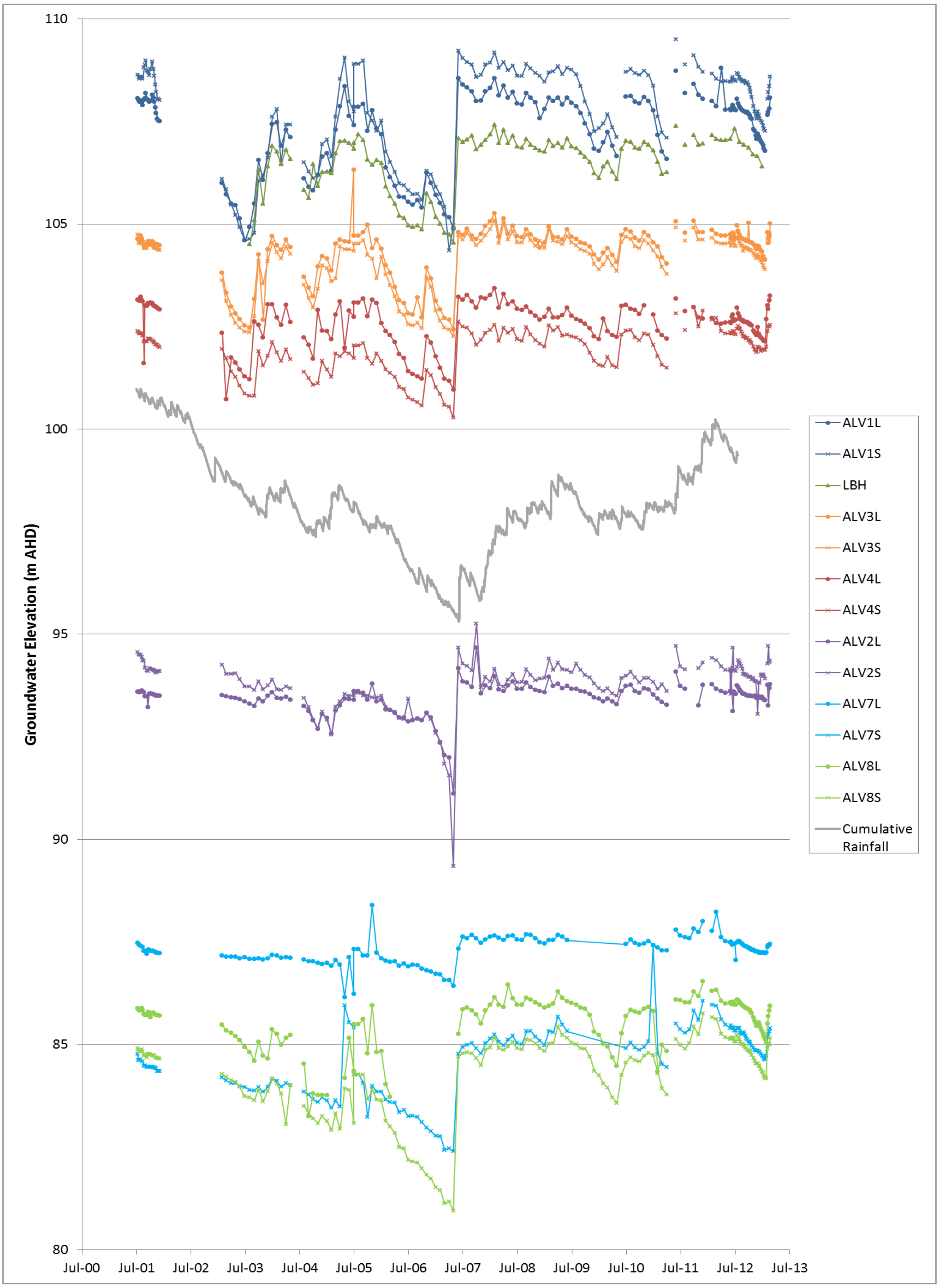
To the north of the mine (ALV1 and ALV3) pressures in the overburden exceed those in the alluvial aquifer, indicating a potential for upward leakage to the alluvial aquifer. As the system progresses south, this differential decreases and to the south of operations (ALV7 and ALV8) the pressures reverse, with potential for leakage from the alluvial aquifer to the underlying beds. There has been no discernible change in the magnitudes of the pressure differentials between the alluvial and overburden aquifers over the duration of the monitoring, indicating that there has been no disruption to the interaction over that period.

Groundwater in the coal measures moves downdip from areas of recharge where individual seams subcrop and outcrop in the north near the Hunter Thrust and in the west near Lake Liddell. Rates of recharge through unweathered Permian bedrock are very low, with estimates varying from near zero to no more than 1% of annual rainfall (MER, 2011b). Recharge can be expected to be slightly higher where more permeable rocks (i.e. coal seams) subcrop and outcrop.

The groundwater flow regime within the coal measures around LCO is influenced by major structural controls shown in **Figure 2-12**, including:

- A northeast to southwest trending dyke, located in the southeast part of the LCO DA boundary but west of Bowmans Creek;
- The Davis Creek Fault, which strikes in a similar direction and is located adjacent to the dyke; and
- A coal barrier left in place between the historical Liddell and Hazeldene underground workings in the east of the LCO operational area.

▪ Figure 2-13 – Hydrographs for Piezometers Targeting Alluvium and Shallow Bedrock



Hydrographs for piezometers targeting the regional hard rock aquifer associated with the coal measures are shown in **Figure 2-14**. The groundwater elevations vary significantly between the different piezometers shown, reflecting differences in groundwater levels between stratigraphic layers and groundwater response due to current and historical mining and dewatering activities. Current and historical open pit development has created groundwater sinks while underground workings act as both sinks and storage areas for regional groundwater.

Groundwater levels observed for the paired piezometers PGW5L and PGW5S, which target the overburden and Pikes Gully coal seam, respectively, have been relatively stable since 2001. PGW5 is located above the former Hazeldene underground workings, which have been subject to periodic dewatering to accommodate mining operations at LCO. Hydrographs for piezometers Haz 3/4 and Haz 6 reflect these dewatering activities (and subsequent recovery) for the Hazeldene workings. The lack of response in groundwater levels for PGW5L and PGW5S indicates the intervening strata between the deeper Hazeldene underground workings and the Pikes Gully seam and overburden effectively confines any depressurization (and recovery) of the deeper strata, with little effect on groundwater pressures in the overlying strata. The similar hydrographs for Haz 3/4 and Haz 6 also reflect their hydraulic connectivity via the Hazeldene workings, with the fluctuations in water levels correlating to pumping schedules for these bores.

Hydrographs for piezometers LC1, Mt Owen 2, 8 South 2 and M49 display similar groundwater levels at all four locations, a product of mining operations at LCO and hydraulic connection between these bores through the Upper and Middle Liddell coal seams. Significant decreases in groundwater levels have occurred since 2007, largely due to pumping at the 8 South 2, Mt Owen 2, and M49 bores to accommodate open cut mining in the South Pit and Entrance Pit.

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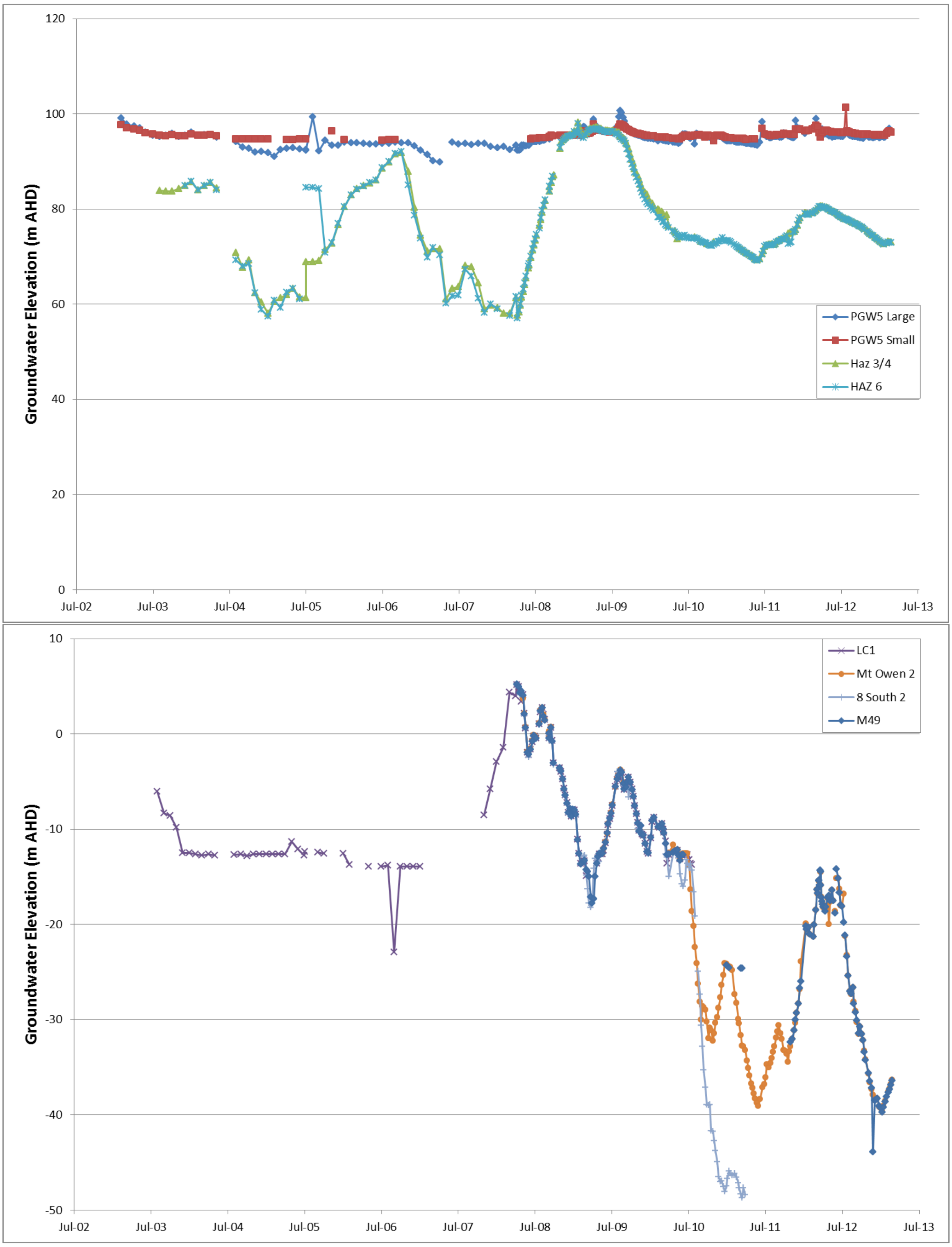
- **Figure 2-14 – Hydrographs for Piezometers Targeting Regional Hard Rock Aquifer (Coal Measures)**



The combination of pumping from bores 8 South 2 and Mt Owen 2, and the NE-SW trending dyke and Davis Creek Fault located east of LC1, has resulted in the separation of groundwater within the Upper and Middle Liddell seams into two distinct underground water bodies. Groundwater levels decreased as a result of pumping, and once levels were lowered below approximately -22 m AHD in 2010 the dyke effectively separated groundwater into two separate water bodies east and west of the dyke (Umwelt, 2008a). The decrease in water levels in the Upper Liddell seam has also led to the drying of LC1 (invert level approximately 5 m AHD), explaining the absence of water level measurements at LC1 since July 2010.

Current operations at LCO include dewatering at the Mt Owen 2 and M49 bores to accommodate open cut mining in the South Pit and Entrance Pit, leading to significant lowering of water levels at these bores since 2007, as shown in **Figure 2-14**. Despite the depressurization of the Upper and Middle Liddell seams resulting from this dewatering, groundwater elevations in the overlying Bowmans Creek alluvium and shallow bedrock overburden do not appear to have been affected, as demonstrated by the hydrographs for dual piezometers ALV7 and ALV8 in **Figure 2-13**. The data indicate minimal (if any) effects on the Bowmans Creek alluvial aquifer and shallow bedrock as a result of current dewatering operations at LCO, in agreement with the previous assessment by Geoterra in 2009 (CBE, 2010).

The coal barrier left in place between the historical Liddell and Hazeldene underground workings allows groundwater levels to be maintained in the Hazeldene underground workings above 60 m AHD even as groundwater levels in the Liddell underground workings falls below 0 m AHD (Umwelt, 2006). Comparing hydrographs for piezometers Haz 3/4 and Haz 6, located within the Hazeldene, with piezometers intercepting the Liddell underground (LC1, Mt Owen 2 and M49), indicates the coal barrier effectively limits hydraulic connectivity between these two former underground workings.

The long history of underground mining in the LCO area has impacted upon Bowmans Creek at various times and in different ways, including leakage induced by depressurisation of the seams at depth, and leakage down connective cracking as a result of subsidence related failures. MER (2001) provided the following summary of events related to reports of loss of flow in Bowmans Creek and underground leakage.

- In December 1979, loss of flow was experienced in the Bowmans Creek in an area near Dams 1 and 4 (near monitoring bores ALV1, LBH and ALV3). Subsidence cracks arising from mining at Hazeldene Colliery were observed in the dry creek bed. Reported loss of flow supports the presence of a connective cracking regime both within the creek bed and in areas beneath the alluvial cover, whilst the widespread presence of transmissive basal gravels within the alluvium would have facilitated localised dewatering of the alluvium. While infilling and closure of cracks undoubtedly occurred at surface, it is not known whether the cracking subsequently closed at depth. At around the same time, local farm bores were reported to go dry.
- In September 1987, an inspection of Hazeldene Colliery by the Department of Mineral Resources (DMR) reported water inflow to the Pikes Gully workings at a rate of 1.5ML/day from a narrow chimney in goaf where convergence of two fault slip planes occurred. Failure is

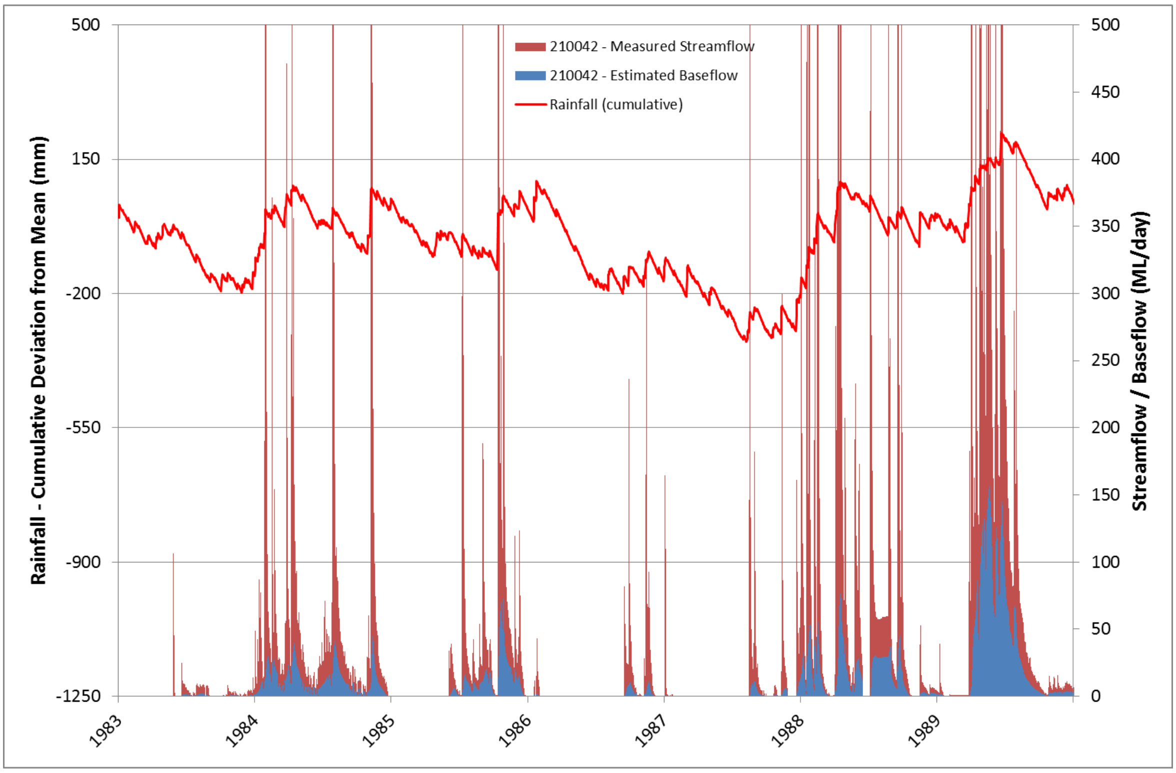
believed to have been induced through mining in the underlying Liddell seams. Leakage was noted to rise sharply following heavy rainfall. It was also noted that conditions for mining were excellent – the roof required minimal support, the coal ribs were stable and the floor comprised a strong sandstone. Mining at Liddell Colliery (Coal & Allied) in the Liddell seam at this time reported influx rates of about 2.5ML/day with no increases during high rainfall periods. Operations at Hazeldene ceased in late 1987 and groundwater levels were then allowed to rise and fully submerge the workings in both seams.

- In October 1987, DMR undertook mapping of the creek bed and alluvium (Beckett, 1987) from Hebden Road crossing in the north and immediately east of Mountain Block, to an area near the confluence with Yorks Creek in the south. Visual assessment of flows suggested a loss of 50% for the creek section transgressing Hazeldene Colliery. Further south in the Liddell Colliery area, surface cracking was observed in outcrop on hill slopes adjacent to the alluvial lands. Leakage of creek water was also inferred from gravel structures in the creek bed in an area where longwall panels were extracted. The depth of cover in these areas is greater than 160 metres, however, and observations may have reflected shallow non-connected cracking. Continuing concern for leakage to workings prompted the installation of 14 groundwater monitoring piezometers in May 1988 in the alluvial lands overlying Liddell Colliery longwall panels.
- In June 1990, the Department of Land and Water Conservation (DLWC) completed monitoring of the 14 piezometers installed in the area above longwall panels of the Liddell Colliery and concluded that creek flows had re-established and that no long term loss of flow would result from mining. MER's (2001) review of monitoring data supports this, as significant changes in creek flow or storage within the alluvial lands do not have an observable influence on water levels within the old workings. This does not, however, preclude the possibility that connective cracking is present and is acting as a relatively constant leakage source governed by crack impedance.

To better evaluate the observations and interpretations of these reports, climatic data for the period must also be considered. Data from streamflow gauge 210042 (refer **Figure 2-15**) is useful in this regard as it was operational during the 1980s. Cumulative rainfall data exhibits a series of drying trends through the decade (downward trajectories on **Figure 2-15**). Years 1986 and 1987 were particularly dry, with stream flow only recorded following moderate events. Increasing rainfall trends in 1984, 1988 and 1989, on the other hand, generated good flows and by 1989, groundwater levels had risen sufficiently that baseflow was a significant proportion of total annual flow for the creek.

Based on these data, conclusions regarding causes for the drying of the creek and local bores are difficult to establish. The distinction between drying due to connective cracking and leakage or to the drier than average climate conditions, or a combination of both, cannot be definitively established.

▪ **Figure 2-15 – Streamflow and Estimated Baseflow Data for Gauge 210042**



2.6.5 Groundwater Quality

Groundwater quality in the alluvial and hard rock aquifers in the region varies, with water quality in the alluvium generally slightly less saline than in the coal measures. Alluvial groundwater in the region is generally classified as fresh to brackish, while the coal seam aquifers are generally brackish. Groundwater quality data is available for both aquifer systems throughout the region as a result of monitoring programs associated with the various mines in the area.

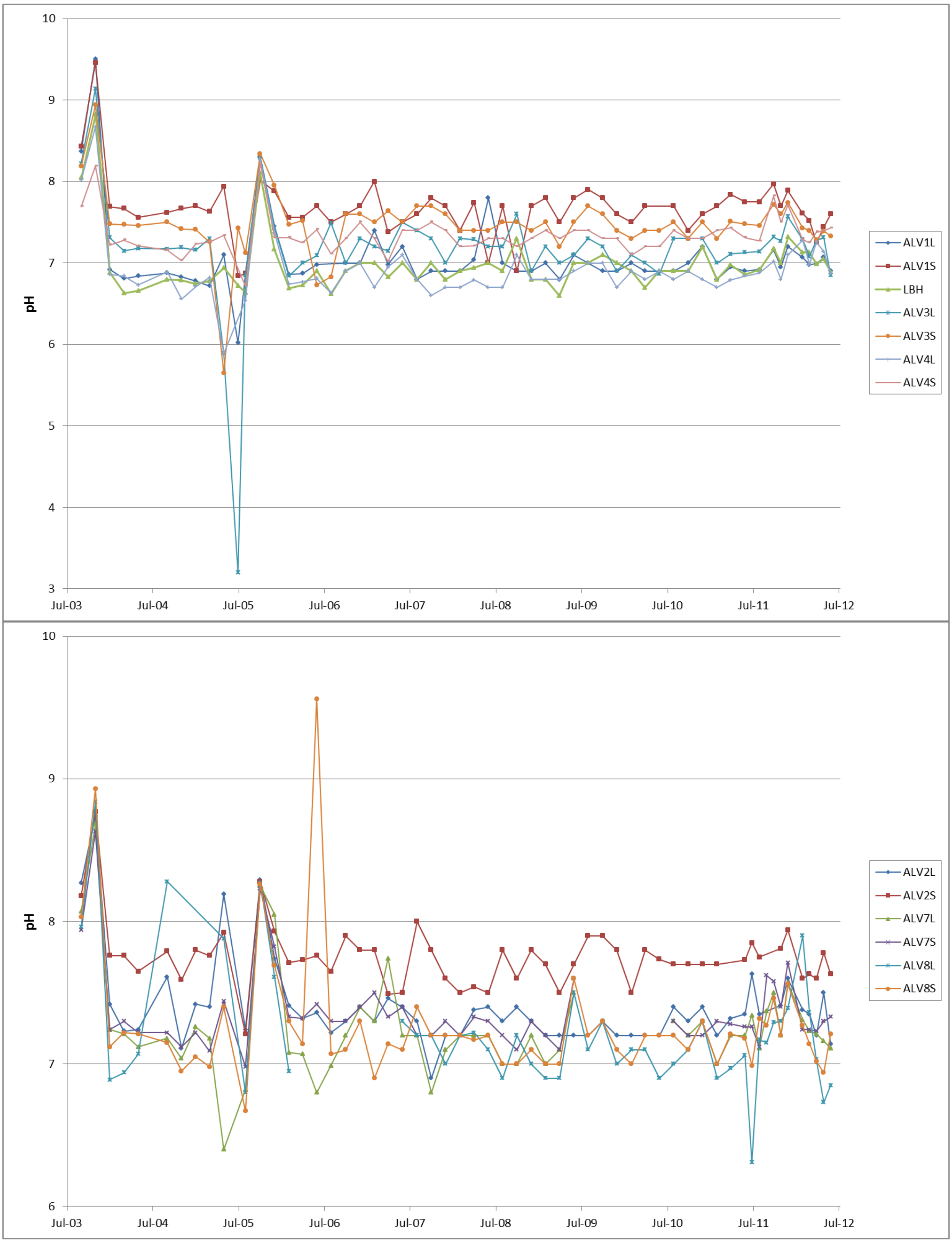
At LCO the groundwater monitoring program includes bi-monthly in situ pH and electrical conductivity (EC) measurements and six monthly analysis of samples for total suspended solids (TSS), total dissolved solids (TDS), heavy metals, cations and anions (AECOM, 2012). The monitoring network includes seven locations targeting the Bowmans Creek alluvial aquifer and shallow bedrock aquifer, and five bores within the deeper coal measures (refer to **Figure 2-12**). **Figure 2-16** and **Figure 2-17** show pH and EC data for piezometers in the alluvial and shallow bedrock aquifer, and **Figure 2-18** shows data for the regional hard rock aquifer associated with the coal measures. **Appendix A** contains analytical results for water samples collected as part of the monitoring program.

pH readings in the alluvium and shallow basement aquifer generally fall between 6.5 and 8, values typically found in natural waters, while pH readings for the deeper hard rock aquifer were slightly higher, generally ranging between pH 7 and 9. Occasional pH measurements for both aquifers fell well outside these typical ranges, though the consistency in readings before and after such measurements suggests these are erroneous.

EC values for the alluvial and shallow bedrock aquifer indicate brackish waters, with values generally below 3000 uS/cm except for piezometer ALV4S, where higher EC values in the range 4000 to 5000 uS/cm are consistently observed. Analysis of EC data for dual piezometers indicates waters extracted from the shallow bedrock (bores with the suffix = S) consistently recorded higher EC readings compared to the alluvial bores (suffix = L).

No major trends are apparent in the pH and conductivity data presented in **Figure 2-16** through **Figure 2-18**, with the exception of a significant decrease in EC values for the hard rock piezometer HAZ 4 between July 2006 and July 2007. This decrease in conductivity at HAZ 4 was accompanied by a slight decrease in pH readings and may be related to adjustments in mining operations during this period, though further investigations are required to determine the cause. Conductivity readings also decreased slightly in the alluvial bore ALV8L soon after July 2007, though this may be attributable to the heavy rainfall and flooding that occurred at that time.

- **Figure 2-16 – pH Data for Piezometers Targeting Alluvium and Shallow Bedrock**



▪ **Figure 2-17 – Conductivity Data for Piezometers Targeting Alluvium and Shallow Bedrock**

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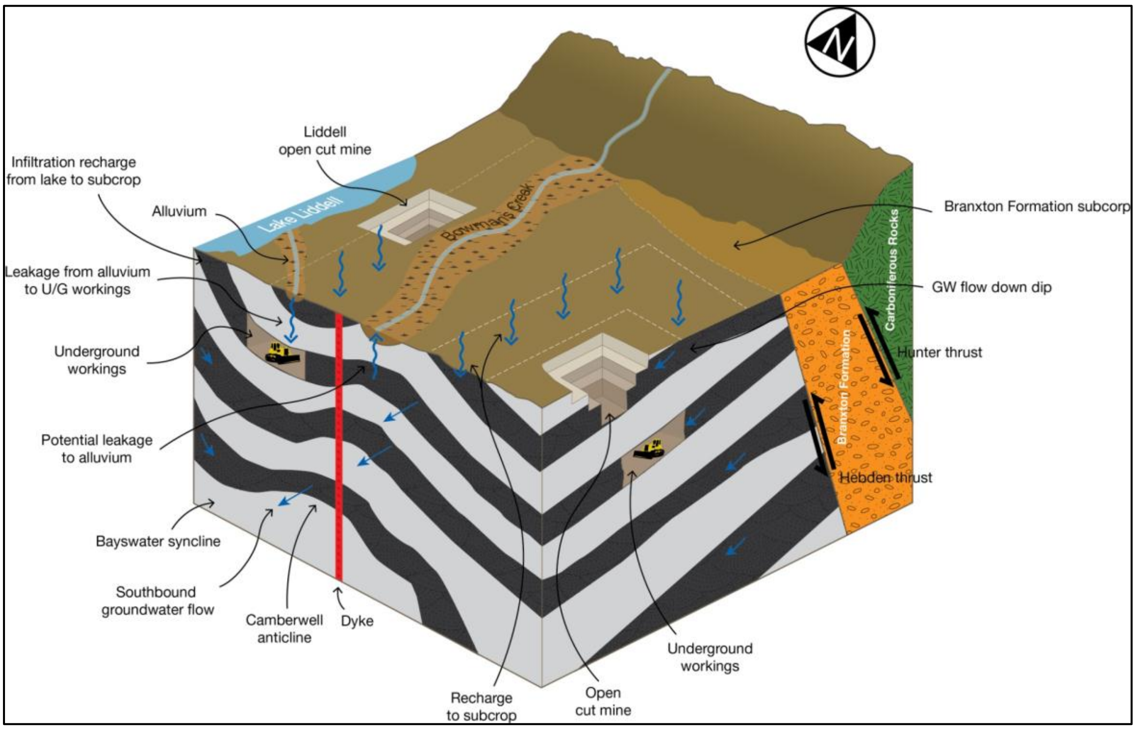
- **Figure 2-18 – pH and Conductivity Data for Piezometers Targeting Regional Hard Rock Aquifer (Coal Measures)**

In addition to pH and EC, data for additional water quality parameters such as TSS, TDS, heavy metals, cations and anions has been collected as part of the monitoring program. **Appendix A** summarizes the data collected for these water quality parameters. The water management plan (Umwelt, 2008b) and groundwater monitoring program (Umwelt, 2008a) currently in place at LCO references the trigger values provided in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC, 2000) as default criteria. The 80th percentile trigger values provided in the ANZECC (2000) guidelines have been adopted due to the highly disturbed nature of the site (Umwelt, 2008a). The data presented in **Appendix A** indicates that analyte concentrations in groundwater samples at LCO generally fall below the adopted criteria, with exceedances of the criteria observed for heavy metals copper and zinc and to a lesser extent aluminium, lead and nickel. No major trends are apparent for these species during the monitoring period, however, indicating minimal impact on groundwater quality as a result of mining activities.

2.6.6 Conceptual Model

Based on the geology and aquifer systems described above, a block diagram describing the conceptual hydrogeological model for the LCO site has been developed and is presented in **Figure 2-19**. This has been used to guide the development of a numerical groundwater flow model for the region.

- **Figure 2-19 – Conceptual Hydrogeologic Model of LCO Site and Surrounds (not to scale)**



3. Groundwater Modelling

SKM has developed a regional numerical groundwater flow model for the Jerrys and Glennies water sources of the Hunter Unregulated and Alluvial WSP in order to provide XCN with a tool for evaluating potential environmental impacts that may accompany further development and expansion of mining operations within the Bowmans Creek catchment and surrounding areas. In particular the model provides estimates of changes in groundwater heads that may occur as a result of mine dewatering activities and any associated changes in baseflow contributions to surface water features in the region. Full details of the groundwater model can be found in **Appendix B**, with a summary of the model provided here.

3.1 Model Description

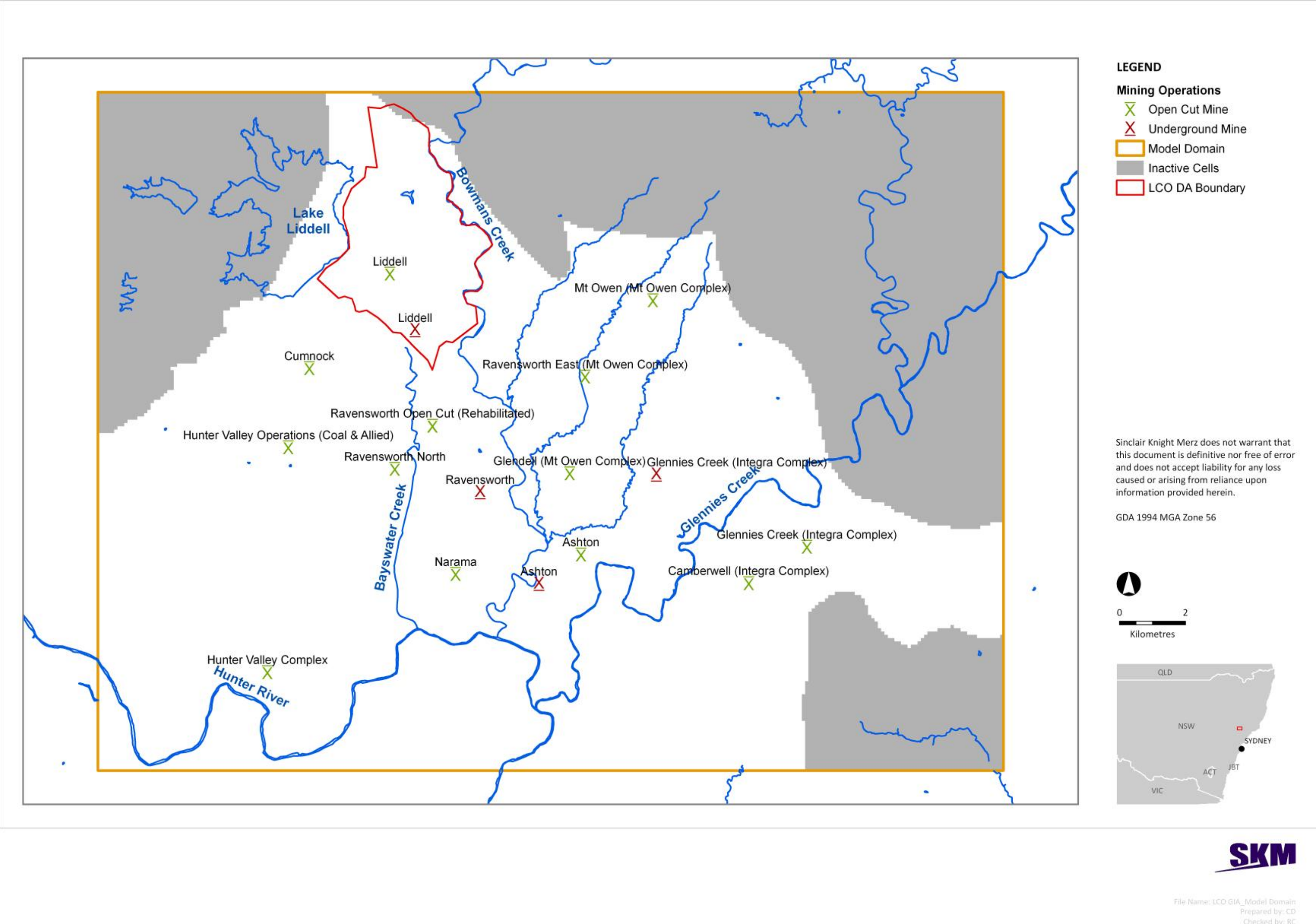
The model constructed was based on the existing model for the Ravensworth Underground Mine (RUM; MER, 2011b) and extended to the north and east to include LCO and the Mt Owen Complex and Glendell mines. The model was created using the Groundwater Vistas pre-processor with the MODFLOW-SURFACT finite difference code (Hydrogeologic, 2011).

3.1.1 Model Domain

The model domain measures 20.5 km in the north-south direction and 27.4 km in the east-west direction. Grid cells are 100 m by 100 m, resulting in a model grid of 205 rows and 274 columns. The extent of the model domain in relation to LCO and other mines in the area is shown in **Figure 3-1**. Model cells were designated inactive in areas were coal seams belonging to the Vane Subgroup were not present, such as in the northwest and southeast corners of the model domain and north of the Hunter Thrust.

The model includes 20 layers representing stratigraphy from the ground surface down to the Saltwater Creek Formation, with a description of each model layer provided in **Table 3-1**. The extent and depth of the model layer representing the Bowmans Creek alluvium was estimated based on LiDAR data and borehole logs (refer **Section 2.6.1**), resulting in the layer shown in **Figure 2-10**. Further information on the assumptions and approximations used in constructing the model layers is provided in **Appendix B**.

▪ **Figure 3-1 – Model Domain**



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- **Table 3-1 – Description of Model Layers**

Layer	Name	Description
1	Alluvium	Alluvial deposits surrounding the major rivers.
2	Alluvium/Regolith	Basal Alluvial sediments surrounding the rivers and Regolith (weathered rock) elsewhere.
3	Overburden	Everything between the base of weathering and the top of the Bayswater Seam, can include seams, but mostly sandstone, claystone and/or siltstone.
4	Bayswater Seam	All the Bayswater Seams. Includes the upper Bayswater 1, upper Bayswater 2 and Lower Bayswater at Liddell. Also includes interburden between these seams.
5-6	Interburden	Everything between the base of the Bayswater Seam and the top of the Upper Pikes Gully Seam, includes Lemington Seam.
7	Upper Pikes Gully Seam	Upper Pikes Gully Seam.
8	Interburden	Everything between the base of the upper Pikes Gully Seam and the top of the middle Pikes Gully Seam.
9	Middle and lower Pikes Gully Seam	Everything between the top of the middle Pikes Gully Seam and the base of the lower Pikes Gully Seam, includes interburden between the two seams.
10	Interburden	Everything between the base of the lower Pikes Gully Seam and the top of the Arties Seam.
11	Arties Seam	All the Arties Seams. Includes the Arties A, Arties B, Arties L1 and Arties L2 at Liddell.
12	Interburden	Everything between the base of the lower Pikes Gully Seam and the top of the Arties Seam.
13	Liddell Seam Sections A & B	All the Liddell Seams in Sections A and B. Includes the Liddell A1, Liddell Parting, Liddell B1, upper Liddell B2 and lower Liddell B2 at Liddell. Also includes interburden between these seams.
14	Liddell Seam Section C	All the Liddell Seams in Section C. Includes the upper Liddell C1, lower Liddell C1 at Liddell. Also includes interburden between the two seams.
15	Liddell Seam Section D	All the Liddell Seams in Section D. Includes the upper Liddell D1, lower Liddell D1 at Liddell. Also includes interburden between the two seams.
16	Interburden	Everything between the base of the Liddell Seam Section D and the top of the Barrett Seam.
17	Barrett Seam	All the Barrett Seams. Includes the Barrett A, upper Barret B, middle Barrett B, lower Barrett B, Barrett C1, Barret C2 and Barrett D at Liddell. Also includes interburden between these seams.
18	Interburden	Everything between the base of the Barrett Seam and the top of the Hebden Seam.
19	Hebden Seam	All the Hebden Seams. Includes upper Hebden and lower Hebden at Liddell. Also includes interburden between the two seams.
20	Saltwater Creek Formation	This layer represents the basement below the Hebden Seam, its upper part is composed of the Saltwater Creek Formation.

3.1.2 Boundary Conditions

Boundary conditions used throughout the model include general head boundaries, river, drain and wall boundaries, and MODFLOW's stream routing package. General head boundaries were assigned to active cells adjacent to model boundaries where the aquifer is known to extend beyond the limit of the model domain. River boundaries were assigned to replicate surface water – groundwater interaction of the Hunter River and associated alluvium in the southern extents of the model area. The stream routing package was used to define surface water – groundwater interactions for Bowmans Creek as it preserves the mass balance between adjacent stream cells, which is important for replicating ephemeral streams and for simulating potential losses in flow restricted streams such as Bowmans Creek. The dyke and coal barrier that influence groundwater flow in the coal measures at LCO are represented in the model using wall boundary conditions, and non-perennial streams are represented with drain cells.

Recharge was applied to the upper most active hydrogeological unit at a rate consistent with the surface geology characterisation. Areas of alluvium were assigned a recharge rate between 0.1% and 20% average annual rainfall, and other areas were assigned recharge rates between 0.001% and 5% average annual rainfall for calibration and sensitivity assessments. Evapotranspiration rates were set to the corrected pan evaporation rate for LCO (approximately 1,460 mm/yr) with an extinction depth of 2 m.

The model incorporates historical and future approved mining operations as part of its base setup. Underground mining prior to 1990 is represented in the model by increased hydraulic conductivity (both horizontal and vertical) as well as increased storage properties (specific yield). Post-1990 modelling stress periods incorporate dewatering associated with underground and open cut operations through the use of drain cells. After cessation of dewatering, and to account for backfill sequencing and final voids at the completion of mining, re-saturation and re-equilibrium was accounted for in the model through the use of time varying hydraulic properties, recharge and evapotranspiration rates for relevant cells.

3.2 Model Calibration

Model calibration was undertaken using a stochastic methodology to generate datasets of model parameters that matched historical groundwater levels within acceptable limits. Monte Carlo analysis was used to generate 10,000 unique combinations of model parameters that were allowed to vary within specified ranges. These datasets were then used as inputs for model calibration simulations, with the model results being compared to historical groundwater levels.

The model parameters used as inputs for the Monte Carlo analysis included hydraulic properties (horizontal and vertical conductivity, specific yield), conductance terms for river, stream, and general head boundary cells, and recharge rates for the uppermost active layer in the model. Historical water levels recorded for the Bowmans Creek alluvial bores (bores ALV1L through ALV8L) were used as the calibration target dataset in the Monte Carlo analysis. These bores were chosen as the potential impacts from mining activities at LCO on the Bowmans Creek alluvial aquifer were specifically identified as a key concern in the DGRs and by NSW Office of Water (refer **Section 1.2**). Historical water levels for bores in the shallow bedrock beneath the Bowmans Creek alluvium (bores ALV1S through ALV8S) were not included in the calibration target dataset.

The calibration simulations identified 37 realisations, or sets of model parameters, that converged and replicated historical groundwater levels within the target calibration criteria. Amongst these calibrated datasets, five realisations included alluvial recharge rates between 5% and 10% of average annual rainfall, which is generally the accepted range used in groundwater models for the region. These five datasets were then used in predictive simulations to estimate potential impacts on groundwater and associated surface water systems resulting from the proposed mining activities. Detailed discussion of the Monte Carlo analysis, calibration datasets, result statistics, and sensitivity analysis can be found in **Appendix B**.

Model calibration using a stochastic approach such as that employed here accounts for the inherent uncertainty associated with complex models based on many inter-related parameters. Each of the 'calibrated' datasets, or realisations that generate model results within the adopted calibration acceptance criteria, is considered equally plausible, and the range of model results generated using these stochastic datasets provides a good indication of the sensitivities and uncertainties associated with predictive modelling. Such uncertainty analysis is imperative in any predictive modelling exercise and is recommended under the National Water Commission's recent *Australian Groundwater Modelling Guidelines* (2012).

3.3 Predictive Simulations

Following model calibration, the stochastic datasets were used to run predictive simulations to investigate the potential impacts of mining activities on local aquifer systems. The objectives of the predictive simulations were to estimate:

- Potential reductions in groundwater flow to Bowmans Creek and its alluvial aquifer as a result of the proposed mine extensions;
- Drawdown in the bedrock and Bowmans Creek alluvium as a result of the proposed modification;
- The cumulative impacts of the proposed modification within the context of regional mining operations;
- Pit inflows and dewatering requirements; and
- Post mining equilibrium and the time period to reach equilibrium.

Predictive simulations were undertaken using three different scenarios in order to better quantify the potential impacts of the proposed mine extensions at LCO on groundwater resources:

- No Liddell case: including other mining operations in the area but excluding all historical and future mining activities at LCO;
- Base case: simulates all historical, current and approved future mining operations at LCO; and
- Proposed case: includes all historical, current and approved future mining operations at LCO including the proposed modifications that are the focus of this assessment.

Model results for the No Liddell and Base case simulations provide an estimation of the cumulative impacts to local groundwater resources that can be attributed to historical and currently approved mining operations at LCO. Results for the Proposed and Base case simulations provide estimates of the additional impacts (if any) that can be attributed to the proposed extensions to open cut pits.

The annual progression of the South Pit and Entrance Pits simulated for the Proposed case scenario is shown in **Figure 3-2**. Drain cells within the boundary of the pit shells were progressively switched on for the years shown in **Figure 3-2** to simulate the extension of the pits under the proposed modification. For modelling purposes progression of the South Pit beneath the MIA was simulated for the 2022 timestep. Initial predictive simulations including progression through the MIA in the 2023 timestep, as is planned, showed this extension has minimal impact on leakage rates and groundwater extraction requirements.

Predictive model results for groundwater fluxes from the Bowmans Creek alluvial aquifer, drawdown in the alluvium and hard rock aquifer, estimates of pit inflows and dewatering requirements, and post mining equilibrium are presented in the following sections. For the purposes of this groundwater impact assessment the results and estimates presented have been evaluated within the following context.

- Given the extent and complexity of the model and the amount of data available, substantial assumptions and simplifications were required to facilitate model construction and development. In keeping with standard practice, SKM adopted conservative values for model parameters for which reliable data was either unavailable or unknown. As a result the predictive model results presented are considered conservative estimates of potential impacts.
- The Hunter Unregulated and Alluvial WSP commenced in August 2009 and specified sustainable allocations of water from Jerrys Water Source based on agricultural, industrial and stock and domestic use at the time of commencement (refer **Section 1.5.1**). No specific estimation or provision for water use by mining operations was made in the allocations. The predictive model results presented here have therefore been assessed against a reference baseline of 2009 to correspond with the introduction of the Hunter Unregulated and Alluvial WSP.

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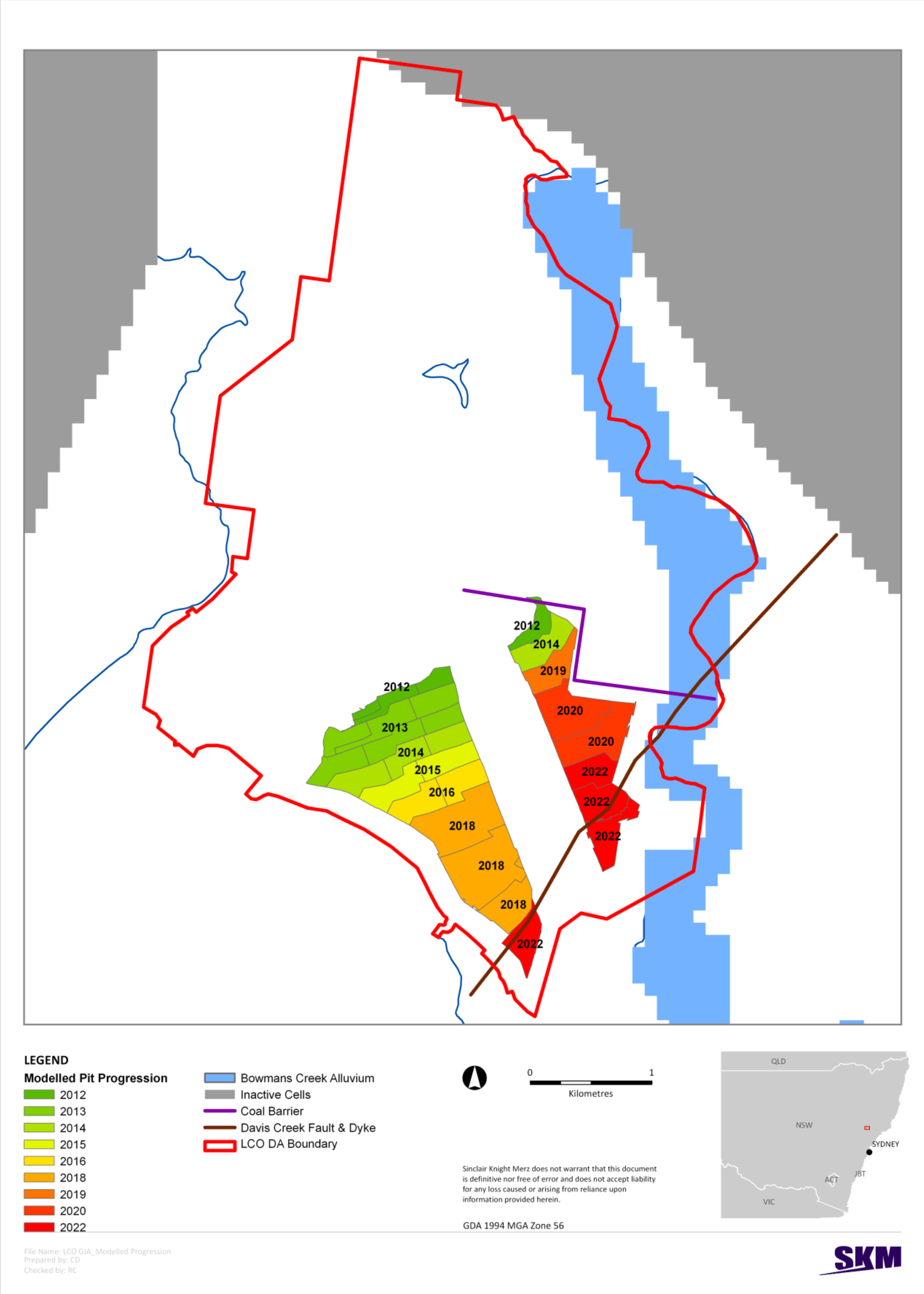
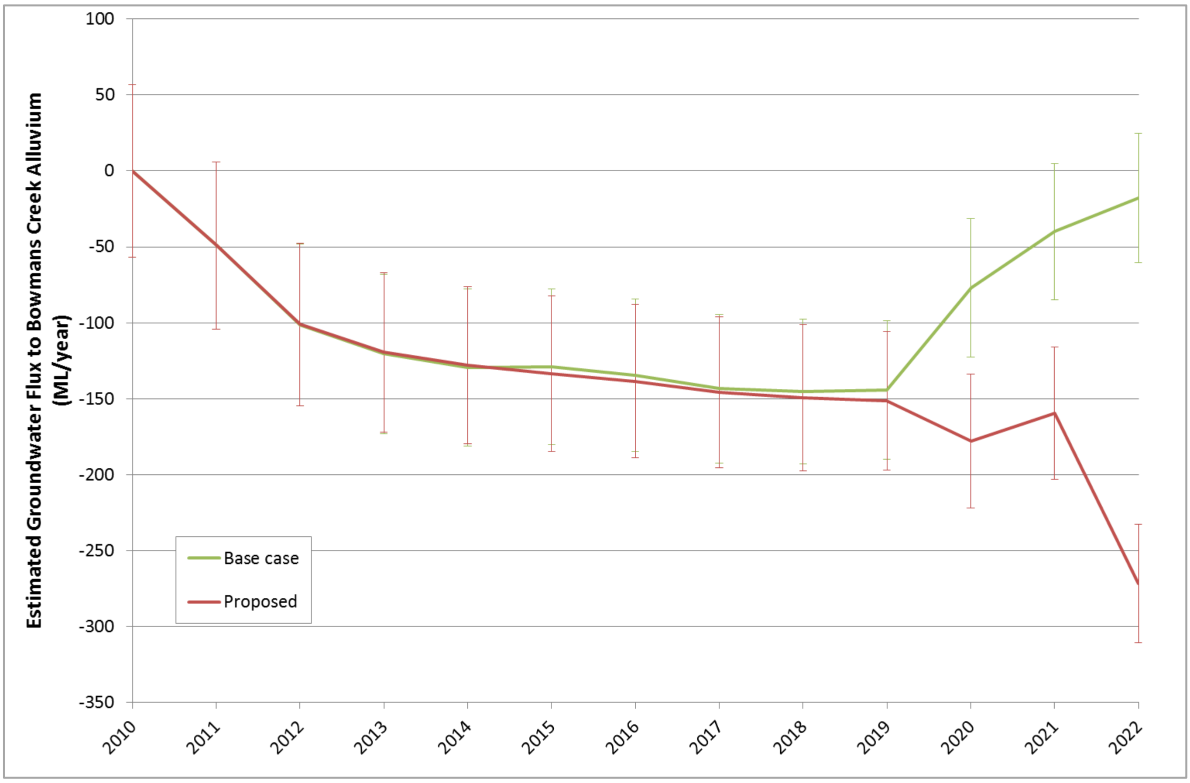
- **Figure 3-2 – Modelled Open Pit Progression for Proposed Case Scenario**



3.3.1 Estimated Groundwater Flows and Drawdowns

Results from the predictive simulations were analysed to evaluate estimated reductions in groundwater flow and corresponding drawdown to the Bowmans Creek alluvial aquifer as a result of mining activities at LCO. By subtracting the estimated groundwater flux to the model layer representing the Bowmans Creek alluvium under the No Liddell scenario from the Base case scenario, the cumulative impact of current mining activities at LCO can be isolated. Similarly, the difference between the No Liddell and Proposed case scenarios allows the cumulative contribution of mining activities under the proposed modification to be quantified. **Figure 3-3** shows the estimated groundwater flows to the Bowmans Creek alluvium under currently approved mining operations (the Base case scenario) and for the proposed modification (Proposed case). The lines shown represent the median (50th percentile) of results from the calibrated stochastic datasets, with error bars representing one standard deviation from the median. Note the estimates are provided from the end of 2009 to correlate with the introduction of the Hunter Unregulated and Alluvial WSP, and negative values correspond to groundwater flows out of the alluvium (i.e. leakage).

- **Figure 3-3 – Estimated Groundwater Fluxes to Bowmans Creek Alluvium**



Analysis of **Figure 3-3** provides an understanding of the influence of current and proposed mining activities on estimated groundwater fluxes to the Bowmans Creek alluvium. In particular, **Figure 3-3** shows:

- Prior to 2019 the estimated leakage from the Bowmans Creek alluvium under the Proposed case scenario is virtually identical to the predicted groundwater fluxes under the Base case scenario. These model results indicate that up to 2019 the estimated leakage under the proposed modification will be similar to that occurring under the currently approved mine plans.
- After 2019 the positive slope in the Base case curve reflects the beginning of system recovery following the end of mining under the currently approved mining plans. This recovery corresponds with the cessation of dewatering of former underground workings from the 8 South 2, Middle Liddell, and M49 pumping bores.
- The similarity in leakage estimates for the Base and Proposed case scenarios prior to 2019 confirms that dewatering of underground workings is primarily responsible for the groundwater losses from the Bowmans Creek alluvium. The progression of the South Pit between 2013 and 2019 in the Proposed case scenario (refer to **Figure 3-2**) appears to have negligible effect on the predicted leakage rates.
- After 2019 the extension of the Entrance Pit begins to have minor additional impacts on leakage rates from the alluvium through to 2021. Between 2021 and 2022 the predicted losses increase by approximately 110 ML/year. This peak leakage rate corresponds to progression of the Entrance Pit to the south-eastern side of the dyke and Davis Creek Fault and into the M49 underground workings.

Figure 3-4 provides the estimated additional drawdown within the Bowmans Creek alluvial model layer under the Proposed case scenario relative to the Base case (i.e. results of the Proposed case minus the Base case) for the years 2019 and 2022. Drawdown estimates have been presented in this format to provide an indication of the estimated additional (or incremental) impact of the proposed modification relative to currently approved mine plans. It should be noted, however, that the incremental drawdown attributable to the proposed modification also takes into account the predicted recovery of groundwater flows to the alluvium (i.e. reduction in leakage) for the Base case scenario beginning in 2019.

Recent groundwater monitoring data for LCO (refer **Section 2.6.4**) indicates groundwater levels in the alluvium have largely been stable, including over the 2010 to 2013 period over which the model is estimating leakage rates up to 120 ML/year. As the model predicts similar leakage rates under both the Base and Proposed case scenarios in 2019, the resulting incremental drawdown is negligible. Furthermore, with the exception of 2022, the groundwater losses predicted are similar in magnitude to the rates estimated by the model for current (2013) mining operations at LCO. Considering the monitoring data available, current and peak estimated leakage rates, the conservative assumptions adopted in constructing and calibrating the model, and the predicted recovery in groundwater flows for the Base case scenario, the incremental drawdown shown for 2022 likely represents a conservative prediction. Additional monitoring data and corresponding revision and validation of the groundwater model under the proposed modification will refine and provide additional confidence in these estimates.

Interrogation of the model provides insight into the mechanisms and causes of the groundwater losses and corresponding drawdown predicted within the Bowmans Creek alluvial aquifer. As described above, the progression of the South Pit under the proposed modification appears to have negligible additional impact on groundwater flows and drawdown from the alluvium, while the Entrance Pit progression has minimal impacts up to 2021. The similarity in results for the Base case and Proposed case scenarios up to 2019, plus the immediate recovery observed in the Base case scenario after 2019 when dewatering ends, indicates that the predicted losses are primarily due to dewatering of the underground workings (from the 8 South 2, Middle Liddell, and M49 bores). The actual progression of the South Pit, and to a lesser extent the Entrance Pit, under the Proposed case scenario has little effect on the predicted alluvial leakage rates.

However, after 2021 the estimated leakage under the proposed modification increases significantly to a peak of 270 ML/year. **Figure 3-2** shows that this year corresponds to progression of the Entrance Pit to the south eastern side of the dyke and Davis Creek Fault and into the former Liddell underground workings that are dewatered by the M49 bore. As discussed in **Section 2.6.4**, historical data and reports indicate leakage into the Liddell seam has been recorded in this area, attributed to fractures and cracking within the intervening strata between the alluvium and underground workings (MER, 2001; Umwelt, 2006). These reported fracture zones were represented in the model in the form of increased vertical conductivity for model cells within the suspected areas, including for the otherwise confining model layers representing interburden strata. As the extension of the Entrance Pit reaches this area, the depressurization of the underground Liddell workings required to accommodate the pit progression leads to increased vertical leakage and corresponding drawdown within the overlying alluvial aquifer.

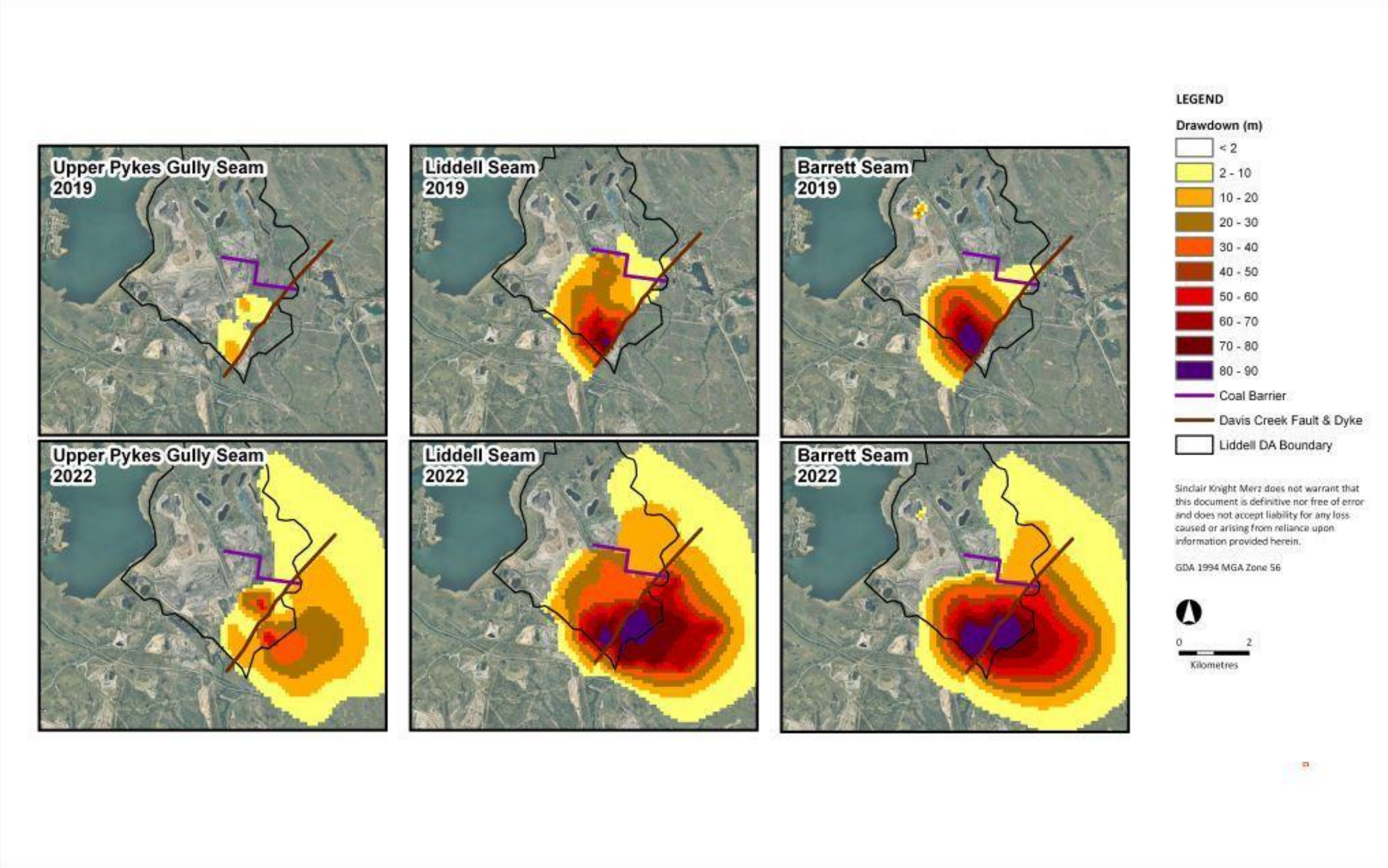
Previous environmental assessments have suggested that the cracking above the former Liddell underground workings has since healed. Umwelt (2006) previously reported that 'several investigations and a review of monitoring data led the [DNR] to conclude that creek flows have re-established and long term loss of flow has resulted from previous mining.' This conclusion was later supported by Geoterra (2009), whose analysis of groundwater elevations in the area determined there was negligible impact on the alluvial aquifer as a result of mine dewatering of the open cut pits (CBE, 2010). However, little further information has been supplied detailing these investigations, which appear to have used surface water and groundwater level data to support conclusions that the fracture zones have healed. Such conclusions ignore the possibility that the surface water and groundwater systems can also achieve a new equilibrium that includes constant leakage via higher permeability (i.e. cracking, fracture) areas (MER, 2001).

Given these considerations, SKM adopted a pre-cautionary approach for the representation of these cracking and fracture areas within the regional groundwater model. In order to provide a conservative assessment (i.e. worst-case scenario), suspected fracture zones were implemented in the model using increased vertical conductivity values under the assumption that cracking is still present and leakage is still occurring. In the absence of site specific data demonstrating such cracking has healed, it was determined that including such features in the model would provide a conservative evaluation of potential impacts to the overlying alluvial aquifer (refer **Section 1.2**). Collection of additional monitoring and lithology data for these areas should provide a better understanding on the presence and extent of connective cracking.

Predicted additional groundwater drawdown for the Upper Pikes Gully, Liddell A and B, and Barrett coal seams are shown in **Figure 3-5**. Significant drawdown is shown for the coal seams due to the dewatering required to undertake mining activities.

- **Figure 3-4 – Predicted Drawdown for Bowmans Creek Alluvium Resulting from Proposed Modification**

- **Figure 3-5 – Predicted Drawdown for Coal Seams Resulting from Proposed Modification**

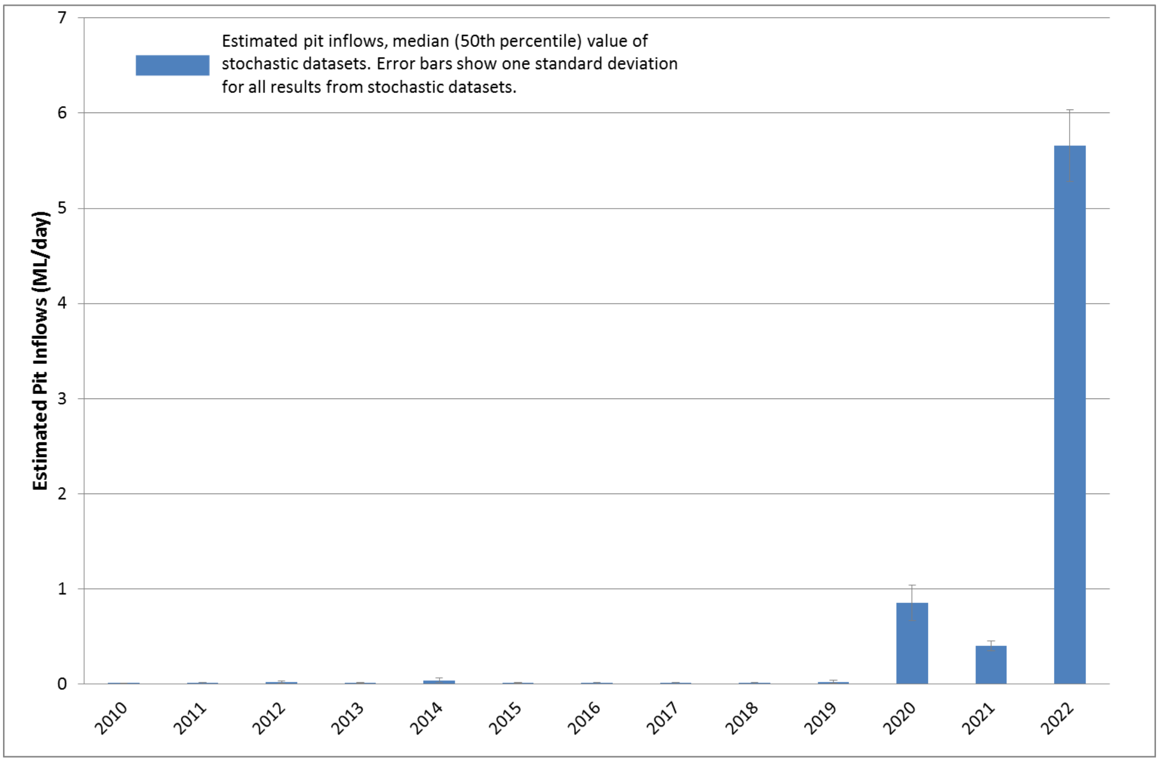


3.3.2 Estimated Pit Inflows and Dewatering

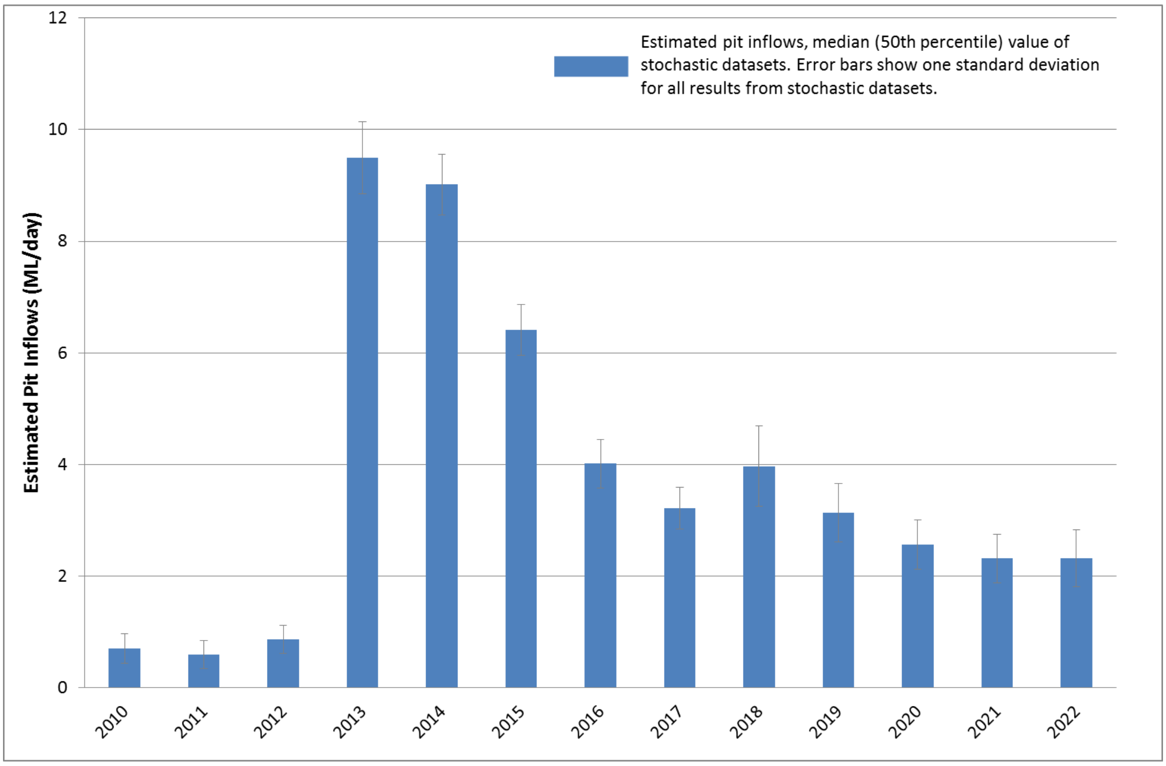
In addition to estimates of reductions in groundwater flow to alluvial systems and groundwater drawdown, the predictive simulations also provide estimates of pit inflows and dewatering requirements needed to accommodate the proposed extensions to open cut pits. **Figure 3-6** and **Figure 3-7** show estimated rates of pit inflows into the Entrance Pit and South Pit, respectively, for the duration of mining under the proposed modification. **Figure 3-8**, **Figure 3-9** and **Figure 3-10** show the predicted dewatering rates required at dewatering bores Hazeldene, M49 and Middle Liddell Bore, respectively.

Figure 3-11 shows the total estimated groundwater extraction required to accommodate the proposed modification. The total extraction requirements are the sum of the pit inflows and dewatering rates predicted in the model simulations, with the rates determined in ML/year to allow comparison with groundwater extraction licenses held by LCO.

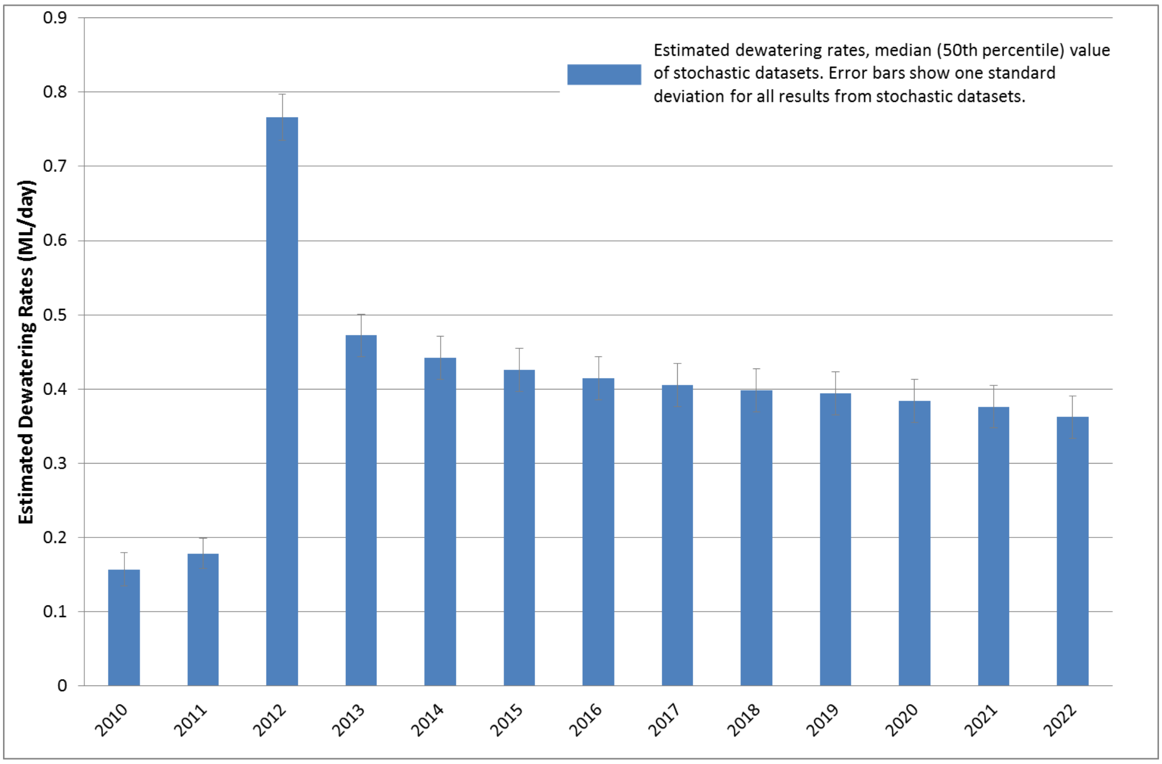
- **Figure 3-6 – Estimated Pit Inflows at Entrance Pit**



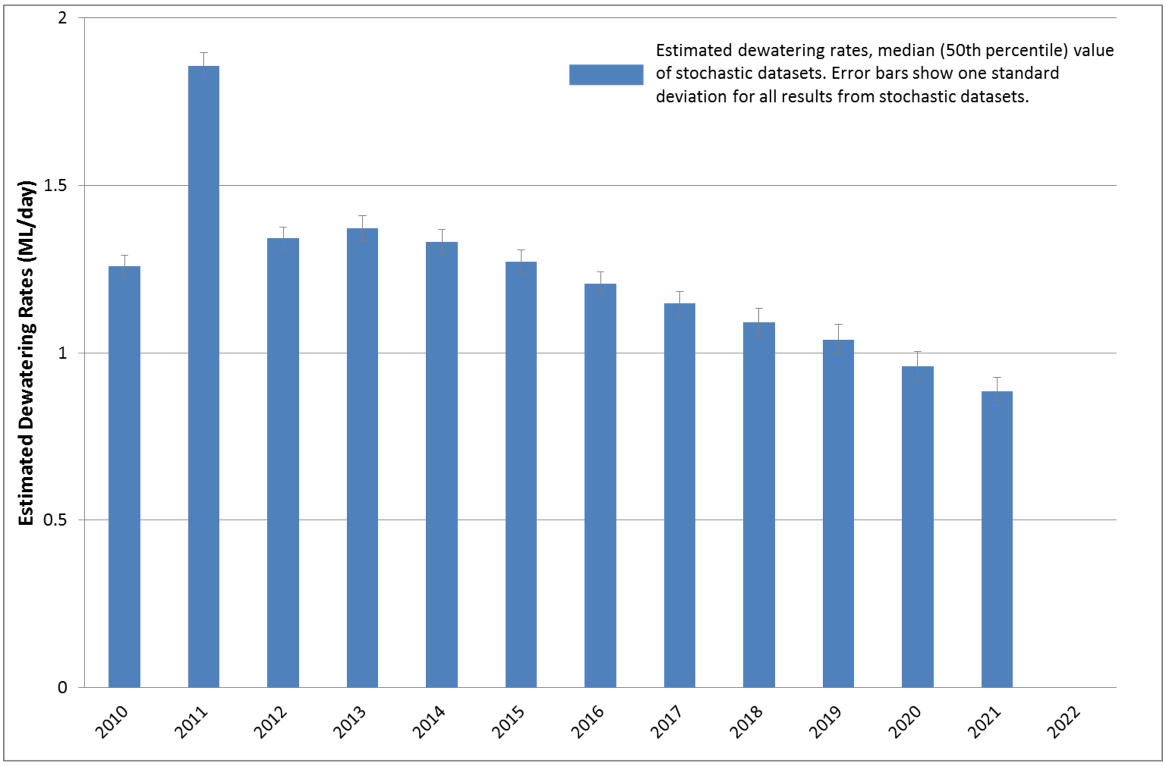
- **Figure 3-7 – Estimated Pit Inflows at South Pit**



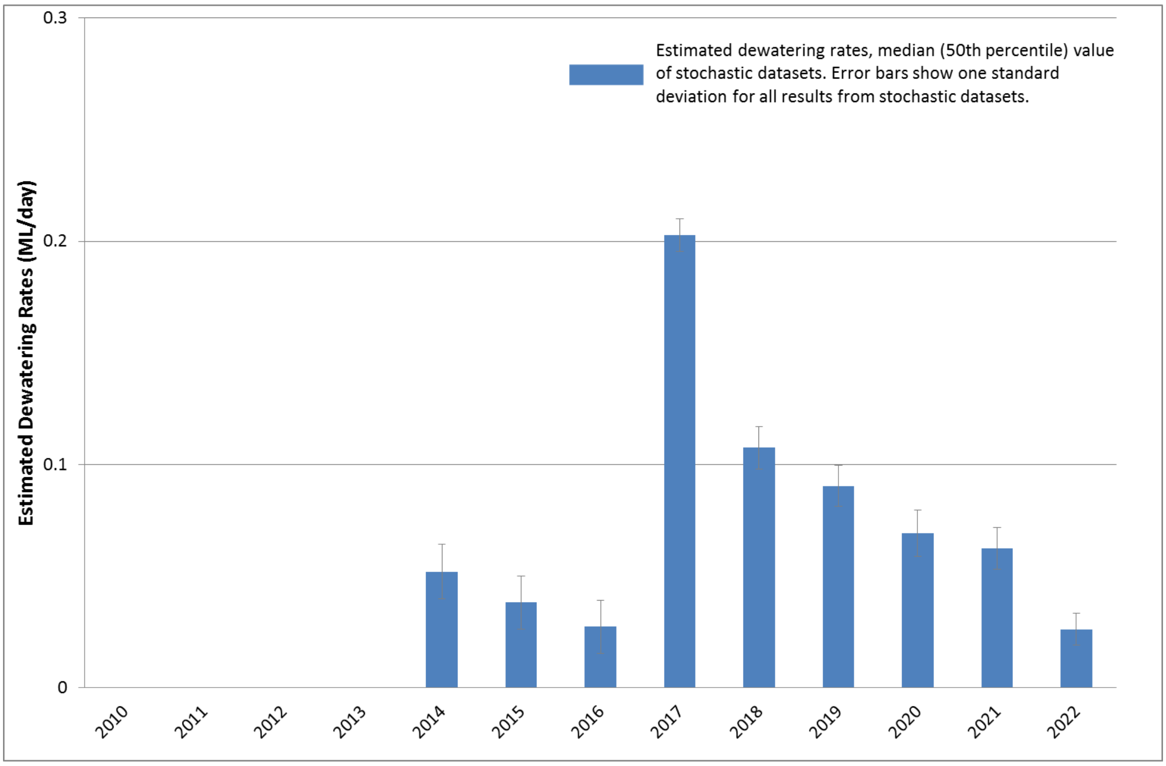
- **Figure 3-8 – Estimated Dewatering Rates at Hazeldene**



- **Figure 3-9 – Estimated Dewatering Rates at M49**



- **Figure 3-10 – Estimated Dewatering Rates at Middle Liddell Bore**



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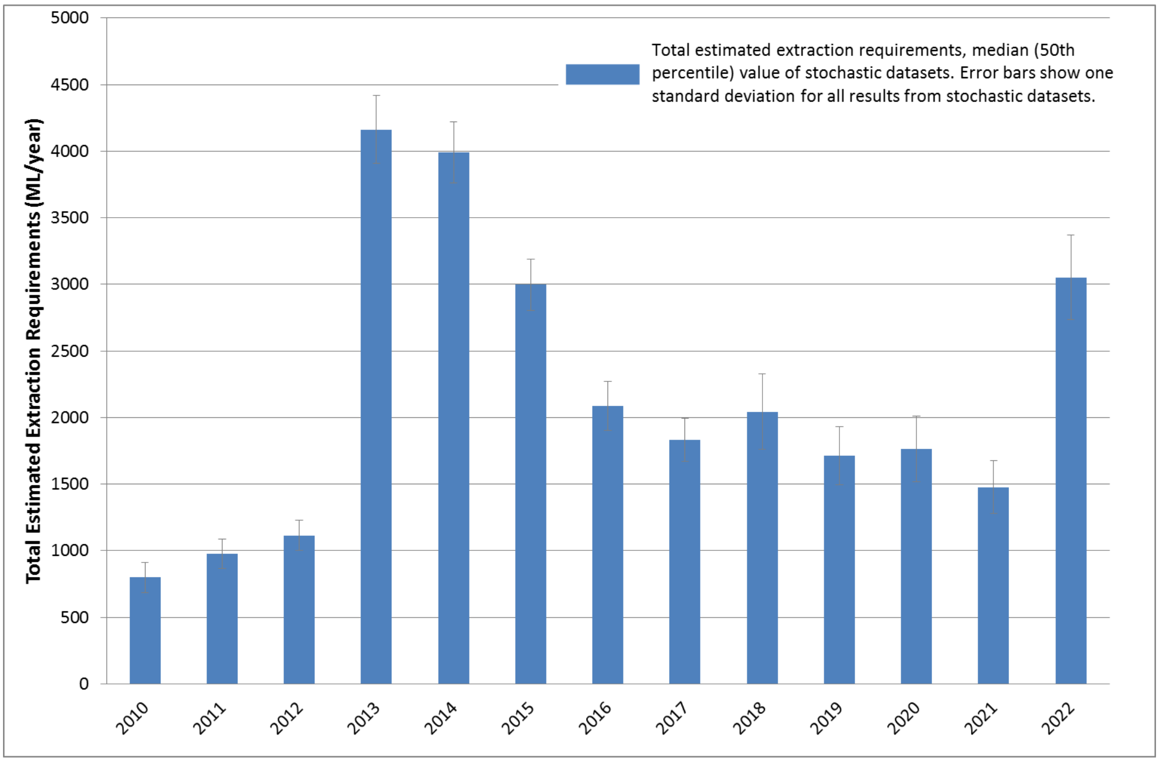
- **Figure 3-11 – Total Estimated Groundwater Extraction Requirements**



3.3.3 Post Mining Equilibrium

Steady state post mining equilibrium simulations were conducted using final void water level information calculated by Gilberts & Associates (G&A, 2013) in their water balance assessment for the proposed modification. Water levels in the final voids of the South Pit and Entrance Pit determined by G&A (2013) were used as boundary conditions in the post mining equilibrium simulations. Results of the G&A assessment and the post mining equilibrium simulations provided the following conclusions:

- G&A (2013) determined that groundwater levels within the final voids of the South Pit and Entrance Pit recover and stabilise to approximately 67 m AHD within 50 years following the end of mining.
- Peak estimated inflow rates to the Entrance Pit and South Pit final voids are predicted to be approximately 43 ML/day and 14 ML/day, respectively.
- Steady state simulations using the final void equilibrium water levels provided by G&A (2013) indicate the Entrance Pit final void will act as a sink for groundwater flow from the surrounding hard rock aquifer (i.e. groundwater heads in the surrounding aquifer will be greater than the final void water level), and the South Pit final void will act as a source of groundwater flow to the hard rock aquifer when water levels are above approximately 65 m AHD.
- As parts of the final voids will not be backfilled, G&A (2013) predicts that evaporation will cause salinity in the South Pit to increase continuously over time. According to G&A (2013), salinity levels in the Entrance Pit are predicted to stabilise at approximately 4,200 mg/L due to

groundwater inflows and water transfer to the South Pit via the remnant Middle Liddell underground workings.

- Steady state post mining equilibrium simulations indicate groundwater heads within the Bowmans Creek alluvial aquifer recover to levels equal to or above the estimated and observed levels at the introduction of the Hunter Unregulated and Alluvial WSP (August 2009), and above water levels in the Entrance Pit and South Pit final voids. This ensures no leakage occurs from the final voids to the alluvial aquifer.

Potential long term impacts to groundwater in the hard rock aquifer may result from leakage of increasingly saline water from the South Pit final void when water levels in the void rise above approximately 65 m AHD.

4. Groundwater Impacts Assessment

The groundwater impacts assessment focuses on the effects of mining-related activities on the region's groundwater systems. Howe et al. (2010) identified four categories into which direct impacts can be classified:

- Groundwater quantity – e.g. dewatering activities, hydraulic load associated with the mine waste facilities;
- Groundwater quality – e.g. acid rock drainage, which has the potential to impact on pH and mobilise metals;
- Groundwater – surface water interactions; and
- Physical disruption of aquifers – e.g. through removal of an ore body.

To assess the risks from these direct impacts, potential receptors must be identified and evaluated with respect to their likelihood for exposure and their response to such impacts. Potential receptors to such impacts include environmental, social and cultural, and economic users of groundwater resources.

The potential impacts of mining and related activities on these receptors can be assessed from the results of numerical groundwater models such as that presented in the previous section. Results from predictive model scenarios, combined with other contextual information on LCO, have been used to evaluate the potential impacts to groundwater resulting from the proposed open cut extensions at LCO.

4.1 Potential Direct Impacts

4.1.1 Groundwater Quantity

Perhaps the most significant direct effects on groundwater systems resulting from mining operations are impacts to groundwater quantity, through either reduction in groundwater levels and pressures due to extraction and dewatering, or through additional hydraulic loads at mine waste and backfill areas where seepage rates are higher than surrounds. Historical mining operations at LCO and in the surrounding region have caused depressurisation and dewatering of coal seams of the regional hard rock aquifer to accommodate mining activities. Current open pit operations at LCO extract coal from the Lemington, Pikes Gully, Arties, Liddell and Barrett seams of the Wittingham Coal Measures (GSS, 2011) and intersect historical underground workings in the area (the former Liddell underground). These historical underground workings contain substantial amounts of groundwater, requiring in-pit pumping and local dewatering to maintain suitable working conditions. As a result, current and historical mining operations at LCO and in the local region have already had significant impacts on groundwater quantity within the regional hard rock aquifer.

Impacts to Bowmans Creek Alluvium

Current model simulations predict that the proposed modifications at LCO will impact groundwater quantity in both the regional hard rock aquifer, where dewatering is required to accommodate mining operations, and for the alluvial aquifer of Bowmans Creek through increased induced leakage. Estimated groundwater losses from the alluvium are predicted to increase slowly through to 2019 to approximately 150 ML/year, with a predicted further increase to around 180 ML/year in 2020. Between 2021 and 2022, estimated losses are predicted to peak, with simulations estimating a cumulative loss of up to 270 ML/year attributable to LCO under the proposed modification (refer **Figure 3-3**). As reasoned in **Section 3.3.1**, these estimates are considered conservative, and on-going monitoring and evaluation is required to substantiate these predictions.

Monitoring data and predictive model results indicate that peak estimated groundwater losses from the Bowmans Creek alluvium at the end of mining (year 2022) may result in up to one meter drawdown within the alluvial aquifer. This drawdown estimate falls below the minimal impact criteria for aquifer interference activities (maximum two meter decline in water table) as specified in the Aquifer Interference Policy (NSW, 2012). Predictive simulations further indicate that alluvial groundwater levels will return to current (2013) levels within 50 years following the end of mining.

As discussed in **Section 2.6.4**, historical mining activities in the coal seams beneath Bowmans Creek are suspected to have introduced cracking and leakage from the alluvial aquifer into the underground workings (MER, 2001), though climatic data for the period in question makes it difficult to establish the causes of the reported drying of the creek and local bores. Nevertheless since 2001 monitoring data for alluvial groundwater levels indicates that leakage from the Bowmans Creek alluvium, if present, is not substantial enough to have resulted in measurable drawdown of groundwater levels within the alluvial aquifer (refer **Figure 2-13**).

Impacts to Hard Rock Aquifers

Predicted drawdown plots for the hard rock aquifer associated with the coal measures (**Figure 3-5**) show significant reductions in groundwater pressures, with maximum predicted drawdown up to 90 m in the Liddell and Barrett seams at the end of mining (year 2022). Such significant drawdown is to be expected as these seams require dewatering as the target coal reserve for the open pits. The predicted drawdown extends beneath the Entrance and South Pits to the southeast beyond the LCO boundary, with **Figure 3-5** showing the significant influence of the impermeable northeast to southwest trending dyke and Davis Creek Fault (refer **Section 2.6.4**) in restricting the cone of depression to this area.

Figure 3-11 shows the total estimated groundwater extraction required to accommodate the proposed modification, calculated from the sum of the estimated pit inflows in the South Pit and Entrance Pit and the estimated dewatering rates from dewatering bores Hazeldene, M49 and Middle Liddell Bore. Results from predictive simulations show extraction requirements peak around 4,000 ML/year in 2014, with smaller peaks of approximately 3,000 ML/year in 2015 and at the end of mining. LCO currently holds licences to extract 27,000 ML/year of groundwater from the regional hard rock aquifer, an amount well above the estimated requirements for the proposed modification.

The expansion of open cut pits at LCO will modify the long-term hydrogeologic regime in the area following the cessation of mining activities, resulting in changes to post-mining equilibrium groundwater levels. Within the hard rock aquifer post-mining equilibrium groundwater levels will be influenced by the final voids, which also serve as discharge areas for the former Liddell underground workings. Estimated peak inflows to the Entrance Pit and South Pit final voids are predicted to be approximately 43 ML/day and 14 ML/day, respectively. According to G&A's water balance assessment (2013) for the proposed modification, water levels in the final voids are predicted to equilibrate to approximately 67 m AHD within 50 years following the end of mining. Steady state simulations using these equilibrium water levels predict the Entrance Pit would be a sink while the South Pit is predicted to act as a source of groundwater to the regional hard rock aquifer.

4.1.2 Groundwater Quality

Impacts to groundwater quality resulting from mining activities are typically associated with two main issues:

- Potential acidification and subsequent mobilization of heavy metals resulting from acid rock drainage (ARD); and
- Changes in salinity due to mixing of groundwater and/or surface water sources, evaporative losses from open pits or shallow water tables, or alterations in hydraulic gradients resulting from mining activities.

ARD occurs when sulphide-bearing rocks oxidize during mining operations, either through exposure to oxygenated waters or to atmospheric conditions, resulting in acidic leachate capable of mobilising heavy metals hosted within the rock. Both the low pH of the leachate and the mobilisation of toxic metals can have significant impacts on surface water and groundwater resources.

Historical groundwater monitoring data at LCO and other regional mines (Aquaterra, 2009b) suggests the coal and rock extracted from the Wittingham Coal Measures do not contain any significant acid forming potential. pH data recorded for the regional hard rock monitoring bores at LCO (**Figure 2-18**) has remained consistent since the beginning of current open cut operations, and water quality data has not revealed any distinct trends in heavy metals concentrations (**Appendix A**). As a result, impacts to groundwater quality as a result of ARD are considered highly unlikely under the proposed open cut extensions.

Mining operations may also impact groundwater quality through changes in salinity, for example if saline water was collected and/or generated in mine workings and then allowed to enter fresher alluvial aquifers. Impacts to groundwater salinity can also occur if an upward pressure gradient exists between the deeper, more saline hard rock aquifer associated with the coal measures and the fresher alluvial aquifers associated with the Hunter River and its tributaries.

For the current and proposed open cut operations at LCO, model simulations predict groundwater fluxes from the Bowmans Creek alluvial layer into the underlying hard rock aquifer, meaning upward leakage from the coal measures to the alluvium is unlikely to be occurring. While previous assessments for LCO have suggested potential for upward leakage (MER, 2001), current and historical open cut and underground mining operations are expected to have altered the hydrogeological regime sufficiently to limit such pressure gradients. A small upward potential is observed in bores to the north of the operations, but not adjacent to, or south of, LCO where impacts to water quality are more likely to occur. Historical groundwater monitoring of alluvial bores do not reflect any significant trends in EC readings with the exception of bore ALV8L. This bore recorded a decrease in EC around July 2007 that is likely attributable to heavy rainfall and flooding.

Steady state post mining equilibrium simulations predict the Entrance Pit final void will act as a sink, while the South Pit final void will act as a source for groundwater flow from the surrounding hard rock aquifer when the final void water levels are above approximately 65 m AHD. G&A's water balance assessment (2013) predicts salinity in the South Pit final void will increase continuously over time (G&A, 2013), resulting in the potential for long term impacts to groundwater quality in the hard rock aquifer due to leakage of increasingly saline water from the South Pit final void when water levels are above approximately 65 m AHD. Predicted post mining equilibrium water levels in the final voids are lower than predicted groundwater heads within the Bowmans Creek alluvial aquifer, indicating leakage from the voids to the alluvial aquifer is unlikely to occur and adversely impact groundwater quality in the alluvium.

4.1.3 Surface Water – Groundwater Interaction

Mining related activities can have significant effects on surface water – groundwater interactions, usually due to either physical alterations to the landscape or groundwater extractions that change the natural dynamic relationship between surface water and groundwater systems. In the Upper Hunter Valley, surface water systems that may be affected by regional mining operations include the Hunter River and its tributaries. These are regulated under the NSW *Water Management Act 2000*, and the alluvial areas are considered BSAL under the Upper Hunter Strategic Regional Land Use Plan. For the proposed extensions to open cut pits at LCO, potential direct impacts to surface water – groundwater systems specifically relate to impacts to Bowmans Creek and its alluvial aquifer.

Model results indicate that the surface water – groundwater system of Bowmans Creek and its related alluvium are currently impacted by mining operations at LCO in the form of leakage from the alluvial aquifer to the underlying strata. Predictive simulations estimate increased leakage under the proposed modifications (refer **Figure 3-3**). To evaluate the impacts of such leakage, the projected losses are compared to the estimated contribution that groundwater baseflow makes to streamflow in Bowmans Creek (refer **Section 2.4**). Historical streamflow and climactic data were used to estimate groundwater contributions to baseflow along Bowmans Creek and is presented in **Table 2-2**. Historical data indicates groundwater baseflow contributes between 20% and 25% of total streamflow in the vicinity of LCO, representing between one and 100 ML/day (365 to 36,500 ML/year).

Table 2-2 and **Figure 2-3** shows the estimated annual baseflow for stream gauges most likely to be impacted by current and future mining operations at LCO (e.g. gauges 210115, 210116, 210042, 210121 and 210130). Estimated baseflow at these gauges ranges from 2,740 ML/year to 5,950 ML/year. Predicted peak losses in groundwater flow from the Bowmans Creek alluvial aquifer resulting from the proposed modifications is estimated to be approximately 270 ML/year at the end of mining (year 2022; refer **Figure 3-3**). This would account for approximately 4% to 8% of the estimated annual baseflow contribution to streamflow, or less than 2% of measured annual streamflow. These peak leakage rates are predicted to occur for only a limited time period (1-2 years) and fall well below the range of estimated baseflow contributions observed throughout the historical record. The model results suggest the proposed modifications are therefore likely to have a minimal impact on the timing and magnitude of interaction between Bowmans Creek and its alluvial aquifer.

Evaluation of historical groundwater monitoring data and predictive model results provides further support for the minimal level of impact from current and potential future mining operations at LCO on the Bowmans Creek alluvial aquifer. Monitoring data show that alluvial groundwater levels have been generally stable since 2001, which includes periods of extensive pumping from underlying workings (refer **Section 2.6.4**). Model simulations predict leakage from the alluvial aquifer is occurring during this period due to dewatering, with alluvial groundwater levels in the model also remaining stable. Based upon the consistency between monitoring data and model results, and considering estimated leakage rates under the proposed modification are not predicted to increase significantly until 2021, the predicted impacts on the Bowmans Creek surface water – groundwater system are expected to be minimal.

4.1.4 Aquifer Impact

In addition to groundwater quantity and quality, mining operations can directly impact groundwater resources through physical disruption of an aquifer, which often occurs during removal of an ore body. Current and historical mining operations at LCO and in the local area have resulted in significant disruption of the regional hard rock aquifer found within the coal measures. The removal of coal reserves from historical underground mines (such as the Hazeldene and Liddell underground) left subsurface voids, while open cut pits and backfill sequencing can transform confined aquifers into unconfined systems with different hydraulic properties.

Compared to the impacts from the long history of mining activity and extent of operations in the local area, the additional impacts to the hard rock aquifer caused by the proposed modification are considered minimal. The proposed expansions to the open cut pits will not extend into the Bowmans Creek alluvium and will not physically disrupt this aquifer system.

4.2 Potential Receptors

In order to fully assess the risks arising from potential direct impacts to groundwater systems, the exposure and response of potential receptors to these impacts must also be evaluated. The term receptor is used here to include social and cultural, environmental, and economic users that may rely on groundwater resources.

4.2.1 Social and Cultural

Potential social and cultural receptors include users of water resources used for recreational purposes and/or social amenity (e.g. water sports, fishing, etc). The region surrounding LCO is characterized by extensive underground and open-cut coal mining operations, and in the vicinity of LCO Bowmans Creek is not recognized for recreational uses or social amenity. As such no social and cultural users of water resources potentially impacted by the proposed modification have been identified.

4.2.2 Environmental

Potential environmental receptors that may be affected by mining operations at LCO include aquatic and riparian ecosystems associated with the Hunter River and its tributaries, which are regulated under the *Water Management Act 2000* and considered BSAL under the Upper Hunter Strategic Regional Land Use Plan. For the proposed modification, Bowmans Creek and its alluvial aquifer has been identified in the DGR's and by NSW Office of Water as potential receptors.

In addition to the Bowmans Creek alluvial aquifer, groundwater dependent ecosystems (GDEs) must be considered as potential environmental receptors that may be affected by the proposed mine expansion. In general there are four types of GDEs:

- Terrestrial ecosystems;
- Baseflow supported aquatic ecosystems;
- Wetlands; and
- Aquifer ecosystems.

The aquatic ecosystem of Bowmans Creek and its associated riparian vegetation represent potential environmental receptors that may be impacted by the proposed mine expansion. Further assessment of local ecology and GDEs along Bowmans Creek has been undertaken as part of the Environmental Assessment for the proposed modification by Ecological Australia (2013) to evaluate their groundwater dependence and the potential impacts to these ecosystems. It is noted that previous environmental assessments for LCO concluded that due to the highly disturbed nature of the area and the lack of significant floral species, no significant impact would occur from mining operations (Umwelt, 2001). There are no known groundwater supported wetlands or recognized aquifer ecosystems in the area.

4.2.3 Economic

Interrogation of NSW Office of Water's PINEENA database identified 12 registered groundwater bores within 2 km of the LCO DA boundary (refer **Section 2.6.2**). The database includes exploration and test wells that may not have been completed as permanent infrastructure, irrigation and stock and domestic extraction bores, observation and monitoring bores, and privately owned bores and a record of bores that may be in use or abandoned.

Amongst the 12 registered bores presented in **Table 2-5**, six of the bores are owned by LCO or XCN's neighbouring Mt Owen mine and three are identified for exploration or mining purposes. Bore GW078085 is registered for stock purposes, however the bore is located to the northeast of LCO and beyond the area of predicted impacts from the proposed modification (refer **Figure 2-11**). The PINEENA database did not contain any ownership or purpose information for bores GW080176 and GW080173, however further research revealed the lots these bores are located on are owned by Ravensworth Operations P/L and Xstrata Mt Owen P/L, respectively. Both of these entities are XCN mining operations. Based on this information and model predictions of groundwater depressurisation in the regional hard rock aquifer extending beyond the LCO DA boundary (refer **Figure 3-5**), neighbouring mining operations are considered potential economic receptors of groundwater impacts caused by the proposed modification at LCO. No other economic users of groundwater within the local area are considered potential receptors to impacts resulting from the proposed modification.

4.3 Groundwater Impacts Assessment

The groundwater impact assessment provides an evaluation of the magnitude of potential direct impacts resulting from the proposed mine extension and the likelihood they will adversely affect the receptors identified. The assessment is undertaken from the perspective of the receptors in order to better identify potential exposure pathways and resultant risks caused by the proposed activities. The potential receptors of groundwater impacts arising from the proposed modification were identified amongst social and cultural, environmental, and economic users of groundwater resources and include:

- *Social and cultural:* no receptors identified;
- *Environmental:* Bowmans Creek and its associated alluvial aquifer system, including dependent riparian and aquatic ecosystems; and
- *Economic:* Neighbouring mining operations.

Table 4-1 presents the groundwater impacts assessment for the proposed modification, relating potential receptors (refer **Section 4.2**) to potential groundwater impacts (refer **Section 4.1)** and summarizing the resulting risks.

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Table 4-1 – Groundwater Impacts Assessment

Potential Receptor	Direct Impact	Discussion
Bowmans Creek alluvium (including groundwater dependent ecosystems)	Groundwater quantity	• Estimated leakage rates as a result of the proposed modification are predicted to peak at approximately 270 ML/year at the end of mining. LCO currently holds groundwater licence allocations of 142 ML/year for this water source. • Model simulations predict a peak drawdown within the alluvial aquifer of less than one meter as a result of the proposed modification. This estimated peak drawdown is expected to be limited to one year at the end of mining and falls below the minimal impact criteria for aquifer interference activities as specified in the Aquifer Interference Policy (NSW, 2012). • Post mining equilibrium simulations indicate that alluvial groundwater levels will return to current (2013) levels within 50 years following the end of mining.
	Groundwater quality	• Historical monitoring data suggests minimal impacts on groundwater quality in the Bowmans Creek alluvial aquifer due to current and historical mining operations at LCO. • Model simulations provide no indication that the proposed modification will alter the hydrogeologic regime in a manner that would adversely affect groundwater quality within the Bowmans Creek alluvium. Predicted post mining equilibrium water levels in the final voids are lower than predicted groundwater heads within the Bowmans Creek alluvial aquifer, indicating leakage from the voids to the alluvial aquifer is unlikely to occur and adversely impact groundwater quality.
	Surface Water – Groundwater Interaction	• Estimates of baseflow contributions to Bowmans Creek streamflow suggest the predicted peak annual leakage rate (270 ML/year) caused by the proposed modification accounts for approximately 4% to 8% of the estimated baseflow component of streamflow and less than 2% of measured annual streamflow. • The estimated peak loss of groundwater flow falls well below the range of baseflow contributions estimated from the historical record (365 to 36,500 ML/year). • Recent groundwater monitoring data and predictive model results indicate leakage from the alluvial aquifer induced by current mining activities at LCO are having negligible impact on groundwater levels within the alluvium. • Taking these data into account, the estimated losses in groundwater flow under the proposed modification is unlikely to have a significant impact on streamflow in Bowmans Creek or on water levels within the associated alluvial aquifer.
	Aquifer Impact	• The proposed open cut extensions do not intercept the Bowmans Creek alluvial system.

Potential Receptor	Direct Impact	Discussion
Neighbouring mining operations	Groundwater quantity	• Predicted depressurisation within the regional hard rock aquifer peaks at approximately 90 m in the Liddell and Barrett seams at the end of mining. **Figure 3-5** shows the predicted maximum depressurisation falls within the LCO DA boundary, however the zone of influence extends beyond the LCO boundary to the southeast. While this depressurisation extends beneath neighbouring mines, these other operations also require depressurisation and dewatering of the coal seams for their own mining purposes. As a result the depressurisation of the hard rock aquifer caused by the LCO modification is not expected to adversely impact neighbouring mining operations. • G&A predicts water levels in the final voids will equilibrate to approximately 67 m AHD within 50 years following the end of mining (G&A, 2013). Post mining equilibrium simulations using these final void water levels indicate the Entrance Pit would be a groundwater sink while the South Pit would act as a source of groundwater to the regional hard rock aquifer.
	Groundwater quality	• Monitoring data collected as part of current open cut mining operations at LCO indicate minimal (if any) impacts to groundwater quality for the Bowmans Creek alluvial aquifer or regional hard rock aquifer. • Following cessation of mining activities, G&A's water balance assessment (2013) predicts salinity in the South Pit final void will increase continuously over time (G&A, 2013), resulting in the potential for long term impacts to groundwater quality in the hard rock aquifer due to leakage of increasingly saline water from the South Pit final void when water levels are above approximately 65 m AHD. These potential impacts may adversely affect neighbouring mining operations by requiring management of higher salinity groundwater extracted as part of mining activities.
	Surface Water – Groundwater Interaction	• Model predictions and monitoring data indicate the proposed modification is unlikely to have a significant impact on streamflow in Bowmans Creek or on water levels within the associated alluvial aquifer. As a result the potential impacts to neighbouring mining operations that may access Bowmans Creek or the associated alluvial aquifer are expected to be negligible.
	Aquifer Impact	• The proposed open cut extensions intercept the regional hard rock aquifer that contains the target coal reserves within the LCO DA boundary. Given the extent of coal mining activities in the region that target the same coal measures, the depressurisation of the hard rock aquifer caused by the LCO modification is not expected to adversely impact neighbouring mining operations

In addition to evaluating the potential risks to receptors from predicted groundwater impacts, the proposed modification also requires assessment within the context of relevant legislation and policies. The *Water Management Act 2000* and Aquifer Interference Policy (2012) provide the legislation and requirements for obtaining licenses for aquifer interference activities and assessing the potential impacts of mining projects on water sources (refer **Section 1.5**). **Table 4-2** presents the assessment of the proposed modification within this regulatory framework. The 'minimal impact considerations' defined in the Aquifer Interference Policy and applied for this assessment comprise the criteria for highly productive alluvial water sources (for the Bowmans Creek alluvial aquifer) and the less productive fractured and porous rock water sources (for the regional hard rock aquifer).

▪ Table 4-2 – Regulatory Framework Assessment

Legislation / Policy	Requirement	Assessment
Water Management Act 2000	Water Licences	• Predicted leakage rates as a result of the proposed modification are estimated to peak at approximately 270 ML/year at the end of mining. LCO currently holds groundwater licence allocations of 142 ML/year for this water source. • Maximum estimated groundwater extraction rates required to accommodate the proposed modification (including pit inflows and local dewatering requirements) amount to less than 4,000 ML/year for the regional hard rock aquifer. LCO currently holds extraction licences totalling 27,000 ML/year for this water source
Aquifer Interference Policy	Minimal impact considerations – highly productive groundwater sources – alluvial water sources	*Water Table* • No high priority groundwater dependent ecosystems or culturally significant sites have been identified within 40 m of the proposed extension. • Model simulations predict a peak drawdown within the alluvial aquifer of less than one meter as a result of the proposed modification. *Water Pressure* • Steady state post mining equilibrium simulations indicate groundwater heads within the Bowmans Creek alluvial aquifer recover to levels equal to or above the estimated and observed levels at the introduction of the Hunter Unregulated and Alluvial WSP (August 2009). *Water Quality* • Model simulations provide no indication that the proposed modification will alter the hydrogeologic regime in a manner that would adversely affect groundwater quality within the Bowmans Creek alluvium.
	Minimal impact considerations – less productive groundwater sources – porous and fractured rock water sources	*Water Table* • No high priority groundwater dependent ecosystems or culturally significant sites have been identified within 40 m of the proposed extension. • No water supply works have been identified within the depressurisation zone predicted in model simulations. *Water Pressure* • No water supply works have been identified within the depressurisation zone predicted in model simulations. *Water Quality* • Following cessation of mining activities, G&A's water balance assessment (2013) predicts salinity in the South Pit final void will increase continuously over time (G&A, 2013), resulting in the potential for long term impacts to groundwater quality in the hard rock aquifer due to leakage of increasingly saline water from the South Pit final void when water levels are above approximately 65 m AHD.

5. Monitoring and Management

5.1 Regional Monitoring

LCO currently undertakes a comprehensive groundwater monitoring program (Umwelt, 2008a), with results reported in Annual Environmental Management Reports. The current groundwater monitoring network is shown in **Figure 2-12** and includes piezometers in the Bowmans Creek alluvium and shallow bedrock (overburden) and bores in the target coal measures. The piezometers are measured monthly for groundwater level and every two months for water quality. Eleven of the piezometers are also sampled biannually, and groundwater samples are analysed for a range of inorganics (refer **Section 2.6.5**; Umwelt, 2008a).

Model simulations of the proposed modification predict drawdown to occur within the Bowmans Creek alluvial aquifer to the southeast of the Liddell DA boundary. Drawdown in the alluvium is predicted to peak at the end of mining, though the incremental drawdown resulting from the modification is predicted to be less than one metre. Taking into account the extent of the current monitoring network, additional sites from the recently established Mt Owen Complex Groundwater Investigation Program (SKM, 2012) should be added to the monitoring program in order to better evaluate the impacts and risks of the proposed mine expansion on the Bowmans Creek alluvial system. These bores include shallow alluvial standpipes as well as multiple depth vibrating wire piezometers (VWPs) along Bowmans Creek to the southeast of LCO.

5.2 Bowmans Creek Alluvial Aquifer

Model simulations predict that leakage from the Bowmans Creek alluvium into the underlying strata occurs as a result of current operations at LCO and will continue under the proposed modification. The additional leakage, however, is not expected to have a significant additional impact on groundwater levels within the alluvium under the proposed modification. Bowmans Creek is classified as BSAL under the Upper Hunter Strategic Regional Land Use Plan and has been identified in the DGR's and by NSW Office of Water as a potential receptor of concern; therefore continued monitoring of the alluvial system will be undertaken to identify any potential impacts. Such monitoring and management is especially applicable towards the end of the proposed modification (years 2020 to 2022) when the predicted leakage rates substantially increase.

Based upon the impact assessment and predictive model results, an adaptive management strategy is proposed for the monitoring and (if necessary) mitigation of any potential unacceptable impacts to the Bowmans Creek alluvial system. Key aspects and justification for this approach are presented in **Table 5-1**.

Table 5-1 – Adaptive Management Approach for Groundwater Management

Management Approach	Discussion
Continue monitoring the alluvial and shallow bedrock groundwater systems in accordance with the current Groundwater Monitoring Program for LCO	• Site monitoring data suggests current operations are having negligible impacts on the alluvial system, and model results predict that leakage rates will not significantly increase over and above those estimated for current operations until 2019. The progression of the South Pit, which with the exception of the MIA finishes in 2019, therefore appears to have negligible impact on the alluvial system compared to current mine operations.
Supplement the existing monitoring program with additional monitoring locations for the alluvial system, focusing on those areas predicted by the model to have drawdown as a result of the proposed modification	• Site monitoring data suggests current operations are having negligible impacts on the alluvial system, and model results predict that drawdown may occur in the alluvial aquifer to the southeast of the LCO DA boundary. Including the shallow alluvial standpipes and VWPs installed as part of the Mt Owen Complex Groundwater Investigation Program (SKM, 2012) would provide suitable additional locations to monitor and track these predicted impacts.
Continued refinement and re-validation of the groundwater model with additional data collected to provide more confidence in the predictive results	• As with any model representations of real systems, additional site data will allow alteration and refinement of the model and will provide added confidence in the results. As discussed in **Section 3.3**, the groundwater model was constructed using a pre-cautionary approach, with results considered to represent conservative estimations of potential impacts. The results of monitoring programs and additional studies can be used to determine the frequency of refinement for the model.
If necessary, pursuit of additional licenses for the Jerrys Water Source to cover the predicted losses from the Bowmans Creek alluvial system	• Based on the predictive modelling results, LCO currently holds sufficient water licence allocations for the Jerry Water Source to account for the estimated losses from the Bowmans Creek alluvium until 2017. The estimated leakage beyond that date exceeds their current licence allocations, though not to a significant degree until 2022. Initial investigations by LCO have revealed the total licenced allocations for this water source (greater than 600 ML/year) would allow LCO to pursue additional licences to account for any additional losses.
If and where necessary, adjustment of mining and/or dewatering plans to mitigate unacceptable actual or predicted impacts on the alluvial system	• Given the predicted impacts to the alluvial system do not significantly increase over and above those estimated for current operations until 2019, additional data and modelling scenarios can be collected and evaluated within a timeframe that would allow changes to be enacted prior to the predicted impacts occurring.

5.3 Groundwater Extraction

Current operations at LCO require dewatering of historical underground workings and areas surrounding open cut pits and the management of pit inflows to accommodate mining activities. LCO implements an integrated Water Management Plan and Groundwater Monitoring Program that are designed to monitor and mitigate the impact of mining operations on the surrounding environment. Management relates to two facets of groundwater extraction: removal of groundwater to facilitate mining operations, and accountability of extractions under current legislation.

5.3.1 Dewatering and Inflow Management

The current water management system at LCO (updated in 2012 after Umwelt, 2008b) has been designed to address four main areas:

- Surface water runoff to existing pits and operation areas;
- Groundwater seepage in open cut and old underground workings;
- Mine operation water for the coal handling and processing plant and dust suppression; and
- Off-site discharges and water sharing arrangements.

The water management system includes a system of surface water structures designed to separate and capture surface runoff and seepage water from open cut pits and collect groundwater extracted from dewatering bores. Under current operating conditions the site water balance results in LCO being a net water producer, with surplus water being exported to surrounding mines.

Groundwater modelling undertaken for this assessment has provided estimates of dewatering rates and pit inflows for the proposed modification (refer **Figure 3-11**). The current Water Management Plan (Umwelt, 2008b) should be reviewed and updated to ensure the management system can accommodate these estimated loads. The update should include a review of the site water balance, erosion and sediment control plan, and surface water and groundwater response plan to account for the estimated extraction loads and expansion of open cut pits. Given the proposed modification falls entirely within the approved LCO DA boundary and extends current open cut operations, significant amendments to the water management strategy and site water balance are not expected to be required.

5.3.2 Water Licenses

Estimates of total groundwater extraction rates (i.e. dewatering rates plus pit inflows) required to accommodate the proposed modification peak at approximately 4,000 ML/year. LCO currently holds sufficient licenses (27,000 ML/year) to extract groundwater from the regional hard rock aquifer to accommodate these flows.

5.4 Review and Reporting

As mentioned above, the existing Water Management Plan and Groundwater Monitoring Program for LCO should be updated to include the above management and monitoring recommendations. In line with current practice, the water management system, site water balance, and monitoring results should be subject to an annual review by an experienced hydrogeologist and reported in

LCO's Annual Environmental Management Report. Should any review or monitoring data indicate significant variance with model predictions, existing monitoring data, or otherwise suggest substantial and/or unexpected impacts to surface water or groundwater systems, the implications and potential risks should be assessed and appropriate response actions undertaken in accordance with the Surface Water and Groundwater Response Plan contained in the Water Management Plan.

In addition, after commencement of the proposed modification, the groundwater model should continue to be updated and refined as additional data are collected to evaluate model predictions with respect to site monitoring data. When necessary, model re-calibration and predictive scenarios should be undertaken to reduce model uncertainty and provide confirmatory predictions.

6. Conclusions

6.1 Conclusions

This Groundwater Impact Assessment addresses those DGRs, and specific issues outlined by NSW Office of Water, that require assessment of potential impacts of LCO's proposed mine modification on local groundwater resources. These issues have been addressed through the use of a regional numerical groundwater model and evaluation of impacts to receptors in the context of the regional setting and historical mining activities.

Results from numerical model simulations allow us to evaluate the magnitude of potential direct impacts resulting from the proposed mine extension and the likelihood that these impacts will adversely affect potential receptors. The results of the predictive model simulations provide the following conclusions:

Impacts to Bowmans Creek alluvial aquifer

- With the exception of the final year of the Entrance Pit progression (year 2022), the magnitude of alluvial losses estimated by the model under the Proposed is similar to the leakage rates predicted for current mining operations at LCO. These estimated losses from the alluvium amount to between 150 to 180 ML/year up to 2021, and peak at 270 ML/year for 2022. LCO currently holds licence allocations totalling 142 ML/year for this water source.
- Under the proposed modification, model results predict that the progression of the South Pit has negligible impact on the Bowmans Creek alluvial aquifer in terms of increased leakage or drawdown. This is due to the fact that the dewatering required to accommodate the extension to the South Pit is the same as the dewatering currently being undertaken at LCO to accommodate present mining operations.
- Model results indicate the extension of the Entrance Pit causes small increases in leakage rates from the alluvium up to 2021, though between 2021 and 2022 the estimated losses increase by approximately 110 ML/year. This peak leakage rate corresponds to progression of the Entrance Pit to the south-eastern side of the dyke and Davis Creek Fault and into the M49 underground workings.
- Estimates of historical baseflow contributions to Bowmans Creek streamflow suggest the peak estimated loss of groundwater flow caused by the proposed modification accounts for approximately 4% to 8% of the estimated baseflow component of streamflow and less than 2% of measured annual streamflow. Furthermore the peak estimated leakage rate falls well below the range of baseflow contributions estimated from the historical record.
- Recent groundwater monitoring data and predictive model results indicate leakage from the alluvial aquifer induced by current mining activities at LCO are having negligible impact on groundwater levels within the alluvium. As a result the estimated losses in groundwater flow under the proposed modification are unlikely to have a significant impact on streamflow in Bowmans Creek or on water levels within the associated alluvial aquifer.
- Historical monitoring of groundwater within the Bowmans Creek alluvium suggests minimal impact of mining operations on groundwater quality, and model simulations provide no

indication that the proposed modification will alter the hydrogeologic regime in a manner that would adversely affect groundwater quality.

- Predicted drawdown within the Bowmans Creek alluvial aquifer is expected to be negligible (less than 0.25 m) relative to current water levels up to 2019. Site monitoring data confirms no measurable drawdown has occurred within the alluvial aquifer under current mining operations at LCO. When estimated leakage rates peak at the end of mining, drawdown is predicted to peak at less than one meter relative to current water levels. This peak drawdown estimate falls below the minimal impact criteria for aquifer interference activities as defined in the Aquifer Interference Policy (2012).

Impacts to hard rock aquifers

- Estimated total groundwater extraction from the regional hard rock aquifer, determined as the sum of pit inflows and dewatering requirements, needed to accommodate the proposed modification peaks at less than 4,000 ML/year. LCO currently holds extraction licenses totalling 27,000 ML/year for this water source.
- Post mining equilibrium simulations predict the Entrance Pit final void will act as a sink and the South Pit will act as a source for groundwater flow from and to the regional hard rock aquifer when final void water levels are above approximately 65 m AHD. Predicted increases in salinity in the South Pit final void (G&A, 2013) result in potential long term impacts to groundwater quality in the hard rock aquifer due to leakage of increasingly saline water from the South Pit final void when water levels in the void are above approximately 65 m AHD.

6.2 Management Approach

Based upon the impact assessment and predictive model results, an adaptive management strategy is proposed for the monitoring and (if necessary) mitigation of any potential unacceptable impacts to the Bowmans Creek alluvial system. The following measures are provided for consideration for monitoring and management of these potential impacts:

- The current Water Management Plan for LCO should be reviewed and updated to ensure the management system can accommodate the estimated dewatering rates and pit inflows for the proposed open cut extensions.
- Monitoring of the Bowmans Creek alluvium and shallow bedrock groundwater systems in accordance with the current Groundwater Monitoring Program for the site should continue.
- The existing monitoring network should be supplemented with additional monitoring locations for the alluvial system, focusing on those areas predicted by the model results for potential additional drawdown as a result of the proposed modification. The Groundwater Monitoring Program should be reviewed and updated to include the expanded monitoring network. The bores installed as part of the recently completed Mt Owen Complex Groundwater Investigation Program (SKM, 2012) would provide suitable additional monitoring locations.

- Continue to update, refine and re-validate the groundwater model with additional site and monitoring data as it is collected. Additional data will provide more confidence in the predictive model results and allow LCO to re-visit predictive simulations when necessary. The frequency for review and updates to the model should be determined based on the results of monitoring programs and other studies. Additional modelling may not be required if observed data confirms the conservative nature of the numerical model.
- If updated model results continue to predict future groundwater losses from the Bowmans Creek alluvial aquifer in excess of LCO's license allocations for the Jerrys Water Source, LCO should pursue additional licences to cover the estimated losses.
- If and where necessary, adjustment of mining and/or dewatering plans to mitigate actual or predicted impacts on the alluvial system may be required.

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Appendix A LCO Groundwater Monitoring Program Analytical Results

APPENDIX A: LIDDELL COLLIERY GROUNDWATER MONITORING RESULTS

SAMPLE ID	**ANZECC (2000) 80th%ile Trigger Value**	ALV1L	ALV1L	ALV1L	ALV1L	ALV1L	ALV1L	ALV1L	ALV1L	ALV1L	ALV1L	ALV1L	ALV1L	ALV1L	ALV1L	ALV1L	ALV1L	Range of Values	
Sample Date		1/12/2003	1/06/2004	1/12/2004	1/06/2005	1/12/2005	1/06/2006	1/12/2006	1/06/2007	1/12/2008	1/06/2009	1/12/2009	1/06/2010	1/12/2010	1/06/2011	1/12/2011	1/06/2012	Min	Max
Aluminium	0.15	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02
Arsenic	0.14	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Barium	--	0.319	0.36	0.325	0.346	0.128	0.116	0.101	0.124	0.09	0.084	0.079	0.09	0.093	0.108	0.083	0.085	0.079	0.36
Beryllium	--	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	185	169	191	187	202	218	205	196	192	211	181	223	187	185	199	192	169	223
Boron	1.3	0.06	0.06	0.06	0.06	0.05	0.06	0.05	<0.05	<0.05	0.06	<0.05	0.05	0.07	0.06	0.05	0.06	<0.05	0.07
Cadmium	0.8	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Caesium	--	86	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	86
Calcium	--	<1	91	83	108	128	127	108	123	77	72	54	80	71	79	69	67	<1	128
Carbonate Alkalinity as CaCO3	--	<0.001	<1	<1	<1	<1	<1	<1	<1	<1	<1	15	<1	<1	<1	<1	<1	<1	15
Chloride	--	245	239	204	260	277	284	278	276	183	183	184	178	222	214	199	180	178	284
Chromium	0.04	<0.010	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Cobalt	0.0028	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Conductivity	--	1560	1330	1200	1510	1760	1520	1550	1684		1238	1241	1238	1294	1440	1230	1130	1130	1760
Copper	0.0025	0.001	0.002	0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Ionic Balance	--							1.67	18.1	0.1	4.74	1.22	1.85	3.22	0.89	2.04	0.94	0.1	18.1
Iron	--	0.02	0.02	2.9	3.47	0.09	2.89	1.21	2.28	2.33	1.87	2.03	2.1	2.13	2.4	2.06	1.7	0.02	3.47
Lead	0.0094	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Lithium	--	0.009	0.009	0.008	0.01	0.009	0.009	0.01	0.009	0.008	0.008	0.008	0.009	0.008	0.009	0.008	0.008	0.008	0.01
Magnesium	--	35	34	36	44	48	49	48	50	31	29	29	31	31	32	29	26	26	50
Manganese	3.6	0.337	0.351	0.302	0.401	0.431	0.396	0.394	0.427	0.266	0.239	0.233	0.25	0.259	0.259	0.229	0.218	0.218	0.431
Mercury	0.0054	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Nickel	0.017	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
pH Value	--	6.92	6.72	7.51	6.81	7.06	6.98	7.01	7.2		7.1	6.9	7	7.2	6.82	7.2	7.29	6.72	7.51
Potassium	--	2	4	4	2	3	4	4	4	3	3	3	3	3	3	3	4	2	4
Rubidium	--	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Selenium	0.034	<0.01	<0.01	<0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND
Silicon	--	9.21	9	10.4	10	9.32	8.86	20.5	9.68	8.23	9.92	9.83	11.6	8.98	10.4	9.52	9.68	8.23	20.5
Sodium	--	146	131	129	140	174	176	171	193	159	143	156	152	164	160	154	159	129	193
Strontium	--	1.14	1.1	1.16	1.38	0.009	1.5	1.36	1.5	0.997	0.937	0.842	0.922	0.95	1.05	0.843	0.931	0.009	1.5
Sulphate as SO4 2-	--	177	186	189	228	304	301	265	308	211	187	151	156	199	198	170	161	151	308
Suspended Solids (SS)	--	101	49	96	805	181	910	2060	150	50	29	112	22	6	104	28	40	6	2060
Total Alkalinity as CaCO3	--					202	218	205	196	192	211	196	223	187	185	199	192	185	223
Total Anions	--					18.2	18.6	17.5	18.7	13.4	13.4	12.2	12.7	14.2	13.9	13.1	12.3	12.2	18.7
Total Cations	--					18	18.1	16.9	1.65	13.4	12.2	12	13.2	13.3	13.6	12.6	12.5	1.65	18.1
Total Dissolved Solids @180°C	--	779	824	918	884	1070	1180	1350	1140	790	730	760	794	766	794	682	676	676	1350
Zinc	0.031	0.008	0.006	<0.005	0.012	0.05	0.01	<0.005	0.016	<0.005	0.006	0.021	0.011	<0.005	0.009	0.022	0.023	<0.005	0.05

SAMPLE ID	**ANZECC (2000) 80th%ile Trigger Value**	ALV1S	ALV1S	ALV1S	ALV1S	ALV1S	ALV1S	ALV1S	ALV1S	ALV1S	ALV1S	ALV1S	ALV1S	ALV1S	ALV1S	ALV1S	ALV1S	Range of Values	
Sample Date		1/12/2003	1/06/2004	1/12/2004	1/06/2005	1/12/2005	1/06/2006	1/12/2006	1/06/2007	1/12/2008	1/06/2009	1/12/2009	1/06/2010	1/12/2010	1/06/2011	1/12/2011	1/06/2012	Min	Max
Aluminium	0.15	0.02	0.02	0.05	0.02	0.02	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.7	<0.01	0.7
Arsenic	0.14	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Barium	--	0.079	0.089	0.086	0.094	0.102	0.153	0.138	0.134	0.182	0.169	0.15	0.159	0.174	0.164	0.146	0.149	0.079	0.182
Beryllium	--	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	232	206	226	219	231	234	223	207	222	237	243	261	240	227	260	240	206	261
Boron	1.3	0.1	0.09	0.1	0.09	0.09	0.1	0.09	0.08	0.08	0.09	0.08	0.1	0.1	0.1	0.08	0.09	0.08	0.1
Cadmium	0.8	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001
Caesium	--	36	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	36
Calcium	--	<1	42	46	52	52	68	70	65	51	63	65	62	61	58	59	54	<1	70
Carbonate Alkalinity as CaCO3	--	<0.001	<1	<1	7	<1	<1	<1	<1	<1	<1	<1	<1	7	<1	<1	<1	<1	7
Chloride	--	187	187	171	192	198	234	254	252	224	221	228	217	254	234	247	220	171	254
Chromium	0.04	<0.010	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	<0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004
Cobalt	0.0028	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Conductivity	--	1050	1180	1130	1240	1370	1410	1580	1568		1548	1582	1524	1485	1620	1520	1400	1050	1620
Copper	0.0025	0.004	<0.001	0.002	0.001	0.001	<0.001	0.001	0.026	<0.001	<0.001	0.002	0.018	<0.001	0.01	<0.001	0.044	<0.001	0.044
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Ionic Balance	--							0.2	16.3	2.66	1.84	2.03	3.07	1.76	1.18	2.48	1.79	0.2	16.3
Iron	--	0.02	0.02	<0.1	0.16	<0.05	0.06	0.06	<0.05	0.58	<0.05	0.13	0.08	0.08	<0.05	0.27	<0.05	<0.05	0.58
Lead	0.0094	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	0.007	0.006	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.003	<0.001	0.007
Lithium	--	0.039	0.032	0.032	0.038	0.038	0.044	0.045	0.041	0.051	0.046	0.047	0.048	0.053	0.045	0.046	0.047	0.032	0.053
Magnesium	--	29	31	34	40	34	52	56	51	53	50	52	51	47	47	48	45	29	56
Manganese	3.6	0.054	0.083	0.101	0.133	0.043	0.094	0.104	0.042	0.119	0.048	0.125	0.005	0.064	0.005	0.066	0.008	0.005	0.133
Mercury	0.0054	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Nickel	0.017	0.002	0.001	0.003	0.002	<0.001	0.009	0.005	0.015	<0.001	0.01	0.003	0.013	0.001	0.006	0.003	<0.001	<0.001	0.015
pH Value	--	7.69	7.49	8.19	7.27	7.71	7.7	7.69	7.5		7.8	7.6	7.8	7.6	7.56	7.89	7.93	7.27	8.19
Potassium	--	2	4	4	3	3	4	4	4	4	4	4	4	4	3	4	4	2	4
Rubidium	--	0.003	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.006	0.005	0.005	0.004	0.005	0.003	0.006
Selenium	0.034	<0.01	<0.01	<0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND
Silicon	--	7.84	8.3	9.3	9.25	8.55	8.72	20.8	8.54	8.43	8.6	9.02	8.62	8.34	8.86	8.37	8.46	7.84	20.8
Sodium	--	159	150	148	144	165	193	219	219	217	201	216	216	210	200	206	219	144	219
Strontium	--	3.23	3.22	3.79	4.28	0.028	5.59	5.72	5.59	6.06	5.74	5.09	5.2	5.5	5.62	5.28	5.61	0.028	6.06
Sulphate as SO4 2-	--	92	124	141	133	136	252	290	242	232	269	230	216	221	229	221	214	92	290
Suspended Solids (SS)	--	13	18	9	34	27	45	71	51	38	10	73	16	6	14	73	47	6	73
Total Alkalinity as CaCO3	--					231	234	223	207	222	237	243	261	246	227	260	240	207	261
Total Anions	--					13	16.5	17.7	17.1	15.6	16.6	16.4	15.8	16.7	15.9	16.8	15.5	13	17.7
Total Cations	--					12.7	16.2	17.7	2.4	16.4	16.1	17	16.8	16.1	15.5	16	16	2.4	17.7
Total Dissolved Solids @180°C	--	592	683	746	708	766	988	990	984	952	932	970	970	818	950	870	826	592	990
Zinc	0.031	0.025	0.011	0.016	0.012	0.09	<0.005	0.007	0.103	<0.005	0.014	0.013	0.106	0.021	0.07	<0.005	0.049	<0.005	0.106

SAMPLE ID	**ANZECC (2000) 80th%ile Trigger Value**	ALV2L	ALV2L	ALV2L	ALV2L	ALV2L	ALV2L	ALV2L	ALV2L	ALV2L	ALV2L	ALV2L	ALV2L	ALV2L	ALV2L	ALV2L	ALV2L	Range of Values	
Sample Date		1/12/2003	1/06/2004	1/12/2004	1/06/2005	1/12/2005	1/06/2006	1/12/2006	1/06/2007	1/12/2008	1/06/2009	1/12/2009	1/06/2010	1/12/2010	1/06/2011	1/12/2011	1/06/2012	Min	Max
Aluminium	0.15	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.02
Arsenic	0.14	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Barium	--	0.107	0.088	0.063	0.04	0.058	0.056	0.069	0.058	0.047	0.078	0.109	0.064	0.072	0.045	0.044	0.094	0.04	0.109
Beryllium	--	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	419	125	298	258	321	270	307	257	281	344	408	311	329	231	285	366	125	419
Boron	1.3	0.07	0.07	0.07	0.07	0.011	0.07	0.07	0.08	0.06	0.07	0.06	0.07	0.08	0.07	0.06	0.08	0.011	0.08
Cadmium	0.8	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Caesium	--	125	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	125
Calcium	--	<1	93	79	53	75	75	90	76	53	107	82	72	83	54	58	113	<1	113
Carbonate Alkalinity as CaCO3	--	<0.001	<1	<1	11	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	11
Chloride	--	461	370	284	232	343	304	356	317	208	327	414	280	346	234	214	329	208	461
Chromium	0.04	<0.010	<0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002
Cobalt	0.0028	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Conductivity	--	2050	2250	1930	1420	1870	1590	1950	1694		1960	2530		1864	1530	1390	2110	1390	2530
Copper	0.0025	0.002	0.002	<0.001	0.004	0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.002	0.001	<0.001	0.001	0.001	<0.001	<0.001	0.004
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Ionic Balance	--							1.91	0.42	0.62	1.06	2.54	1.96	1.99	0.84	1.78	2.64	0.42	2.64
Iron	--	0.02	0.02	<0.1	0.07	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.28	<0.05	<0.05	0.28
Lead	0.0094	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Lithium	--	0.011	0.008	0.006	0.003	0.018	0.008	0.019	0.02	0.02	0.013	0.019	0.011	0.01	0.004	0.004	0.018	0.003	0.02
Magnesium	--	58	43	38	25	43	37	53	43	31	54	70	42	44	27	30	57	25	70
Manganese	3.6	0.014	0.032	0.021	0.005	0.046	0.033	0.093	0.005	0.025	0.003	0.014	0.038	0.026	0.001	0.003	0.009	0.001	0.093
Mercury	0.0054	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Nickel	0.017	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.002
pH Value	--	7.42	7.18	7.29	7.43	7.65	7.36	7.37	7.4		7.2	7.2		7.4	7.32	7.6	7.6	7.18	7.65
Potassium	--	3	5	4	2	3	4	4	4	3	4	4	3	4	3	3	4	2	5
Rubidium	--	0.001	0.002	0.001	<0.001	0.002	0.001	0.002	0.001	0.003	0.002	0.002	0.002	0.001	<0.001	<0.001	0.001	<0.001	0.003
Selenium	0.034	<0.01	<0.01	<0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.001	<0.01	ND	ND
Silicon	--	9.16	9.7	9.8	9.42	9.79	9.89	22.2	9.79	9.56	10.8	10.3	11.8	9.24	9.51	9.73	10.4	9.16	22.2
Sodium	--	397	275	251	218	290	276	315	248	207	270	352	277	298	223	212	330	207	397
Strontium	--	1.93	1.38	1.2	0.717	0.011	1.1	1.73	1.29	1.23	1.73	2.35	1.24	1.46	0.868	0.896	2.43	0.011	2.43
Sulphate as SO4 2-	--	354	309	226	136	204	235	272	190	124	281	360	208	257	155	166	332	124	360
Suspended Solids (SS)	--	976	12	2	136	162	153	4360	1060	194	85	176	48	<5	70	18	26	<5	4360
Total Alkalinity as CaCO3	--					321	270	307	257	281	344	408	311	329	231	285	366	231	408
Total Anions	--					20.3	18.9	21.8	18	14.1	22	24	18.4	21.7	14.4	15.2	23.5	14.1	24
Total Cations	--					20	19	22.7	18.2	14.2	21.6	25.3	19.2	20.8	14.7	14.7	24.8	14.2	25.3
Total Dissolved Solids @180°C	--	1620	1390	1140	830	1100	1110	2400	1060	794	1210	1830	990	1070	850	764	1300	764	2400
Zinc	0.031	0.064	<0.005	0.005	0.011	0.07	0.014	<0.005	0.015	0.012	0.009	0.09	0.01	0.006	0.045	0.014	<0.005	<0.005	0.09

Notes: ANZECC 80th%-ile Trigger Value selected based on Umwelt (2008)

ND = Not Detected

LIDDELL COLLIERY GROUNDWATER MONITORING RESULTS

SAMPLE ID	ANZECC (2000) 80th%ile Trigger Value	ALV2S	ALV2S	ALV2S	ALV2S	ALV2S	ALV2S	ALV2S	ALV2S	ALV2S	ALV2S	ALV2S	ALV2S	ALV2S	ALV2S	ALV2S	ALV2S	Range of Values	
Sample Date		1/12/2003	1/06/2004	1/12/2004	1/06/2005	1/12/2005	1/06/2006	1/12/2006	1/06/2007	1/12/2008	1/06/2009	1/12/2009	1/06/2010	1/12/2010	1/06/2011	1/12/2011	1/06/2012	Min	Max
Aluminium	0.15	<0.01	<0.01	0.02	0.24	0.02	0.03	<0.01	<0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.24
Arsenic	0.14	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Barium	--	0.051	0.05	0.049	0.06	0.053	0.046	0.044	0.053	0.054	0.047	0.044	0.047	0.048	0.048	0.044	0.05	0.044	0.06
Beryllium	--	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	506	296	464	424	480	516	501	418	496	490	474	490	435	448	475	452	296	516
Boron	1.3	0.12	0.1	0.11	0.11	0.05	0.11	0.1	0.09	0.1	0.1	0.09	0.11	0.11	0.09	0.08	0.11	0.05	0.12
Cadmium	0.8	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	0.0002
Caesium	--	22	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	22
Calcium	--	<1	23	27	31	30	22	24	38	30	23	26	23	22	25	24	23	<1	38
Carbonate Alkalinity as CaCO3	--	<0.001	7	6	30	<1	<1	<1	<1	<1	<1	<1	<1	48	<1	<1	<1	<1	48
Chloride	--	587	554	558	539	590	499	565	572	641	558	593	700	620	583	585	580	499	700
Chromium	0.04	<0.010	<0.005	<0.001	<0.001	<0.001	<0.001	0.002	0.001	<0.001	<0.005	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003
Cobalt	0.0028	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Conductivity	--	2220	2650	2860	2640	2730	2390	2550	2540		2770	2830		2710	2840	2700	2730	2220	2860
Copper	0.0025	0.003	<0.001	0.001	0.005	0.002	<0.001	0.001	<0.001	0.004	0.008	0.006	0.003	<0.001	<0.001	0.009	<0.001	<0.001	0.009
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Ionic Balance	--							2.53	1.27	1.11	2.9	0.59	3.61	3.87	0.4	1.21	4.06	0.4	4.06
Iron	--	0.02	<0.01	<0.1	0.41	<0.05	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.38	0.1	0.18	0.12	<0.05	<0.05	0.41
Lead	0.0094	<0.001	<0.001	<0.001	0.006	<0.001	<0.001	0.01	0.012	0.01	0.004	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.012
Lithium	--	0.148	0.114	0.119	0.119	0.111	0.125	0.126	0.094	0.132	0.127	0.125	0.133	0.135	0.116	0.114	0.141	0.094	0.148
Magnesium	--	30	29	33	40	33	30	34	46	35	30	33	32	29	31	30	29	29	46
Manganese	3.6	<0.001	0.02	0.03	0.063	0.006	0.032	0.019	0.052	0.029	0.012	0.004	0.034	0.031	0.039	0.055	0.01	<0.001	0.063
Mercury	0.0054	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Nickel	0.017	0.003	0.002	0.001	0.004	0.002	0.005	0.004	0.005	0.005	0.017	0.014	0.005	<0.001	0.006	0.028	0.004	<0.001	0.028
pH Value	--	7.76	7.62	7.66	7.55	7.97	7.76	7.8	7.5		7.7	7.8		7.7	7.68	7.94	8.01	7.5	8.01
Potassium	--	4	6	6	5	5	6	6	5	5	5	5	4	5	5	5	5	4	6
Rubidium	--	0.015	0.015	0.015	0.015	0.014	0.015	0.014	0.013	0.015	0.015	0.015	0.016	0.015	0.016	0.012	0.015	0.012	0.016
Selenium	0.034	<0.01	<0.01	<0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND
Silicon	--	5.32	5.5	6.1	6.28	6.14	5.86	13.4	7.24	6.2	5.45	5.8	6.46	5.83	6.04	5.78	5.46	5.32	13.4
Sodium	--	588	496	524	488	561	585	620	494	591	586	606	632	559	562	567	631	488	632
Strontium	--	2.82	2.66	2.78	3.5	0.05	2.63	2.69	3.2	2.86	2.72	2.58	2.6	2.65	2.85	2.5	3.14	0.05	3.5
Sulphate as SO4 2-	--	146	167	150	186	163	150	174	170	139	125	151	201	146	153	151	157	125	201
Suspended Solids (SS)	--	31	18	5	60	12	64	70	44	32	26	42	54	10	40	58	69	5	70
Total Alkalinity as CaCO3	--					480	516	501	418	496	490	474	490	482	448	475	452	418	516
Total Anions	--					30.1	27.5	29.6	28	30.9	28.1	30.1	33.7	30.2	28.6	29.1	28.7	27.5	33.7
Total Cations	--					28.8	29.1	31.1	27.3	30.2	29.2	30.5	31.4	27.9	28.4	28.5	31.1	27.3	31.4
Total Dissolved Solids @180°C	--	1540	1640	1420	1530	1580	1580	1610	1460	1540	1580	1890	1440	1480	1520	1410	1530	1410	1890
Zinc	0.031	0.083	0.022	0.007	0.091	0.09	<0.005	0.026	0.052	0.052	0.035	0.15	0.008	<0.005	0.007	0.164	0.057	<0.005	0.164

SAMPLE ID	ANZECC (2000) 80th%ile Trigger Value	ALV3L	ALV3L	ALV3L	ALV3L	ALV3L	ALV3L	ALV3L	ALV3L	ALV3L	ALV3L	ALV3L	ALV3L	ALV3L	ALV3L	ALV3L	ALV3L	Range of Values	
Sample Date		1/12/2003	1/06/2004	1/12/2004	1/06/2005	1/12/2005	1/06/2006	1/12/2006	1/06/2007	1/12/2008	1/06/2009	1/12/2009	1/06/2010	1/12/2010	1/06/2011	1/12/2011	1/06/2012	Min	Max
Aluminium	0.15	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05
Arsenic	0.14	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Barium	--	0.034	0.062	0.043	0.084	0.132	0.117	0.073	0.048	0.026	0.029	0.045	0.056	0.032	0.033	0.016	0.027	0.016	0.132
Beryllium	--	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	176	179	192	204	278	290	210	140	190	190	211	215	199	177	221	209	140	290
Boron	1.3	0.08	0.8	0.08	0.09	0.025	0.09	0.07	0.07	0.06	0.07	0.07	0.08	0.07	0.07	0.06	0.08	0.025	0.8
Cadmium	0.8	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Caesium	--	49	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	49
Calcium	--	<1	87	62	120	179	152	110	60	37	41	47	71	46	42	28	38	<1	179
Carbonate Alkalinity as CaCO3	--	<0.001	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	11	<1	<1	<1	<1	11
Chloride	--	176	285	195	319	408	359	286	220	119	130	209	253	157	152	66	121	66	408
Chromium	0.04	<0.010	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.002
Cobalt	0.0028	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Conductivity	--	881	1550	1230	1860	2640	2070	1900	1480		980	1378		1017	1180	694	852	694	2640
Copper	0.0025	0.002	<0.001	<0.001	0.003	0.003	<0.001	0.001	0.001	<0.001	0.001	<0.001	0.007	<0.001	0.001	<0.001	<0.001	<0.001	0.007
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Ionic Balance	--							1.21	14.7	0.58	1.92	1.19	1.98	2.45	1.19	1.15	0.83	0.58	14.7
Iron	--	0.02	0.02	<0.1	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.1
Lead	0.0094	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Lithium	--	0.006	0.007	0.006	0.014	0.01	0.009	0.007	0.007	0.006	0.006	0.007	0.008	0.006	0.005	0.004	0.006	0.004	0.014
Magnesium	--	28	42	35	64	83	82	59	33	21	22	38	41	24	23	14	21	14	83
Manganese	3.6	0.003	0.002	<0.001	0.031	0.002	0.004	0.001	0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	<0.001	0.031
Mercury	0.0054	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Nickel	0.017	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
pH Value	--	7.31	6.99	7.96123	7.14	7.2	7.09	7.3	7.5		7.1	6.9		7.3	7.16	7.57	7.42	6.9	7.96123
Potassium	--	2	4	4	4	5	6	5	4	3	3	3	3	3	3	2	2	2	6
Rubidium	--	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Selenium	0.034	<0.01	<0.01	<0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND
Silicon	--	8.64	10.1	10.3	11.3	10.2	10.8	23.6	9.41	9.3	10.7	10.4	12.1	9.58	10.4	10.7	10.7	8.64	23.6
Sodium	--	145	165	146	176	321	333	301	222	135	138	184	212	146	157	111	128	111	333
Strontium	--	0.666	0.959	0.794	1.83	0.025	1.8	1.28	0.858	0.5	0.524	0.793	0.919	0.542	0.587	0.297	0.603	0.025	1.83
Sulphate as SO4 2-	--	135	225	172	367	632	596	513	272	119	76	188	260	125	135	47	72	47	632
Suspended Solids (SS)	--	48	106	<1	450	215	128	873	206	274	190	63	4	<5	106	22	28	<1	873
Total Alkalinity as CaCO3	--					278	290	210	140	190	190	211	215	211	177	221	209	140	290
Total Anions	--					30.2	28.3	22.9	15.5	9.62	9.04	13.9	16.8	11.2	10.6	7.26	9.09	7.26	30.2
Total Cations	--					29.9	28.9	23.5	2.78	9.51	9.91	13.6	16.2	10.7	10.9	7.43	9.24	2.78	29.9
Total Dissolved Solids @180°C	--	634	973	800	1300	1900	1840	2000	984	578	576	878	950	522	638	362	548	362	2000
Zinc	0.031	0.046	0.013	0.011	0.035	0.08	0.022	0.006	0.022	0.007	0.018	0.011	0.007	<0.005	0.009	0.012	<0.005	<0.005	0.08

SAMPLE ID	ANZECC (2000) 80th%ile Trigger Value	ALV3S	ALV3S	ALV3S	ALV3S	ALV3S	ALV3S	ALV3S	ALV3S	ALV3S	ALV3S	ALV3S	ALV3S	ALV3S	ALV3S	ALV3S	ALV3S	Range of Values	
Sample Date		1/12/2003	1/06/2004	1/12/2004	1/06/2005	1/12/2005	1/06/2006	1/12/2006	1/06/2007	1/12/2008	1/06/2009	1/12/2009	1/06/2010	1/12/2010	1/06/2011	1/12/2011	1/06/2012	Min	Max
Aluminium	0.15	<0.01	<0.01	0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.03
Arsenic	0.14	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Barium	--	0.085	0.112	0.09	0.096	0.096	0.1	0.095	0.092	0.111	0.06	0.079	0.036	0.07	0.035	0.028	0.038	0.028	0.112
Beryllium	--	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	298	274	298	326	340	332	318	284	355	345	556	312	490	272	296	314	272	556
Boron	1.3	0.09	0.07	0.09	0.08	0.08	0.08	0.07	0.08	0.08	0.07	0.09	0.08	0.1	0.07	0.07	0.08	0.07	0.1
Cadmium	0.8	0.0003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0003
Caesium	--	53	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	53
Calcium	--	<1	63	53	64	65	61	59	57	54	54	16	45	56	47	44	41	<1	65
Carbonate Alkalinity as CaCO3	--	<0.001	<1	<1	8	<1	<1	<1	<1	<1	<1	<1	<1	19	<1	<1	<1	<1	19
Chloride	--	322	445	266	335	326	309	321	332	356	342	796	295	878	278	290	358	266	878
Chromium	0.04	<0.010	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	<0.005	<0.001	<0.001	0.006	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.006
Cobalt	0.0028	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Conductivity	--	1430	1980	1590	1890	1950	1670	1840	1900		2030	3760		3940	1780	1660	1920	1430	3940
Copper	0.0025	0.013	<0.001	0.002	0.002	0.002	<0.001	0.002	0.002	0.002	0.005	0.004	0.015	<0.001	0.007	<0.001	<0.001	<0.001	0.015
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Ionic Balance	--							0.95	20	1.61	4.56	1.41	1.21	0.85	0.11	0.65	2.73	0.11	20
Iron	--	0.02	0.02	0.3	0.28	<0.05	0.64	<0.05	0.11	0.14	0.12	0.08	<0.05	0.31	<0.05	0.64	0.048	<0.05	0.64
Lead	0.0094	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.011	0.007	0.014	0.004	0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.014
Lithium	--	0.04	0.03	0.033	0.037	0.031	0.034	0.036	0.035	0.054	0.037	0.069	0.036	0.083	0.03	0.032	0.035	0.03	0.083
Magnesium	--	48	56	49	58	53	55	56	54	62	52	82	49	76	44	45	45	44	82
Manganese	3.6	0.014	0.112	0.072	0.171	<0.001	0.132	0.01	0.03	0.041	0.063	0.067	0.06	0.055	0.01	0.069	0.082	<0.001	0.171
Mercury	0.0054	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Nickel	0.017	0.003	<0.001	0.001	0.002	<0.001	0.003	0.002	0.012	0.003	0.023	0.008	0.003	<0.001	0.003	0.002	0.001	<0.001	0.023
pH Value	--	7.48	7.39	7.84	7.52	7.75	7.54	7.63	7.5		7.5	7.4		7.5	7.42	7.74	7.8	7.39	7.84
Potassium	--	2	4	3	3	3	4	4	4	4	4	5	3	5	3	3	3	2	5
Rubidium	--	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.006	0.004	0.007	0.006	0.008	0.004	0.004	0.004	0.004	0.008
Selenium	0.034	<0.01	<0.01	<0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND
Silicon	--	11.4	10.7	12.4	11.8	12.2	11.4	26.8	11.5	11.1	11.7	11.4	14.7	10.5	12.8	12.2	11.5	10.5	26.8
Sodium	--	276	283	226	248	288	288	320	322	361	337	710	298	714	258	271	370	226	714
Strontium	--	2.82	2.95	2.79	3.37	2.74	3.04	3.12	3.12	4.78	3.51	5.59	2.7	5.92	2.6	2.8	3.04	2.6	5.92
Sulphate as SO4 2-	--	202	212	210	216	203	218	277	237	274	157	263	206	288	193	187	210	157	288
Suspended Solids (SS)	--	20	10	6	49	32	70	71	22	34	28	20	50	7	29	58	51	6	71
Total Alkalinity as CaCO3	--					340	332	318	284	355	345	556	312	508	272	296	314	272	556
Total Anions	--					20.2	19.9	21.2	21.4	22.8	19.8	37.5	18.8	40.9	17.3	18	20.7	17.3	40.9
Total Cations	--					20.2	20.2	21.6	3.36	23.6	21.8	38.6	19.3	40.2	17.3	17.8	21.9	3.36	40.2
Total Dissolved Solids @180°C	--	1010	1140	1100	1140	1140	1130	1140	1160	1270	1180	2240	884	2120	964	912	1230	884	2240
Zinc	0.031	0.065	0.017	0.037	0.021	0.036	0.048	0.042	0.061	0.069	0.062	0.112	0.036	<0.005	0.075	0.01	<0.005	<0.005	0.112

Notes: ANZECC 80th%-ile Trigger Value selected based on Umwelt (2008)
ND = Not Detected

LIDDELL COLLIERY GROUNDWATER MONITORING RESULTS

SAMPLE ID / Sample Date	ANZECC (2000) 80th%ile Trigger Value	ALV4L 1/12/2003	ALV4L 1/06/2004	ALV4L 1/12/2004	ALV4L 1/06/2005	ALV4L 1/12/2005	ALV4L 1/06/2006	ALV4L 1/12/2006	ALV4L 1/06/2007	ALV4L 1/12/2008	ALV4L 1/06/2009	ALV4L 1/12/2009	ALV4L 1/06/2010	ALV4L 1/12/2010	ALV4L 1/06/2011	ALV4L 1/12/2011	ALV4L 1/06/2012	Range of Values Min	Range of Values Max
Aluminium	0.15	<0.01	0.02	0.01	0.28	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.28
Arsenic	0.14	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002
Barium	--	0.075	0.083	0.078	0.106	0.075	0.085	0.083	0.095	0.098	0.096	0.086	0.094	0.097	0.091	0.157	0.187	0.075	0.187
Beryllium	--	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	272	222	237	240	261	251	251	228	246	283	254	257	230	231	232	237	222	283
Boron	1.3	0.07	0.06	0.07	0.17	0.06	0.07	0.06	0.06	0.05	0.06	<0.05	0.06	0.07	0.05	0.05	0.06	<0.05	0.17
Cadmium	0.8	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Caesium	--	42	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	42
Calcium	--	<1	44	48	48	50	48	48	60	65	76	40	64	57	57	104	103	<1	104
Carbonate Alkalinity as CaCO3	--	<0.001	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	9	<1	<1	<1	<1	9
Chloride	--	188	196	168	178	184	204	204	246	228	239	227	237	263	225	557	577	168	577
Chromium	0.04	<0.010	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.005	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002
Cobalt	0.0028	0.001	<0.001	<0.001	0.002	0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003
Conductivity	--	1010	1310	1170	1300	1370	1280	1350	1490		1511	1457		1427	1520	2310	2390	1010	2390
Copper	0.0025	0.002	0.002	<0.001	0.017	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.017
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Ionic Balance	--							0.47	16.1	0.92	2.78	4.58	0.55	2.32	1.02	1.88	0.38	0.38	16.1
Iron	--	0.02	0.02	0.9	1.59	<0.05	0.97	0.06	0.96	1.04	1.03	0.55	0.84	1.32	1.14	1.78	1.68	<0.05	1.78
Lead	0.0094	<0.001	<0.001	<0.001	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.01
Lithium	--	0.021	0.016	0.017	0.098	0.018	0.018	0.016	0.019	0.022	0.023	0.02	0.02	0.023	0.019	0.025	0.03	0.016	0.098
Magnesium	--	36	35	38	39	36	38	44	51	50	51	48	50	46	45	81	80	35	81
Manganese	3.6	0.167	0.209	0.157	0.38	0.222	0.212	0.275	0.227	0.281	0.341	0.246	0.263	0.213	0.215	0.323	0.404	0.157	0.404
Mercury	0.0054	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Nickel	0.017	<0.001	<0.001	<0.001	0.009	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.009
pH Value	--	6.86	6.68	7.28	6.73	6.89	6.81	6.99	7.1		6.9	6.7		6.8	6.79	7.1	7.25	6.68	7.28
Potassium	--	2	3	4	2	3	4	3	3	3	4	3	3	3	3	4	4	2	4
Rubidium	--	0.002	0.002	0.003	0.008	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.002	0.008
Selenium	0.034	<0.01	<0.01	<0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND
Silicon	--	11.4	11.2	13.1	12.6	12.5	11.7	26.5	11.8	10.3	11.8	12	14.6	11.7	12.5	12	11.8	10.3	26.5
Sodium	--	183	170	160	148	180	183	188	208	189	173	191	207	200	181	277	313	148	313
Strontium	--	1	0.97	1.01	8.05	1	1.06	1.08	1.37	1.41	1.42	1.16	1.22	1.28	1.26	2.06	2.6	0.97	8.05
Sulphate as SO4 2-	--	126	154	163	159	137	157	173	222	197	180	194	210	187	184	220	222	126	222
Suspended Solids (SS)	--	449	842	185	700	1140	877	366	460	234	66	1060	264	32	76	42	38	32	1140
Total Alkalinity as CaCO3	--					261	251	251	228	246	283	254	257	239	231	232	237	228	283
Total Anions	--					13.3	14	14.4	16.4	15.4	16.2	15.7	16.2	16.1	14.8	24.9	25.6	13.3	25.6
Total Cations	--					13.4	13.6	14.2	0.8	15.7	15.6	14.3	16.4	15.4	14.5	24	25.4	0.8	25.4
Total Dissolved Solids @180°C	--	719	874	808	770	770	788	1150	955	934	900	1220	1100	812	812	1360	1600	719	1600
Zinc	0.031	0.083	0.014	0.015	0.238	0.13	0.011	0.005	0.016	<0.005	<0.005	0.024	0.012	<0.005	0.015	0.021	0.009	<0.005	0.238

SAMPLE ID / Sample Date	ANZECC (2000) 80th%ile Trigger Value	ALV4S 1/12/2003	ALV4S 1/06/2004	ALV4S 1/12/2004	ALV4S 1/06/2005	ALV4S 1/12/2005	ALV4S 1/06/2006	ALV4S 1/12/2006	ALV4S 1/06/2007	ALV4S 1/12/2008	ALV4S 1/06/2009	ALV4S 1/12/2009	ALV4S 1/06/2010	ALV4S 1/12/2010	ALV4S 1/06/2011	ALV4S 1/12/2011	ALV4S 1/06/2012	Range of Values Min	Range of Values Max
Aluminium	0.15	<0.01	<0.01	0.09	0.03	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.09
Arsenic	0.14	<0.001	0.003	0.001	0.002	0.002	0.001	<0.001	0.002	0.002	0.001	0.001	0.002	<0.001	0.001	0.001	<0.001	<0.001	0.003
Barium	--	0.134	0.127	0.119	0.106	0.101	0.108	0.103	0.089	0.088	0.091	0.085	0.09	0.09	0.096	0.081	0.092	0.081	0.134
Beryllium	--	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	697	595	671	614	695	682	704	643	659	691	677	714	575	637	680	617	575	714
Boron	1.3	0.19	0.17	0.2	0.19	0.19	0.19	0.17	0.18	0.18	0.2	0.16	0.2	0.2	0.18	0.17	0.19	0.16	0.2
Cadmium	0.8	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002
Caesium	--	86	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	86
Calcium	--	<1	76	32	80	80	79	83	76	65	79	9	79	79	81	88	78	<1	88
Carbonate Alkalinity as CaCO3	--	<0.001	<1	<1	39	<1	<1	<1	<1	<1	<1	<1	<1	72	<1	<1	<1	<1	72
Chloride	--	1310	1300	1340	1270	1320	1210	1290	1360	1290	1280	1300	1300	1310	1350	1310	1220	1210	1360
Chromium	0.04	<0.010	<0.001	<0.001	<0.001	<0.005	<0.001	0.003	<0.005	<0.005	<0.005	0.008	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.008
Cobalt	0.0028	0.002	0.005	0.002	0.001	0.002	0.002	0.002	0.001	<0.001	<0.001	0.002	0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.005
Conductivity	--	4670	5210	4940	4750	6440	3780	5370	4740		5220	5390		5130	5500	5360	5200	3780	6440
Copper	0.0025	0.003	0.001	<0.001	0.003	0.002	0.001	<0.001	0.001	<0.001	<0.001	0.005	0.003	<0.001	0.003	0.003	<0.001	<0.001	0.005
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Ionic Balance	--							3.02	57.4	4.64	3.27	0.06	2.62	0.06	0.15	1.79	3.14	0.06	57.4
Iron	--	0.03	0.02	0.4	0.57	<0.05	0.31	0.34	0.42	0.65	0.98	0.3	1.42	1.04	0.16	<0.05	0.49	<0.05	1.42
Lead	0.0094	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	0.003	0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004
Lithium	--	0.091	0.076	0.097	0.106	0.107	0.1	0.106	0.108	0.125	0.13	0.116	0.135	0.142	0.128	0.129	0.135	0.076	0.142
Magnesium	--	133	124	129	135	123	135	149	126	122	127	137	147	130	135	140	128	122	149
Manganese	3.6	0.492	0.493	0.418	0.377	0.326	0.345	0.313	0.302	0.237	0.236	0.246	0.247	0.206	0.178	0.077	0.201	0.077	0.493
Mercury	0.0054	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Nickel	0.017	0.003	<0.001	0.002	0.006	<0.001	0.014	0.004	0.005	0.001	0.005	0.009	0.007	0.002	0.005	0.004	0.001	<0.001	0.014
pH Value	--	7.22	7.17	7.73	7.21	7.68	7.41	7.46	7.4		7.4	7.3		7.3	7.32	7.71	7.77	7.17	7.77
Potassium	--	9	11	12	10	9	11	12	9	10	10	10	8	9	9	10	9	8	12
Rubidium	--	0.007	0.007	0.008	0.008	0.009	0.009	0.008	0.008	0.009	0.009	0.009	0.01	0.01	0.01	0.008	0.009	0.007	0.01
Selenium	0.034	<0.01	<0.01	<0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND
Silicon	--	10.8	10.2	10.4	10.1	10.1	9.87	23.2	9.33	8.74	9.32	9.52	11.1	9.26	9.18	9.57	9.34	8.74	23.2
Sodium	--	926	864	982	868	886	921	1020	971	943	939	968	1020	955	976	982	971	864	1020
Strontium	--	8.68	8.25	9.47	8.54	8.42	8.79	9.27	8.38	8.88	9.23	8.44	8.62	9.02	9.82	9.28	9.53	8.25	9.82
Sulphate as SO4 2-	--	312	289	296	283	279	302	337	294	494	331	274	310	308	328	300	320	274	494
Suspended Solids (SS)	--	17	36	30	84	26	131	96	42	70	26	63	26	18	33	60	110	17	131
Total Alkalinity as CaCO3	--					695	682	704	643	659	691	677	714	648	637	680	617	617	714
Total Anions	--					56.8	54	57.4	56.6	59.8	56.9	54.1	57.5	56.3	57.6	56.8	53.4	53.4	59.8
Total Cations	--					52.9	55.4	61	0.7	54.6	55.5	54.1	60.6	56.4	57.8	58.9	56.9	0.7	61
Total Dissolved Solids @180°C	--	3020	3070	3150	2920	2980	2850	3170	3060	2960	3170	3350	3200	3030	3160	3000	3230	2850	3350
Zinc	0.031	0.046	0.031	0.008	0.039	0.096	0.021	<0.005	0.02	0.008	<0.005	0.077	0.015	<0.005	0.076	0.096	<0.005	<0.005	0.096

SAMPLE ID / Sample Date	ANZECC (2000) 80th%ile Trigger Value	PGW5L 1/12/2003	PGW5L 1/06/2004	PGW5L 1/12/2004	PGW5L 1/06/2005	PGW5L 1/12/2005	PGW5L 1/06/2006	PGW5L 1/12/2006	PGW5L 1/06/2007	PGW5L 1/12/2008	PGW5L 1/06/2009	PGW5L 1/12/2009	PGW5L 1/06/2010	PGW5L 1/12/2010	PGW5L 1/06/2011	PGW5L 1/12/2011	PGW5L 1/06/2012	Range of Values Min	Range of Values Max
Aluminium	0.15	<0.01	<0.01	0.02	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.11	<0.01	0.11
Arsenic	0.14	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Barium	--	0.105	0.107	0.065	0.044	0.042	0.04	0.04	0.045	0.05	0.042	0.049	0.049	0.041	0.058	0.042	0.044	0.04	0.107
Beryllium	--	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	696	604	1010	872	925	961	968	655	710	1030	806	913	1150	840	866	915	604	1150
Boron	1.3	0.11	0.09	0.12	0.11	0.11	0.11	0.11	0.09	0.1	0.11	0.09	0.11	0.12	0.1	0.09	0.11	0.09	0.12
Cadmium	0.8	0.0006	0.0013	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	0.0005	<0.0001	<0.0001	<0.0001	0.0013
Caesium	--	53	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	53
Calcium	--	<1	51	65	62	62	60	58	52	54	62	5	69	77	69	78	69	<1	78
Carbonate Alkalinity as CaCO3	--	<0.001	<1	<1	74	<1	<1	<1	<1	<1	<1	<1	<1	116	<1	<1	<1	<1	116
Chloride	--	560	593	668	634	678	589	605	536	497	545	611	636	714	668	644	672	497	714
Chromium	0.04	<0.010	<0.001	<0.001	<0.001	<0.005	<0.005	<0.001	<0.005	<0.005	<0.005	0.004	0.005	<0.001	<0.001	<0.001	<0.001	<0.001	0.005
Cobalt	0.0028	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Conductivity	--	2960	3720	5420	4330	6580	3730	3990	3410		4650	4400		5780	4780	4490	4940	2960	6580
Copper	0.0025	0.112	0.23	0.002	0.002	0.004	0.089	0.002	0.002	0.101	0.002	0.01	0.003	0.002	0.694	0.003	0.002	0.002	0.694
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Ionic Balance	--							2.52	39	0.7	0.57	1.75	3.56	0.8	1	2.32	1.53	0.57	39
Iron	--	0.03	0.02	0.3	0.8	<0.05	<0.05	<0.05	0.12	<0.05	0.33	<0.05	0.88	<0.05	<0.05	0.65	<0.05	<0.05	0.88
Lead	0.0094	0.002	0.002	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.005	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.005
Lithium	--	0.171	0.121	0.203	0.227	0.194	0.202	0.198	0.134	0.179	0.238	0.183	0.227	0.378	0.195	0.213	0.254	0.121	0.378
Magnesium	--	76	71	128	126	110	121	122	79	84	125	110	134	189	123	128	128	71	189
Manganese	3.6	0.004	0.012	0.108	0.072	0.073	0.029	0.083	0.085	0.222	0.08	0.061	0.065	0.056	0.107	0.079	0.076	0.004	0.222
Mercury	0.0054	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	0.0001
Nickel	0.017	0.013	0.022	0.004	<0.001	<0.001	0.004	0.002	0.005	0.009	0.001	0.003	0.001	<0.001	0.018	0.002	0.001	<0.001	0.022
pH Value	--	7.81	7.61	7.41	7.36	7.69	7.61	7.79	7.7		7.4	7.6		7.2	7.58	7.73	7.8	7.2	7.81
Potassium	--	8	11	11	10	10	12	11	8	8	11	10	10	14	10	10	10	8	14
Rubidium	--	0.013	0.012	0.02	0.019	0.018	0.017	0.018	0.012	0.016	0.018	0.015	0.017	0.027	0.016	0.016	0.018	0.012	0.027
Selenium	0.034	<0.01	<0.01	<0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND
Silicon	--	4.6	4.5	6	6.26	6.44	6.34	13.9	6.07	5.49	6.24	5.64	6.8	6.86	6.19	5.96	5.83	4.5	13.9
Sodium	--	723	659	902	865	888	934	968	772	736	932	876	995	1240	920	911	1010	659	1240
Strontium	--	5.95	5.65	7.91	8.14	7.24	7.62	7.76	6.2	7.33	7.96	7.61	8.14	10.3	8.44	8.68	10.3	5.65	10.3
Sulphate as SO4 2-	--	537	520	766	726	742	755	775	520	627	714	698	853	1290	822	785	919	520	1290
Suspended Solids (SS)	--	18	48	30	28	17	15	58	14	49	10	14	47	<5	6	6	13	<5	58
Total Alkalinity as CaCO3	--					925	961	968	655	710	1030	806	913	1260	840	866	915	655	1260
Total Anions	--					53.8	51.5	52.5	42.9	41.2	50.8	45.9	54	72.3	52.7	51.8	56.4	41.2	72.3
Total Cations	--					51.1	53.9	55.3	4.7	41.9	54.2	47.6	58	73.5	53.8	54.3	58.2	4.7	73.5
Total Dissolved Solids @180°C	--	2230	2310	3540	1150	2950	3000	3000	2250	2380	3150	2830	3060	3550	3090	2910	3420	1150	3550
Zinc	0.031	0.065	3.71	0.25	0.007	0.094	0.585	0.024	0.291	1.45	0.011	0.15	0.007	<0.005	3.52	0.144	0.232	<0.005	3.71

Notes: ANZECC 80th%-ile Trigger Value selected based on Umwelt (2008)

ND = Not Detected

LIDDELL COLLIERY GROUNDWATER MONITORING RESULTS

SAMPLE ID	ANZECC (2000) 80th%ile Trigger	PGW5S	PGW5S	PGW5S	PGW5S	PGW5S	PGW5S	PGW5S	PGW5S	PGW5S	PGW5S	PGW5S	PGW5S	PGW5S	PGW5S	PGW5S	PGW5S	Range of Values	
Sample Date	**Value**	1/12/2003	1/06/2004	1/12/2004	1/06/2005	1/12/2005	1/06/2006	1/12/2006	1/06/2007	1/12/2008	1/06/2009	1/12/2009	1/06/2010	1/12/2010	1/06/2011	1/12/2011	1/06/2012	Min	Max
Aluminium	0.15	<0.01											<0.01	<0.01			0.01	<0.01	0.01
Arsenic	0.14	0.002											<0.001	0.001			<0.001	<0.001	0.002
Barium	--	0.117											0.077	0.089			0.086	0.077	0.117
Beryllium	--	<0.001											<0.001	<0.001			<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	920											824	507			968	507	968
Boron	1.3	0.08											0.08	0.08			0.08	0.08	0.08
Cadmium	0.8	<0.0001											<0.0001	<0.0001			<0.0001	ND	ND
Caesium	--	114											<0.001	<0.001			<0.001	<0.001	114
Calcium	--	<1											136	125			165	<1	165
Carbonate Alkalinity as CaCO3	--	<0.001											<1	<1			<1	ND	ND
Chloride	--	928											912	942			827	827	942
Chromium	0.04	<0.010											<0.001	<0.001			<0.001	ND	ND
Cobalt	0.0028	0.009											<0.001	0.006			0.003	<0.001	0.009
Conductivity	--	3710												3930			5210	3710	5210
Copper	0.0025	0.002											0.005	<0.001			<0.001	<0.001	0.005
Hydroxide Alkalinity as CaCO3	--	<1											<1	<1			<1	ND	ND
Ionic Balance	--												3.61	0.67			1.99	0.67	3.61
Iron	--	0.03											<0.05	<0.05			0.2	<0.05	0.2
Lead	0.0094	<0.001											<0.001	<0.001			<0.001	ND	ND
Lithium	--	0.134											0.113	0.109			0.136	0.109	0.136
Magnesium	--	120											155	116			165	116	165
Manganese	3.6	0.136											0.119	0.339			0.203	0.119	0.339
Mercury	0.0054	<0.0001											<0.0001	<0.0001			<0.0001	ND	ND
Nickel	0.017	0.004											0.004	0.002			0.002	0.002	0.004
pH Value	--	7.41												6.9			7.68	6.9	7.68
Potassium	--	5											4	5			6	4	6
Rubidium	--	0.005											0.003	0.005			0.006	0.003	0.006
Selenium	0.034	<0.01											<0.01	<0.01			<0.01	ND	ND
Silicon	--	10.7											14.2	10.6			10.2	10.2	14.2
Sodium	--	823											833	640			954	640	954
Strontium	--	5.61											5.84	5.21			8.44	5.21	8.44
Sulphate as SO4 2-	--	445											472	312			878	312	878
Suspended Solids (SS)	--	3490											7170	2180			8600	2180	8600
Total Alkalinity as CaCO3	--												824	507			968	507	968
Total Anions	--												52	43.2			61	43.2	61
Total Cations	--												55.9	43.8			63.5	43.8	63.5
Total Dissolved Solids @180°C	--	2790											3140	2300			4830	2300	4830
Zinc	0.031	0.017											0.058	0.015			0.022	0.015	0.058

SAMPLE ID	ANZECC (2000) 80th%ile Trigger	ALV7L	ALV7L	ALV7L	ALV7L	ALV7L	ALV7L	ALV7L	ALV7L	ALV7L	ALV7L	ALV7L	ALV7L	ALV7L	ALV7L	ALV7L	ALV7L	Range of Values	
Sample Date	**Value**	1/12/2003	1/06/2004	1/12/2004	1/06/2005	1/12/2005	1/06/2006	1/12/2006	1/06/2007	1/12/2008	1/06/2009	1/12/2009	1/06/2010	1/12/2010	1/06/2011	1/12/2011	1/06/2012	Min	Max
Aluminium	0.15	<0.01	<0.01	0.28	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.28
Arsenic	0.14	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.001	<0.001	0.003
Barium	--	0.068	0.077	0.082	0.068	0.078	0.08	0.072	0.066	0.055	0.055	0.042	0.045	0.042	0.05	0.043	0.046	0.042	0.082
Beryllium	--	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	401	233	211	141	277	272	265	223	242	285	279	147	221	250	246	256	141	401
Boron	1.3	0.06	0.07	0.08	0.06	0.08	0.08	0.07	0.07	0.07	0.07	0.05	0.07	0.07	0.08	0.06	0.07	0.05	0.08
Cadmium	0.8	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Caesium	--	76	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	76
Calcium	--	<1	104	126	106	127	122	123	111	95	90	44	66	75	79	91	83	<1	127
Carbonate Alkalinity as CaCO3	--	<0.01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Chloride	--	403	340	390	362	426	339	366	364	308	261	272	237	285	255	244	272	237	426
Chromium	0.04	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Cobalt	0.0028	<0.001	0.001	0.001	<0.001	0.001	<0.001	0.001	0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.004	<0.001	0.004
Conductivity	--	2190	1830	2160	1870	2090	1750	1950	1920		1715	1560		1420	1630	1460	1540	1420	2190
Copper	0.0025	<0.001	<0.001	0.003	0.002	0.003	<0.001	<0.001	0.001	<0.001	0.002	0.004	0.002	<0.001	0.002	0.001	<0.001	<0.001	0.004
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Ionic Balance	--							1.17	0.03	1.54	0.01	4.7	4.2	0.98	0.44	2.94	2.54	0.01	4.7
Iron	--	<0.1	0.01	0.2	<0.05	<0.05	0.13	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.2
Lead	0.0094	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Lithium	--	0.044	0.004	0.005	0.004	0.007	0.008	0.006	0.005	0.006	0.006	0.006	0.006	0.006	0.006	0.004	0.007	0.004	0.044
Magnesium	--	60	45	58	60	55	55	60	50	44	42	38	32	36	37	40	40	32	60
Manganese	3.6	0.023	0.363	0.344	0.008	0.197	0.469	0.319	0.177	0.017	0.207	0.021	0.214	0.086	0.174	0.029	0.403	0.008	0.469
Mercury	0.0054	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	0.0001
Nickel	0.017	0.002	0.002	0.002	0.002	0.003	0.006	0.003	0.004	0.002	0.007	0.003	0.006	0.002	0.006	0.002	0.008	0.002	0.008
pH Value	--	7.24	7.19	7.15	6.92	7.3	7.28	7.4	7.2		7.5	7		7.3	7.29	7.57	7.64	6.92	7.64
Potassium	--	5	2	3	2	2	3	3	3	2	3	2	2	2	2	2	2	2	5
Rubidium	--	0.009	<0.001	0.002	,0.001	<0.001	0.001	<0.001	0.001	0.001	0.001	0.001	0.001	<0.001	0.001	<0.001	0.001	<0.001	0.009
Selenium	0.034	<0.01	<0.01	<0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND
Silicon	--	13.8	13.7	14.7	22.6	12.3	10.8	26	11.8	12.4	11	10.9	12.4	13.3	11.5	14	11.4	10.8	26
Sodium	--	280	220	217	189	249	251	273	239	230	220	211	189	217	199	206	233	189	280
Strontium	--	3.29	1.07	1.27	1.12	1.34	1.42	1.3	1.14	1.05	1.02	0.827	0.785	0.797	0.885	0.773	0.98	0.773	3.29
Sulphate as SO4 2-	--	98	257	288	326	270	275	329	261	264	208	187	165	165	175	196	190	98	329
Suspended Solids (SS)	--	20	15700	6270	1100	1340	3890	10800	3720	1070	844	744	88	199	242	605	322	20	15700
Total Alkalinity as CaCO3	--					277	272	265	223	242	285	279	147	221	250	246	256	147	285
Total Anions	--					23.2	20.7	22.5	20.1	19	17.4	16	13	15.9	15.8	15.9	16.7	13	23.2
Total Cations	--					21.8	21.6	23	20.1	18.4	17.6	14.5	14.2	16.2	15.7	16.8	17.6	14.2	23
Total Dissolved Solids @180°C	--	1190	1340	1400	1230	1250	1280	1900	1260	1060	1090	1380	698	802	906	750	902	698	1900
Zinc	0.031	0.018	0.044	0.149	0.507	0.237	0.068	0.026	0.056	0.038	0.049	0.059	0.043	0.02	0.04	0.037	0.051	0.018	0.507

SAMPLE ID	ANZECC (2000) 80th%ile Trigger	ALV7S	ALV7S	ALV7S	ALV7S	ALV7S	ALV7S	ALV7S	ALV7S	ALV7S	ALV7S	ALV7S	ALV7S	ALV7S	ALV7S	ALV7S	ALV7S	Range of Values	
Sample Date	**Value**	1/12/2003	1/06/2004	1/12/2004	1/06/2005	1/12/2005	1/06/2006	1/12/2006	1/06/2007	1/12/2008	1/06/2009	1/12/2009	1/06/2010	1/12/2010	1/06/2011	1/12/2011	1/06/2012	Min	Max
Aluminium	0.15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	0.02
Arsenic	0.14	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Barium	--	0.05	0.081	0.074	0.068	0.072	0.073	0.07	0.066	0.063	0.058	0.055	0.069	0.064	0.068	0.068	0.071	0.05	0.081
Beryllium	--	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	258	417	401	446	415	428	423	412	456	414	417	405	356	369	402	387	258	456
Boron	1.3	0.08	0.06	0.07	0.05	0.06	0.07	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.07	0.05	0.08
Cadmium	0.8	0.0003	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.002	<0.0001	<0.0001	<0.0001	<0.0001	0.002
Caesium	--	82	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	82
Calcium	--	<1	81	85	85	77	80	82	75	76	75	24	78	75	80	91	80	<1	91
Carbonate Alkalinity as CaCO3	--	<0.01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Chloride	--	249	278	405	424	416	459	429	457	462	447	485	429	479	462	478	453	249	485
Chromium	0.04	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002
Cobalt	0.0028	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Conductivity	--	1610	2170	2250	2050	2140	1820	2080	2200		2300	2250		2130	2280	2160	2120	1610	2300
Copper	0.0025	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	0.001	0.01	<0.001	<0.001	0.001	<0.001	<0.001	0.01
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Ionic Balance	--							3.84	0.92	0.25	2.76	2.1	1.93	1.89	3.3	0.39	2.71	0.25	3.84
Iron	--	<0.1	0.01	0.2	<0.05	<0.05	0.24	0.14	0.3	0.06	0.44	0.18	<0.05	0.36	0.61	0.17	0.15	<0.05	0.61
Lead	0.0094	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.005	0.009	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.009
Lithium	--	0.005	0.035	0.039	0.016	0.043	0.044	0.047	0.044	0.057	0.056	0.05	0.046	0.053	0.045	0.041	0.046	0.005	0.057
Magnesium	--	38	60	65	57	59	61	67	58	65	60	63	62	61	61	63	61	38	67
Manganese	3.6	0.076	0.063	0.051	0.304	0.041	0.066	0.076	0.078	0.069	0.054	0.041	0.063	0.057	0.065	0.066	0.118	0.041	0.304
Mercury	0.0054	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Nickel	0.017	0.003	<0.001	0.001	0.002	0.001	0.007	0.001	0.007	0.011	0.007	0.001	0.002	<0.001	0.002	0.008	0.001	<0.001	0.011
pH Value	--	7.24	7.24	7.22	7.15	7.69	7.42	7.45	7.4		7.6	6.9		7.2	7.31	7.71	7.77	6.9	7.77
Potassium	--	2	5	5	4	4	5	6	6	5	5	5	4	5	4	5	5	2	6
Rubidium	--	<0.001	0.009	0.009	0.004	0.009	0.01	0.009	0.008	0.01	0.009	0.009	0.01	0.009	0.009	0.008	0.008	<0.001	0.01
Selenium	0.034	<0.01	<0.01	<0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND
Silicon	--	14	13.2	13.8	14.3	13.2	12.3	28.8	12.6	12.9	12.3	12.6	15	13.1	14.2	13.8	13.5	12.3	28.8
Sodium	--	191	240	258	260	0.302	306	355	333	359	348	352	328	346	349	330	346	0.302	359
Strontium	--	0.966	2.92	3.09	1.57	3.12	3.38	3.34	3.02	3.79	3.71	3.29	2.8	3.31	3.32	3.17	3.4	0.966	3.79
Sulphate as SO4 2-	--	172	120	106	45	103	109	135	119	125	98	114	111	116	112	120	115	45	172
Suspended Solids (SS)	--	2140	41	27	82	28	57	108	48	51	12	32	24	18	24	50	56	12	2140
Total Alkalinity as CaCO3	--					415	428	423	412	456	414	417	405	356	369	402	387	356	456
Total Anions	--					22.6	23.8	23.4	23.6	24.8	22.9	22.7	22.5	23	22.7	24	22.9	22.5	24.8
Total Cations	--					21.9	22.4	25.2	23.2	24.9	23.9	21.8	23.4	23.9	24.3	24.2	24.2	21.8	25.2
Total Dissolved Solids @180°C	--	924	1230	1240	1190	1210	1230	1250	1250	1280	1370	1490	1220	1150	1230	1240	1170	924	1490
Zinc	0.031	0.205	0.029	<0.005	<0.005	0.038	0.006	<0.005	0.042	0.116	<0.005	0.034	0.048	<0.005	<0.005	0.007	<0.005	<0.005	0.205

Notes: ANZECC 80th%-ile Trigger Value selected based on Umwelt (2008)

ND = Not Detected

LIDDELL COLLIERY GROUNDWATER MONITORING RESULTS

SAMPLE ID	ANZECC (2000) 80th%ile Trigger	ALV8L	ALV8L	ALV8L	ALV8L	ALV8L	ALV8L	ALV8L	ALV8L	ALV8L	ALV8L	ALV8L	ALV8L	ALV8L	ALV8L	ALV8L	ALV8L	Range of Values	
Sample Date	Value	1/12/2003	1/06/2004	1/12/2004	1/06/2005	1/12/2005	1/06/2006	1/12/2006	1/06/2007	1/12/2008	1/06/2009	1/12/2009	1/06/2010	1/12/2010	1/06/2011	1/12/2011	1/06/2012	Min	Max
Aluminium	0.15	<0.01	<0.01		<0.01	<0.01			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND
Arsenic	0.14	<0.001	<0.001		<0.001	<0.001			0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Barium	--	0.059	0.09		0.068	0.057			0.042	0.037	0.032	0.029	0.033	0.04	0.038	0.02	0.018	0.018	0.09
Beryllium	--	<0.001	<0.001		<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	108	144		248	174			76	156	177	180	121	166	164	140	172	76	248
Boron	1.3	0.05	0.05		0.08	<0.05			0.05	<0.05	<0.05	<0.05	0.06	0.05	0.06	<0.05	0.05	<0.05	0.08
Cadmium	0.8	<0.0001	<0.0001		<0.0001	<0.0001			0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001
Caesium	--	90	<0.001		<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	90
Calcium	--	<1	127		120	84			73	54	45	47	44	63	54	34	23	<1	127
Carbonate Alkalinity as CaCO3	--	<0.01	<1		10	<1			<1	<1	<1	<1	<1	5	<1	<1	<1	<1	10
Chloride	--	349	360		354	318			313	227	179	187	193	278	237	128	74	74	360
Chromium	0.04	<0.005	<0.005		0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Cobalt	0.0028	<0.001	<0.001		<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Conductivity	--	1840	2240		1910	1750			1484		1197	1201		1370	1420	880	723	723	2240
Copper	0.0025	0.002	0.002		0.001	0.004			0.002	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004
Hydroxide Alkalinity as CaCO3	--	<1	<1		<1	<1			<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Ionic Balance	--								0.34	2	1.56	1.24	4.59	1.05	1.38	2.48	1.41	0.34	4.59
Iron	--	<0.1	0.02		<0.05	<0.05			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.02
Lead	0.0094	<0.001	<0.001		<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Lithium	--	0.004	0.004		0.006	0.003			0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.003	0.006
Magnesium	--	53	70		55	46			42	31	26	28	27	37	31	18	13	13	70
Manganese	3.6	0.001	0.005		0.442	0.002			0.019	0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.442
Mercury	0.0054	<0.0001	<0.0001		<0.0001	<0.0001			<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	0.0001
Nickel	0.017	<0.001	<0.001		0.004	<0.001			0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004
pH Value	--	6.89	8.9		7.52	7.24			7.3		7.5	7		7.3	7.19	7.39	7.49	6.89	8.9
Potassium	--	3	3		2	2			2	2	2	2	2	2	2	2	1	1	3
Rubidium	--	<0.001	<0.001		<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Selenium	0.034	<0.01	<0.01		<0.010	<0.010			<0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND
Silicon	--	23.4	22		13	20.2			22.7	21.4	21.6	21.2	22.4	21.4	21.4	22.7	22.8	13	23.4
Sodium	--	203	221		199	212			198	184	167	169	171	205	191	139	121	121	221
Strontium	--	1.1	1.3		1.36	0.88			0.677	0.598	0.508	0.47	0.54	0.639	0.585	0.314	0.3	0.3	1.36
Sulphate as SO4 2-	--	262	378		274	234			258	156	168	136	144	174	157	116	85	85	378
Suspended Solids (SS)	--	121	1290		804	478			622	69	66	296	58	<5	51	112	421	<5	1290
Total Alkalinity as CaCO3	--					174			76	156	177	180	121	170	164	140	172	76	180
Total Anions	--					17.3			15.7	12.8	12.1	11.7	10.9	14.9	13.2	8.82	7.29	7.29	17.3
Total Cations	--					17.3			15.8	13.3	11.7	12	11.9	15.2	13.6	9.28	7.51	7.51	17.3
Total Dissolved Solids @180°C	--	1090	1240		1300	1070			912	770	740	768	718	780	788	526	442	442	1300
Zinc	0.031	0.034	0.041		0.069	0.391			0.252	0.037	0.006	0.042	0.009	0.006	0.019	0.019	0.009	0.006	0.391

SAMPLE ID	ANZECC (2000) 80th%ile Trigger	ALV8S	ALV8S	ALV8S	ALV8S	ALV8S	ALV8S	ALV8S	ALV8S	ALV8S	ALV8S	ALV8S	ALV8S	ALV8S	ALV8S	ALV8S	ALV8S	Range of Values	
Sample Date	Value	1/12/2003	1/06/2004	1/12/2004	1/06/2005	1/12/2005	1/06/2006	1/12/2006	1/06/2007	1/12/2008	1/06/2009	1/12/2009	1/06/2010	1/12/2010	1/06/2011	1/12/2011	1/06/2012	Min	Max
Aluminium	0.15	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02
Arsenic	0.14	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Barium	--	0.069	0.079	0.076	0.072	0.07	0.065	0.069	0.061	0.092	0.078	0.07	0.081	0.079	0.078	0.066	0.067	0.061	0.092
Beryllium	--	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	442	426	436	389	459	480	470	439	432	386	381	403	372	366	374	337	337	480
Boron	1.3	0.05	0.05	0.05	0.07	0.05	0.06	0.05	0.05	<0.05	<0.05	<0.05	0.06	0.06	0.05	0.05	0.07	<0.05	0.07
Cadmium	0.8	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	0.0009	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0009
Caesium	--	83	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	83
Calcium	--	<1	87	90	81	85	85	83	79	89	76	34	70	75	77	81	65	<1	90
Carbonate Alkalinity as CaCO3	--	<0.01	<1	<1	20	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	20
Chloride	--	378	333	415	401	439	429	441	442	421	328	330	356	406	391	364	303	303	442
Chromium	0.04	<0.005	<0.005	<0.001	<0.001	<0.001	<0.005	<0.001	<0.001	0.001	<0.001	0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.005
Cobalt	0.0028	<0.001	<0.001	0.001	<0.001	<0.001	0.002	0.001	0.001	0.001	0.001	<0.001	0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.002
Conductivity	--	2160	2160	2230	2010	2090	1820	2060	2040		1970	1980		1920	2070	1860	1680	1680	2230
Copper	0.0025	0.002	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.001	0.003	0.011	0.012	0.008	<0.001	0.02	0.002	0.002	<0.001	0.02
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Ionic Balance	--							2.36	1.98	1.69	1.08	1.11	0.73	0.88	1.83	3.18	4.18	0.73	4.18
Iron	--	<0.1	0.01	0.4	<0.05	<0.05	0.58	0.4	0.42	<0.05	0.1	<0.05	<0.05	0.3	<0.05	0.57	0.16	<0.05	0.58
Lead	0.0094	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	0.011	0.003	0.002	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.011
Lithium	--	0.018	0.014	0.016	0.044	0.016	0.014	0.016	0.015	0.022	0.02	0.02	0.022	0.023	0.019	0.02	0.021	0.014	0.044
Magnesium	--	52	53	57	63	52	54	58	53	57	48	49	48	50	50	49	42	42	63
Manganese	3.6	0.226	0.357	0.279	0.065	0.016	0.382	0.316	0.257	0.14	0.107	0.046	0.098	0.104	0.074	0.088	0.076	0.016	0.382
Mercury	0.0054	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Nickel	0.017	0.004	0.003	0.001	0.001	0.016	0.008	0.002	0.004	0.004	0.007	0.016	0.009	0.003	0.008	0.015	0.002	0.001	0.016
pH Value	--	7.12	7.05	7.07	7.3	7.61	7.25	7.31	7.1		7.6	7.1		7.3	7.22	7.56	7.66	7.05	7.66
Potassium	--	6	6	5	4	5	6	5	5	4	4	5	5	4	4	5	4	4	6
Rubidium	--	0.004	0.004	0.004	0.009	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.004	0.009
Selenium	0.034	<0.01	<0.01	<0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND
Silicon	--	14.7	13.8	14.4	13.8	13.8	12.9	29.5	13.3	14.2	13.4	14.4	14.1	13.9	14.6	15.4	14.4	12.9	29.5
Sodium	--	283	257	264	253	303	308	339	298	298	290	310	309	323	280	312	297	253	339
Strontium	--	1.55	1.53	1.53	3.16	1.47	1.5	1.55	1.36	1.58	1.39	1.23	1.29	1.32	1.43	1.26	1.33	1.23	3.16
Sulphate as SO4 2-	--	70	70	56	113	39	49	42	48	120	166	124	126	132	127	129	137	39	166
Suspended Solids (SS)	--	16	26	30	58	39	71	87	47	23	23	48	74	10	30	78	75	10	87
Total Alkalinity as CaCO3	--					459	480	470	439	432	386	381	403	372	366	374	337	337	480
Total Anions	--					22.7	22.7	22.7	22.2	23	20.4	19.8	20.7	21.6	21	20.4	18.1	18.1	23
Total Cations	--					21.8	22.2	23.8	21.4	22.2	20.5	19.3	21	22	20.2	21.8	19.7	19.3	23.8
Total Dissolved Solids @180°C	--	1140	1220	1210	1190	1190	1180	1180	1110	1230	1190	1350	1100	1040	1210	1030	922	922	1350
Zinc	0.031	0.05	0.063	0.009	0.014	0.058	0.01	0.005	0.05	0.04	0.034	0.158	0.047	0.007	0.178	0.055	0.099	0.005	0.178

SAMPLE ID	ANZECC (2000) 80th%ile Trigger	HAZ 4	HAZ 4	HAZ 4	HAZ 4	HAZ 4	HAZ 4	HAZ 4	HAZ 4	HAZ 4	HAZ 4	HAZ 4	HAZ 4	HAZ 4	HAZ 4	HAZ 4	HAZ 4	Range of Values	
Sample Date	Value	1/12/2003	1/06/2004	1/12/2004	1/06/2005	1/12/2005	1/06/2006	1/12/2006	1/06/2007	1/12/2008	1/06/2009	1/12/2009	1/06/2010	1/12/2010	1/06/2011	1/12/2011	1/06/2012	Min	Max
Aluminium	0.15	<0.01	<0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01						<0.01	0.01
Arsenic	0.14	0.001	0.001	<0.001	0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001						<0.001	0.001
Barium	--	0.052	0.059	0.05	0.049	0.054	0.054	0.056	0.042	0.07	0.133	0.097						0.042	0.133
Beryllium	--	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001						ND	ND
Bicarbonate Alkalinity as CaCO3	--	556	504	580	496	516	554	488	217	121	201	190						121	580
Boron	1.3	0.14	0.12	0.14	0.13	0.13	0.14	0.11	0.08	<0.05	0.07	0.07						<0.05	0.14
Cadmium	0.8	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001						ND	ND
Caesium	--	33	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001						<0.001	33
Calcium	--	23	33	33	31	33	30	47	67	57	75	62						23	75
Carbonate Alkalinity as CaCO3	--	<0.001	<1	<1	57	59	<1	<1	<1	<1	<1	<1						<1	59
Chloride	--	842	887	849	823	839	809	806	190	155	194	240						155	887
Chromium	0.04	<0.010	<0.001	<0.001	<0.001	<0.001	<0.005	<0.001	<0.005	<0.001	<0.001	<0.001						ND	ND
Cobalt	0.0028	0.007	0.006	0.004	0.002	0.003	0.003	0.002	<0.001	<0.001	<0.001	<0.001						<0.001	0.007
Conductivity	--	3520	4630	4310	4170	6200	3780	3670	1426		1138	1295						1138	6200
Copper	0.0025	0.004	0.004	0.003	0.002	0.003	0.001	0.002	0.002	<0.001	0.005	0.004						<0.001	0.005
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1						ND	ND
Ionic Balance	--							1.25	15.4	1.23	3.83	4.66						1.23	15.4
Iron	--	0.03	0.02	<0.1	0.12	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05						<0.05	0.12
Lead	0.0094	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001						ND	ND
Lithium	--	0.168	0.121	0.136	0.148	0.136	0.152	0.115	0.01	0.005	0.011	0.012						0.005	0.168
Magnesium	--	124	120	123	128	114	125	122	51	27	28	33						27	128
Manganese	3.6	0.296	0.259	0.242	0.27	0.26	0.278	0.208	0.008	<0.001	0.001	0.004						<0.001	0.296
Mercury	0.0054	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001						ND	ND
Nickel	0.017	0.006	0.006	0.006	0.004	<0.001	0.005	0.004	0.002	<0.001	0.001	0.002						<0.001	0.006
pH Value	--	8.18	8.18	8.21	8.15	8.34	8.26	8.27	7.5		7.6	7.7						7.5	8.34
Potassium	--	10	13	12	11	11	13	11	3	2	3	3						2	13
Rubidium	--	0.011	0.012	0.012	0.011	0.011	0.013	0.01	0.002	<0.001	0.002	0.003						<0.001	0.013
Selenium	0.034	<0.01	<0.01	<0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.01						ND	ND
Silicon	--	3.12	3.2	3.2	2.89	2.96	2.93	5.8	2.24	2.06	2.32	2.1						2.06	5.8
Sodium	--	876	827	878	799	858	886	821	192	89	118	145						89	886
Strontium	--	3.67	3.55	3.53	3.73	0.064	3.54	3.93	3.82	1.2	2.54	2.84						0.064	3.93
Sulphate as SO4 2-	--	735	739	748	685	686	712	707	276	120	125	144						120	748
Suspended Solids (SS)	--	60	102	205	120	25	6	84	97	53	24	56						6	205
Total Alkalinity as CaCO3	--					575	554	488	217	121	201	190						121	575
Total Anions	--					49.4	48.7	47.2	16	9.28	12.1	13.4						9.28	49.4
Total Cations	--					48.6	50.7	48.4	1.81	9.05	11.2	12.2						1.81	50.7
Total Dissolved Solids @180°C	--	2680	2540	2970	2820	2760	2890	2630	932	540	670	798						540	2970
Zinc	0.031	0.056	0.175	0.072	0.028	0.064	0.042	0.026	0.424	0.183	0.597	0.498						0.026	0.597

Notes: ANZECC 80th%-ile Trigger Value selected based on Umwelt (2008)

ND = Not Detected

LIDDELL COLLIERY GROUNDWATER MONITORING RESULTS

SAMPLE ID	ANZECC (2000) 80th%ile Trigger Value	HAZ 6	HAZ 6	HAZ 6	HAZ 6	HAZ 6	HAZ 6	HAZ 6	HAZ 6	HAZ 6	HAZ 6	HAZ 6	HAZ 6	HAZ 6	HAZ 6	HAZ 6	HAZ 6	Range of Values	
Sample Date		1/12/2003	1/06/2004	1/12/2004	1/06/2005	1/12/2005	1/06/2006	1/12/2006	1/06/2007	1/12/2008	1/06/2009	1/12/2009	1/06/2010	1/12/2010	1/06/2011	1/12/2011	1/06/2012	Min	Max
Aluminium	0.15	<0.01	<0.01	0.05		0.47	0.03	0.02	0.06	0.02	0.01	0.02	0.02	0.03	0.01	<0.01	0.04	<0.01	0.47
Arsenic	0.14	<0.001	0.001	<0.001		<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	0.002
Barium	--	0.06	0.062	0.059		0.012	0.054	0.061	0.043	0.066	0.063	0.062	0.065	0.067	0.074	0.08	0.084	0.012	0.084
Beryllium	--	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	793	783	831		160	651	862	652	912	908	867	780	743	672	666	730	160	912
Boron	1.3	0.15	0.14	0.17		0.07	0.13	0.13	0.11	0.14	0.14	0.12	0.15	0.15	0.12	0.11	0.14	0.07	0.17
Cadmium	0.8	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Caesium	--	81	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	81
Calcium	--	<1	56	54		5	25	40	35	33	46	6	53	46	50	69	56	<1	69
Carbonate Alkalinity as CaCO3	--	<0.001	59	31		141	34	<1	<1	<1	<1	<1	<1	99	<1	<1	<1	<1	141
Chloride	--	895	853	835		600	769	843	737	1030	917	901	836	951	852	781	829	600	1030
Chromium	0.04	<0.010	<0.005	<0.001		<0.001	<0.001	<0.001	<0.005	0.003	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003
Cobalt	0.0028	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Conductivity	--	4240	5700	5780		2930	3930	5400	4370		5430	5550		5180	5000	4380	4820	2930	5780
Copper	0.0025	0.004	0.003	<0.001		0.008	0.002	0.001	0.002	0.001	<0.001	0.002	0.002	0.002	0.004	0.004	<0.001	<0.001	0.008
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	ND	ND
Ionic Balance	--							2.95	47.3	4.87	2.38	0.33	3.47	0.49	2.09	2.32	2.3	0.33	47.3
Iron	--	0.03	0.04	0.3		<0.05	<0.05	<0.05	<0.05	0.05	0.1	<0.05	<0.05	<0.05	<0.05	0.08	0.43	<0.05	0.43
Lead	0.0094	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ND	ND
Lithium	--	0.26	0.195	0.232		0.135	0.207	0.219	0.188	0.264	0.251	0.228	0.25	0.264	0.192	0.187	0.24	0.135	0.264
Magnesium	--	73	77	79		16	61	72	51	67	75	77	72	73	68	59	63	16	79
Manganese	3.6	0.041	0.098	0.101		<0.001	0.029	0.06	0.027	0.033	0.041	0.049	0.05	0.062	0.066	0.14	0.112	<0.001	0.14
Mercury	0.0054	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Nickel	0.017	0.003	0.003	0.003		<0.001	0.004	0.004	0.006	0.003	0.003	0.003	0.002	0.003	0.022	0.024	0.006	<0.001	0.024
pH Value	--	7.79	7.83	7.79		9.59	8.37	8.15	8.25		8.1	7.9		7.9	7.95	8.11	8.12	7.79	9.59
Potassium	--	9	12	11		7	10	10	8	8	9	8	8	9	9	10	10	7	12
Rubidium	--	0.015	0.017	0.017		0.013	0.015	0.016	0.013	0.016	0.015	0.016	0.016	0.016	0.015	0.013	0.014	0.013	0.017
Selenium	0.034	<0.01	<0.01	<0.01		<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND
Silicon	--	8.19	8.5	9.8		6.64	8.04	18.8	7.51	8.55	8.39	8.05	8.86	7.8	7.97	6.84	7.11	6.64	18.8
Sodium	--	1110	1130	1160		677	1070	1250	998	1200	1180	1150	1150	1120	1070	953	1080	677	1250
Strontium	--	9.75	9.47	9.67		<0.005	4.99	8.45	5.89	8.09	8.3	7.79	7.7	7.82	6.94	6.48	7.69	<0.005	9.75
Sulphate as SO4 2-	--	970	994	900		470	775	859	647	880	638	767	754	692	726	592	707	470	994
Suspended Solids (SS)	--	686	52	750		166	170	82	302	12	16	36	6	41	14	31	70	6	750
Total Alkalinity as CaCO3	--					301	684	862	652	912	908	867	780	842	672	666	730	301	912
Total Anions	--					32.7	51.5	58.9	49.5	65.7	57.3	57.3	54.9	58.1	52.6	47.7	52.7	32.7	65.7
Total Cations	--					31.2	52.9	62.5	2.3	59.6	60.2	56.9	58.9	57.5	54.9	50	55.2	2.3	62.5
Total Dissolved Solids @180°C	--	3350	3620	3670		1830	3070	3470	2850	3590	3600	3650	3200	3330	3210	2590	3050	1830	3670
Zinc	0.031	0.088	0.026	0.006		<0.005	0.021	0.007	0.012	0.007	<0.005	0.021	<0.05	0.005	0.013	0.021	<0.005	<0.005	0.088

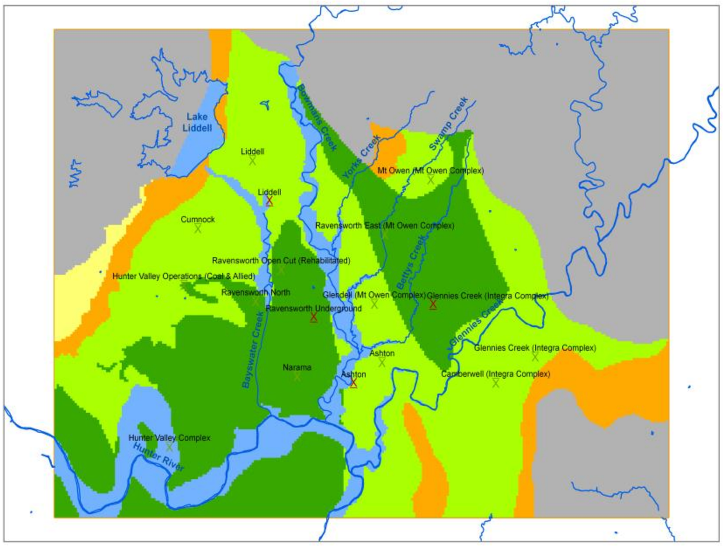
SAMPLE ID	ANZECC (2000) 80th%ile Trigger Value	LBH	LBH	LBH	LBH	LBH	LBH	LBH	LBH	LBH	LBH	LBH	LBH	LBH	LBH	LBH	LBH	Range of Values	
Sample Date		1/12/2003	1/06/2004	1/12/2004	1/06/2005	1/12/2005	1/06/2006	1/12/2006	1/06/2007	1/12/2008	1/06/2009	1/12/2009	1/06/2010	1/12/2010	1/06/2011	1/12/2011	1/06/2012	Min	Max
Aluminium	0.15	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Arsenic	0.14	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Barium	--	0.056	0.081	0.066	0.088	0.131	0.152	0.111	0.076	0.017	0.041	0.051		0.059	0.049	0.029	0.03	0.017	0.152
Beryllium	--	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	ND	ND
Bicarbonate Alkalinity as CaCO3	--	239	212	238	187	260	316	327	245	230	213	248		207	224	213	242	187	327
Boron	1.3	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.07	<0.05	0.07	0.07		0.09	0.08	0.07	0.08	<0.05	0.09
Cadmium	0.8	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0003	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0003
Caesium	--	68	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	68
Calcium	--	<1	102	88	111	158	159	136	102	38	47	62		68	56	40	29	<1	159
Carbonate Alkalinity as CaCO3	--	<0.001	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1		16	<1	<1	<1	<1	16
Chloride	--	215	340	247	326	380	389	331	285	157	181	232		268	211	136	125	125	389
Chromium	0.04	<0.010	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.005	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	0.002
Cobalt	0.0028	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	ND	ND
Conductivity	--	1100	1820	1610	1880	2580	2410	2340	1900		1321	1610		1535	1500	1020	956	956	2580
Copper	0.0025	0.003	0.002	<0.001	0.002	0.003	0.001	0.001	0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	0.003
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1		<1	<1	<1	<1	ND	ND
Ionic Balance	--							4.61	21.6	3.22	0.61	0.82		0.7	1.91	3.53	1.68	0.61	21.6
Iron	--	0.02	0.02	<0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05	<0.05	0.02
Lead	0.0094	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		0.018	<0.001	<0.001	<0.001	<0.001	0.018
Lithium	--	0.003	0.003	0.003	0.004	0.004	0.004	0.003	0.003	<0.001	0.002	0.002		0.003	0.002	0.002	0.002	<0.001	0.004
Magnesium	--	38	51	49	59	77	88	76	55	20	25	36		37	31	20	18	18	88
Manganese	3.6	0.002	0.013	<0.001	0.006	0.01	0.035	0.004	0.003	0.016	0.009	0.027		0.006	<0.001	0.003	0.005	<0.001	0.035
Mercury	0.0054	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	ND	ND
Nickel	0.017	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	0.001
pH Value	--	6.88	6.8	7.35	6.83	6.9	6.9	6.96	7		7	7		7.2	7.05	7.32	7.51	6.8	7.51
Potassium	--	3	5	4	4	5	7	7	4	3	4	4		4	3	3	2	2	7
Rubidium	--	<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Selenium	0.034	<0.01	<0.01	<0.01	<0.010	<0.010	<0.010	<0.010	<0.010	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01	ND	ND
Silicon	--	9.47	10.2	11.4	10.7	10.1	10.1	22.6	11.1	8.99	9.09	9.82		9.36	10.7	10.1	8.89	8.89	22.6
Sodium	--	171	191	175	197	333	383	376	305	210	213	239		250	219	178	177	171	383
Strontium	--	0.759	0.981	0.942	1.26	1.74	1.93	1.64	1.04	0.227	0.52	0.688		0.734	0.615	0.358	0.419	0.227	1.93
Sulphate as SO4 2-	--	180	281	248	366	596	663	536	414	143	207	232		272	190	124	94	94	663
Suspended Solids (SS)	--	10	26	<1	39	16	24	452	21	7	5	18		<5	31	88	46	<1	452
Total Alkalinity as CaCO3	--					260	316	327	245	230	213	248		223	224	213	242	213	327
Total Anions	--					28.3	31.1	27	23	12	13.7	16.3		17.7	14.4	10.7	10.3	10.3	31.1
Total Cations	--					28.8	32	29.6	3.26	12.8	13.7	16.6		17.4	15	11.5	10.7	3.26	32
Total Dissolved Solids @180°C	--	781	1130	1070	1280	1760	1930	1740	1320	730	806	1370		924	898	574	626	574	1930
Zinc	0.031	0.021	0.02	0.008	0.044	0.027	0.022	0.008	0.011	<0.005	0.009	0.031		<0.005	0.006	0.038	0.006	<0.005	0.044

SAMPLE ID	ANZECC (2000) 80th%ile Trigger Value	Mt Owen	Mt Owen	Mt Owen	Mt Owen	Mt Owen	Mt Owen	Mt Owen	Mt Owen	Mt Owen	Mt Owen	Mt Owen	Mt Owen	Mt Owen	Mt Owen	Mt Owen	Mt Owen	Range of Values	
Sample Date		1/12/2003	1/06/2004	1/12/2004	1/06/2005	1/12/2005	1/06/2006	1/12/2006	1/06/2007	1/12/2008	1/06/2009	1/12/2009	1/06/2010	1/12/2010	1/06/2011	1/12/2011	1/06/2012	Min	Max
Aluminium	0.15	<0.01	<0.01	<0.01														ND	ND
Arsenic	0.14	<0.001	<0.001	<0.001														ND	ND
Barium	--	0.114	0.121	0.114														0.114	0.121
Beryllium	--	<0.001	<0.001	<0.001														ND	ND
Bicarbonate Alkalinity as CaCO3	--	1210	1110	1130														1110	1210
Boron	1.3	0.18	0.15	0.18														0.15	0.18
Cadmium	0.8	<0.0001	<0.0001	<0.0001														ND	ND
Caesium	--	22	0.001	0.001														0.001	22
Calcium	--	36	25	26														25	36
Carbonate Alkalinity as CaCO3	--	0.001	90	57														0.001	90
Chloride	--	966	645	938														645	966
Chromium	0.04	<0.010	<0.005	<0.001														ND	ND
Cobalt	0.0028	<0.001	<0.001	<0.001														ND	ND
Conductivity	--	4370	5520	5590														4370	5590
Copper	0.0025	0.001	<0.001	<0.001														<0.001	0.001
Hydroxide Alkalinity as CaCO3	--	<1	<1	<1														ND	ND
Ionic Balance	--																	N/A	N/A
Iron	--	0.02	0.02	0.2														0.02	0.2
Lead	0.0094	<0.001	<0.001	<0.001														ND	ND
Lithium	--	0.31	0.205	0.249														0.205	0.31
Magnesium	--	31	32	33														31	33
Manganese	3.6	0.026	0.03	0.032														0.026	0.032
Mercury	0.0054	<0.0001	<0.0001	<0.0001														ND	ND
Nickel	0.017	0.002	0.002	0.002														0.002	0.002
pH Value	--	7.84	7.78	7.79														7.78	7.84
Potassium	--	6	10	8														6	10
Rubidium	--	0.018	0.02	0.02														0.018	0.02
Selenium	0.034	<0.01	<0.01	<0.01														ND	ND
Silicon	--	5.78	6	6.4														5.78	6.4
Sodium	--	1250	1050	1220														1050	1250
Strontium	--	3.27	3.29	3.23														3.23	3.29
Sulphate as SO4 2-	--	408	440	392														392	440
Suspended Solids (SS)	--	19	2	4														2	19
Total Alkalinity as CaCO3	--																	N/A	N/A
Total Anions	--																	N/A	N/A
Total Cations	--																	N/A	N/A
Total Dissolved Solids @180°C	--	3270	3520	3380														3270	3520
Zinc	0.031	<0.005	<0.005	<0.005														<0.005	<0.005

Notes: ANZECC 80th%-ile Trigger Value selected based on Umwelt (2008)
ND = Not Detected

Appendix B Hunter Valley Regional Groundwater Model Report

Groundwater Model for the Jerrys and Glennies Water Sources



A NUMERICAL GROUNDWATER MODEL TO SUPPORT XSTRATA COAL NSW OPERATIONS IN THE UPPER HUNTER VALLEY

- Model Version 6.1 Liddell
- May 2013

Groundwater Model for the Jerrys and Glennies Water Sources

A NUMERICAL GROUNDWATER MODEL TO SUPPORT XSTRATA COAL NSW OPERATIONS IN THE UPPER HUNTER VALLEY

- Model Version 6.1 Liddell
- May 2013

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Contents

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1. Introduction

1.1 Project Overview

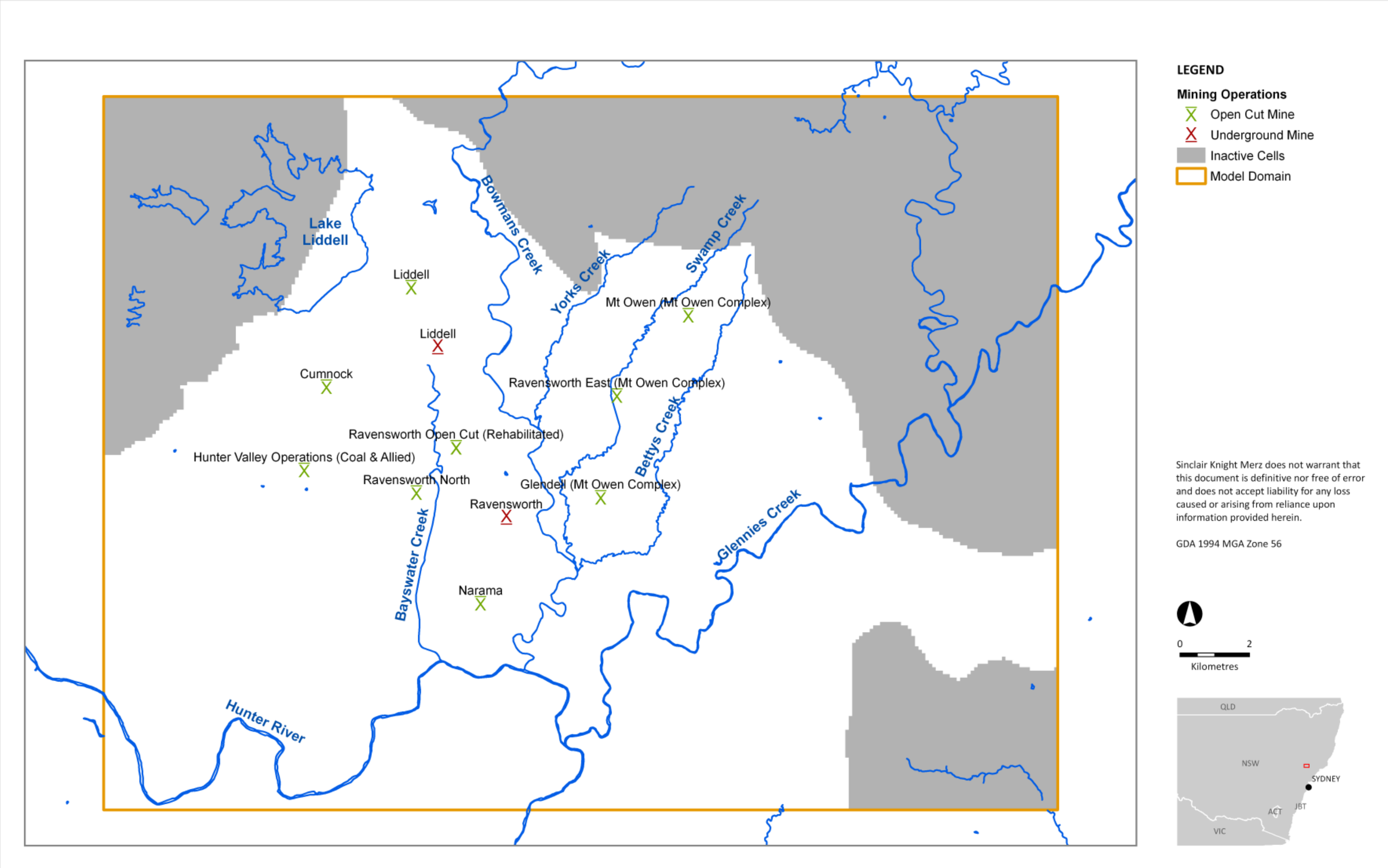
Xstrata Coal NSW (XCN) is committed to sustainable development. Business is conducted that integrates economic, social and environmental values and preserves the long term health, function and viability of the natural environments affected by XCN activities. As part of this commitment, XCN commissioned Sinclair Knight Merz (SKM) to develop a regional scale numerical groundwater model that encompasses XCN operations within the Upper Hunter valley. The model incorporates, to the extent possible, mining operations north of the Hunter River to Lake Liddell, and from Lake Liddell east to Glennies Creek, and includes major tributaries of the Hunter River in the area such as Bowmans and Glennies Creeks. The model extent encompasses significant portions of the Jerrys and Glennies water sources as defined in the Hunter Unregulated and Alluvial Water Sharing Plan (WSP). **Figure 1-1** shows the model extent and mine operations covered by the regional scale model.

SKM has developed the regional scale model in order to provide XCN with a tool for evaluating potential environmental impacts that may accompany further development and expansion of mining operations within the region. The development and construction of the model has been undertaken in consultation with the NSW Office of Water, who, in line with the introduction of Water Sharing Plans (WSPs) under the *Water Management Act 2000* and the *Aquifer Interference Policy (2012),* have supported the development of a regional scale model to assess the potential cumulative impacts of mining operations in the area. The model builds upon previous models developed by Mackie Environmental Research (MER) for XCN operations in the Upper Hunter Valley, specifically integrating and expanding the model developed for the Ravensworth Underground Mine (RUM).

The regional scale model is intended to be updated and refined as XCN operations and future mining plans within the model domain are developed and/or expanded. The model version reflects the progression and updates of the model to its current state, with the version presented in this report being Model Version 6.1. The studies to date that have made use of this model version include:

- Groundwater Impact Assessment for the Ravensworth East Resource Recovery (RERR) Environmental Assessment; and
- Groundwater Impact Assessment for Liddell Coal Operations (LCO) Development Consent Modification 5 Environmental Assessment.

- **Figure 1-1 – Groundwater Model Domain**



1.2 Objectives

The objectives for the development and construction of the regional scale model are to:

- Provide a tool for assessing and predicting potential groundwater impacts resulting from mining activities and operations for current and future project environmental assessments;
- Provide an understanding of the likely range of potential inflows to the various XCN mine operations;
- Provide estimates of the cumulative impacts of mining operations;
- Provide guidance on the key parameters and/or processes that effect the model results and provide recommendations for additional investigations or studies that may be required to reduce uncertainty associated with model predictions; and
- Provide a tool for assessing the potential risks resulting from current and/or proposed mining activities on groundwater resources in the region.

1.3 Model Version and Update Log

Numerical groundwater models used for mining operations inherently require continuous updates and revisions in light of the results that each model version generates and any new information and data collected through observations and monitoring. Given the on-going nature of the model development and the progressive changes to approved mining operations, the regional scale model developed here is a typical example of the fundamental guiding principle of best practice as defined by Middlemis in *Benchmarking Best Practice for Groundwater Flow Modelling* (2004):

> *The fundamental guiding principle for best practice modelling is that model development is an on-going process of refinement from an initially simple representation of the aquifer system to one with an appropriate degree of complexity. Thus, the model realisation at any stage is neither the best nor the last, but simply the latest representation of our developing understanding of the aquifer system.*

SKM has created a model version naming protocol and update log to identify the version of the 'base' model used for various projects. Each update that changes the base condition of the regional model, or what would be considered the baseline condition, such as model structure, calibration, approved current or future mining operations, results in a new version number being assigned. Each time the model is used or modified for project specific purposes it is assigned a build number and project code related to that project. A summary of the model update log as at May 2013 is provided in **Table 1-1**.

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Table 1-1 – Model Update Log

Model Version	Model Build	Project	Description of Modification(s)	Model Version Number
1	0		1) Initial model setup 2) Model calibration	1.0
1	1	Liddell	3) Stochastic predictive simulations of proposed operations	1.1 Liddell
2	0		4) Refined historic mining and backfill sequencing at Ravensworth East, Glendell and Mt Owen operations 5) Updated geology models for Mt Owen and Ravensworth areas	2.0
2	1	Ravensworth East	6) Stochastic predictive simulations of proposed TP2 operations	2.1 Rav
2	2	Liddell	7) Updated stochastic predictive simulations of proposed operations	2.2 Liddell
3	0		8) Refinement of historic Liddell open cut operations 9) Inclusion of additional coal barriers around Hazeldene workings	3.0
3	1	Liddell	10) Updated stochastic predictive simulations of proposed operations	3.1 Liddell
4	0		11) Inclusion of historic dewatering operations at Liddell underground workings 12) Conversion of Bowmans Creek “River” boundary conditions to “Stream” cells 13) Refinement of top and bottom elevations for Bowmans Creek alluvium based upon new LIDAR 14) Recalibration (steady state and transient) 15) Creation\selection of new input datasets for stochastic simulations	4.0
4	1	Liddell	16) Updated stochastic predictive simulations of proposed operations	4.1 Liddell
5	0		17) Modification to underground working at Liddell 18) Addition of new dewatering bore at Middle Liddell underground workings	5.0
5	1	Liddell	19) Updated stochastic predictive simulations of proposed operations	5.1 Liddell
6	0		20) Refined model progression for mining and backfill sequencing based upon peer review comments 21) Updated HFB for faults regionally	6.0
6	1	Liddell	22) Updated stochastic predictive simulations of proposed operations	6.1 Liddell

1.4 Data Sources

Data used in constructing and developing the regional scale model and in preparing this report have been gathered from a number of sources. The availability of detailed quantitative data is primarily limited to XCN operations within the region (e.g. Liddell, Mt Owen, Glendell and Ravensworth underground and surface operations) due to the confidential nature of data from non-XCN sources, though where possible summary information is sourced from publicly available reports for such operations. **Table 1-2** presents a summary of the data sources used in this report.

Table 1-2 – Summary of Data Sources

Source	Mine Operation	Data Type	Timeframe
Aquaterra, 2009	Ashton Underground	• Piezometric elevations • Groundwater chemistry • Aquifer hydraulic properties • Alluvium leakage estimates	2006 – 2009
Beckett, 1987	Liddell: Hazeldene U/G Liddell U/G Foybrook O/C Swamp Creek O/C	• Alluvium leakage estimates • Mine inflow data	1987
MER, 1998	Ravensworth East Open Cut Mine	• Hydrochemistry • Hydraulic properties	1995-1997
MER, 2011a	Mt Owen Complex	• Piezometric elevations • Groundwater salinity • Aquifer hydraulic properties • Baseflow estimates (modelled)	2008 – 2010
MER, 2011b	Ravensworth Underground	• Piezometric elevations • Groundwater chemistry • Aquifer hydraulic properties • Baseflow estimates (modelled) • Alluvium leakage estimates (modelled) • Mine inflow estimates (modelled)	Pre-mining & 2010 - 2024 (modelled) and 2000 – 2011 (measured) 1980 - 2040 2005 - 2035
Probert & Stevenson, 1970	Liddell U/G	• Mine inflow data	1970
Umwelt, 1997	Ravensworth East Open Cut Mine	• Historical information	1972-1999
Umwelt, 2008a	Liddell Coal Operations	• Piezometric elevations • Groundwater quality	2002 – 2007
Umwelt, 2008b	Mt Owen Complex	• Piezometric elevations • Groundwater quality • Mine inflow data (modelled)	2005 – 2008 2008 - 2023

Source	Mine Operation	Data Type	Timeframe
URS, 2009	Integra	• Piezometric elevations • Groundwater quality • Aquifer hydraulic properties • Mine inflow data (modelled) • Alluvium & creek leakage estimates (modelled)	2007 - 2009 2008 - 2040
Xstrata, 2011	Glendell	• Piezometric elevations • Groundwater quality	2008 – 2011

2. Environmental Setting

2.1 Regional Topography

Topography of the Upper Hunter Valley is highlighted by two distinct areas: the gently undulating plain associated with the Hunter River Valley, and the steeper, elevated ranges in the north delineating the flank of the valley. Within the valley ground elevations generally range between 50 and 150 m AHD, rising to elevations up to 500 m AHD along the northwest to southeast trending ridgeline of the Hunter Thrust, as shown in **Figure 2-1**. The Hunter Thrust is associated with outcropping of Carboniferous rocks and marks the northern catchment boundary of the Hunter River Valley.

2.2 Climate

Regional climate can be described as temperate, with hot summers and cool winters. The average daily maximum temperature ranges from approximately 39°C in February to 14°C in June. Rainfall data from two nearby weather stations (Jerrys Plains, located approximately 15 km southwest of Liddell, and Bowmans Creek, 18 km north) is presented in **Table 2-1**, along with pan evaporation rates recorded at the Scone SCS weather station (approximately 38 km north of Liddell). Rainfall at Jerrys Plains averages 645 mm/yr with the highest rainfall occurring between November and February. Rainfall data for Bowmans Creek weather station, located in the upper parts of the Bowmans Creek catchment, shows an annual rainfall some 35% higher than Jerrys Plains at 871 mm/yr. This higher rainfall is likely due to the higher land elevations on the flanks of the Hunter Valley.

- **Table 2-1 – Rainfall and Evaporation Averages (mm) (BOM, 2012)**

Rainfall	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Jerrys Plains	76.7	72.4	58.4	44.5	40.9	48.1	43.5	36.5	42.0	52.2	61.1	67.9	**645**
Bowmans Creek	108.0	95.8	90.7	58.2	60.3	66.9	48.1	46.3	56.3	68.7	84.1	85.0	**871**
Evaporation													
Scone SCS	220	174	155	105	68	48	56	84	117	155	183	220	**1,585**

2.3 Regional Mining Activities

The Upper Hunter Valley region has been subject to extensive underground and open-cut coal mining since the early 20th century which has extensively altered the area's physical features and setting, including the regions surface water and groundwater systems. Locations of mining operations in the region are shown in **Figure 2-2**.

2.4 Hydrology

Surface water features in the region are predominantly comprised of the Hunter River and its tributaries and local dams and lakes associated with mining and power generation activities. The Hunter River forms the primary surface water drainage system in the region in terms of physical size and flow rate, with its catchment area covering approximately 22,000 square kilometres.

Figure 2-3 shows the regional scale model encompasses two major sub-catchments within the Hunter River catchment associated with Bowmans Creek and Glennies Creek, with more minor tributaries Bayswater Creek, Yorks Creek, Swamp Creek and Bettys Creek also included. In the west Lake Liddell was created by damming Bayswater Creek to supply water to several coal-fired power stations in the area.

2.5 Geology

XCN operations in the region reside within the Hunter Coalfield of the Permian and Triassic Sydney Basin. The geology comprises Permian coal measures hosted within an eroded valley that has been infilled with Quaternary to Recent alluvial sediments associated with the Hunter River and its tributaries (Mackie, 2009). To the west and southwest of the Hunter River Valley is steeply incised terrain of the younger Triassic Narrabeen Group, and to the east and northeast are older Carboniferous rocks. The depositional environment is interpreted by a varying cyclic pattern of fluvial to marine deltaic conditions (Mackie, 2009).

The lower elevations of the Hunter Valley sit within an area of gently folded Permian rocks, with the folds generally on a N-S and NNW-SSE axis and plunging gently to the south at 2 to 5 degrees. Structural features in the area include the Muswellbrook Anticline in the west, the Bayswater Syncline, Camberwell Anticline, and Glennies Creek Syncline. To the north and northeast along the flank of the Hunter Valley a series of northwest to southeast trending faults and thrusts, including the minor Hebden Thrust and the major Hunter Thrust, bring older Permian and Carboniferous rocks to the surface. In these thrust areas coal bearing Permian-aged rocks found elsewhere in the valley are not present. **Figure 2-4** shows the geology and the locations of major structural features within the region.

2.5.1 Alluvial Deposits

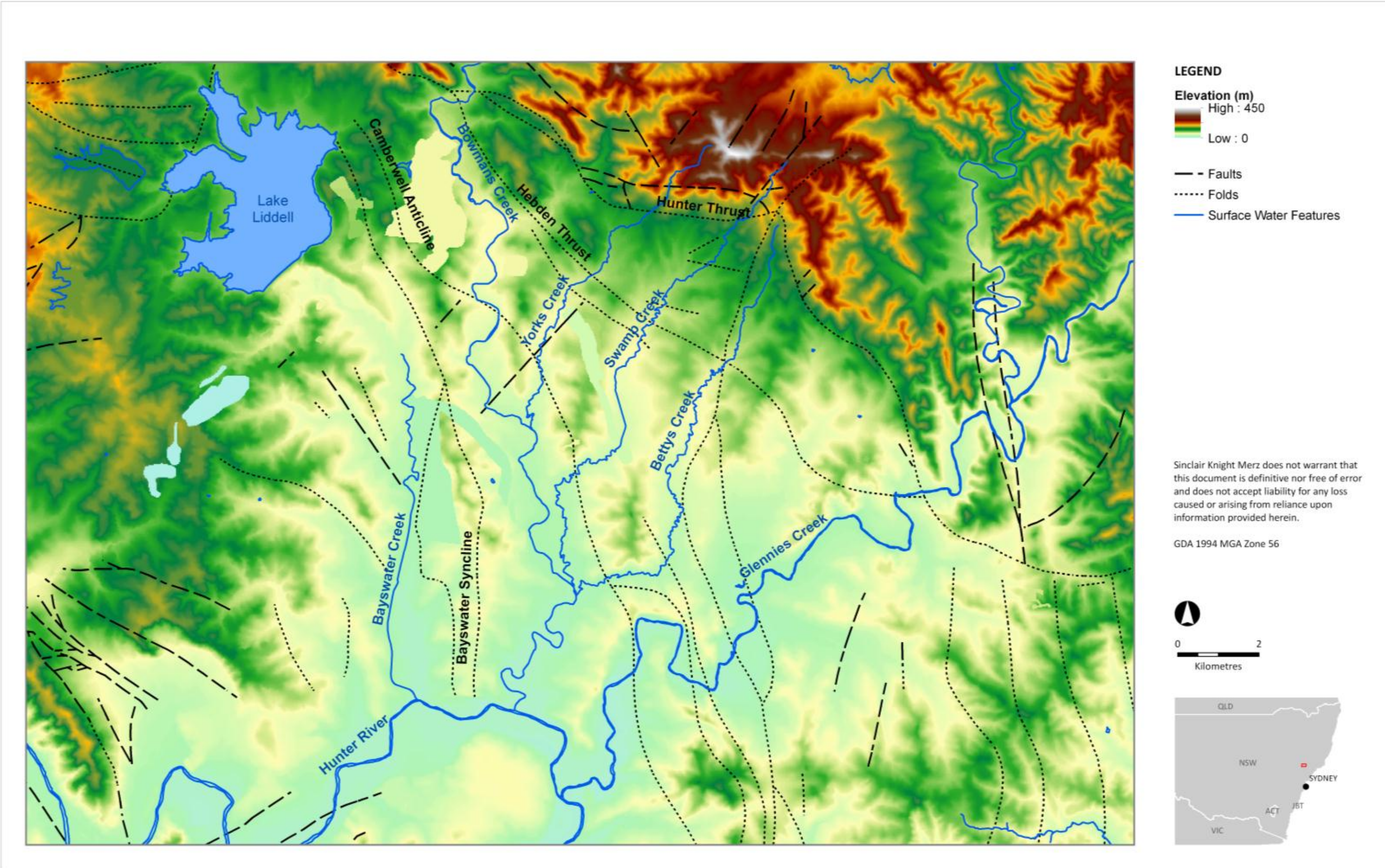
Quaternary and recent alluvial sediments are deposited along major and minor surface water drainages in the region. The thickness of these alluvial deposits is variable, with Mackie (2009) reporting a maximum thickness of 18 m in the region.

The alluvial deposits are generally characterised by a succession of three units, grading from a basal coarse grained bed load comprising sand to cobble size deposits, a middle unit comprising finer grained levee deposits, and finally an upper unit comprising floodplain deposits (Beckett, 1987). The basal unit varies in thickness across the region, ranging from zero to 12 m thickness, whilst the middle and upper units are generally between 1 m and 3 m thickness.

2.5.2 Permian Coal Measures

The main coal-bearing strata in the region are the Permian aged Wittingham Coal Measures of the Singleton Super Group which are summarized in **Table 2-2**. These strata were deposited at a time when global sea levels and tectonism led to widespread deltaic conditions favourable for the development of coal (Mackie, 2009).

- **Figure 2-1 – Regional Topography**



File Name: Model Report_Regional Topography
Prepared by: CD
Checked by: RC

▪ **Figure 2-2 – Regional Mining Operations**

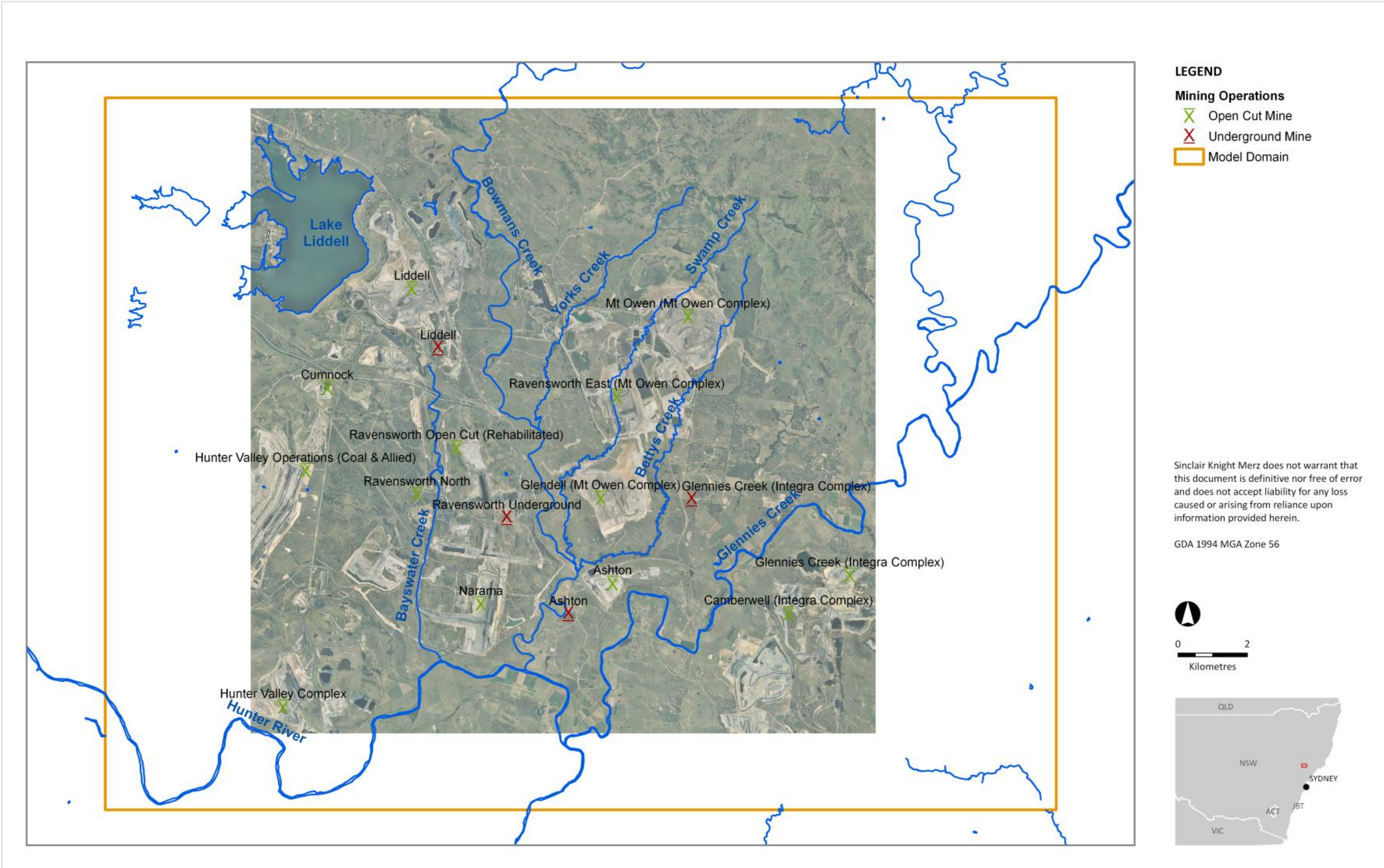
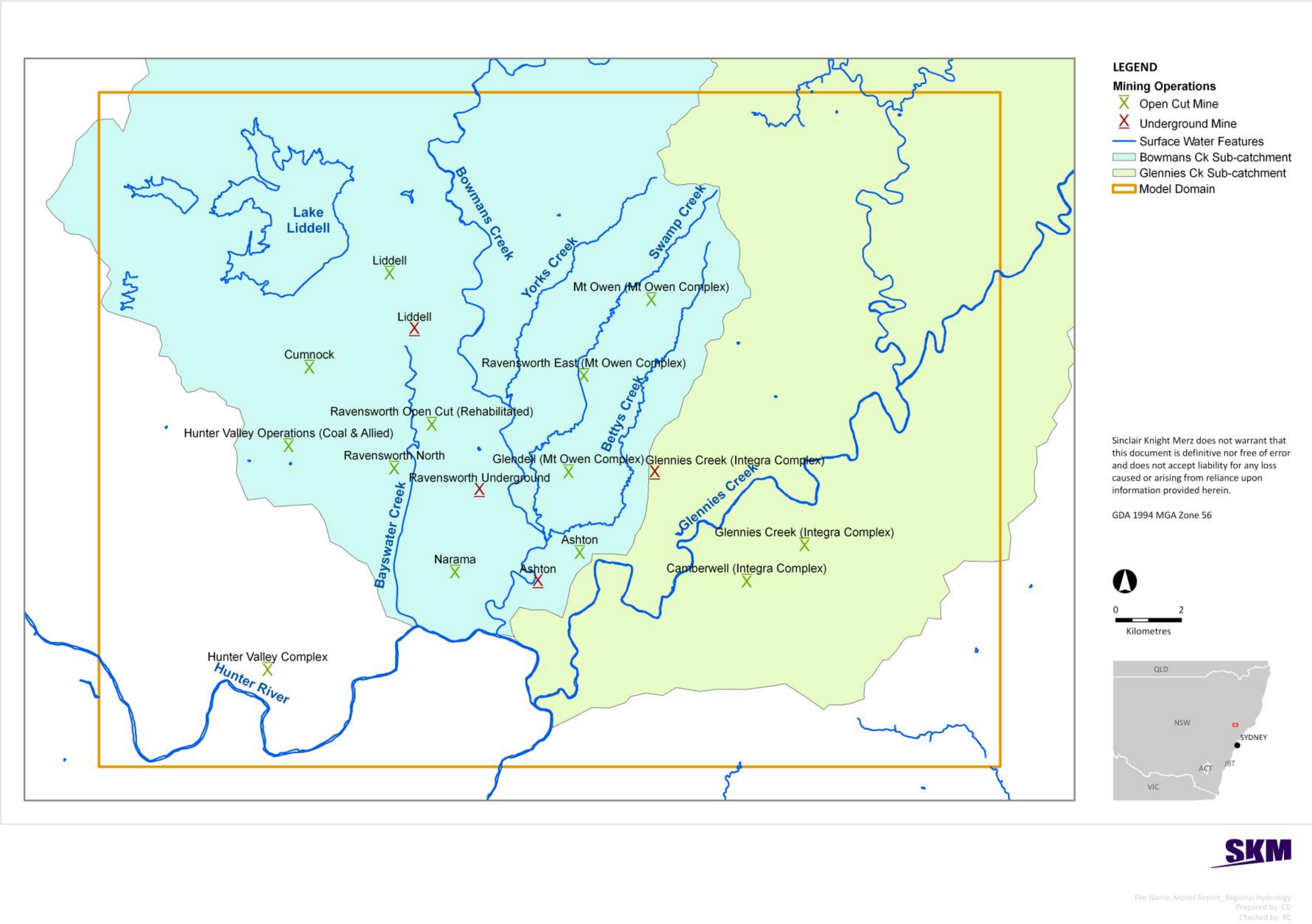
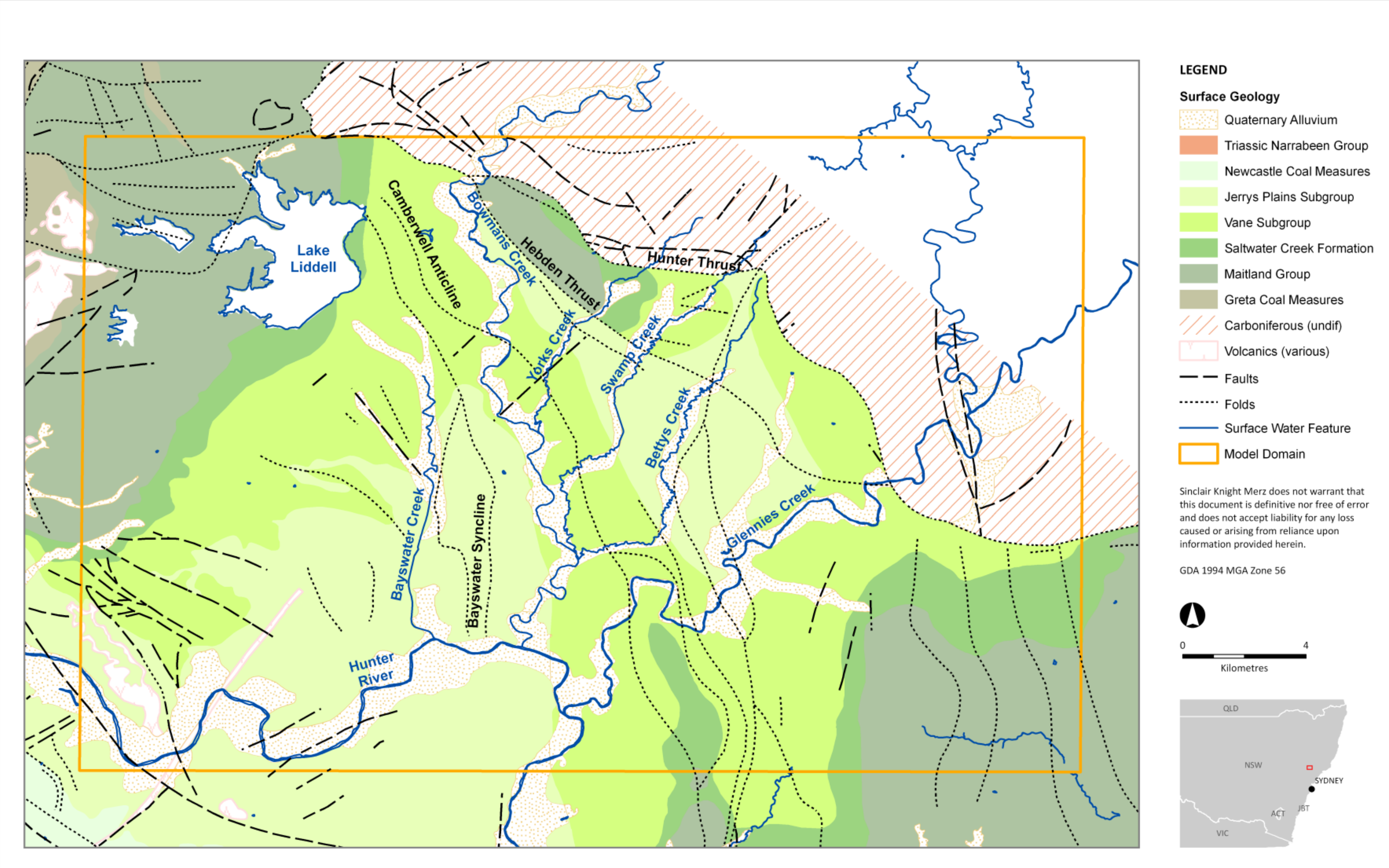


Figure 2-3 – Regional Hydrology



▪ Figure 2-4 – Regional Geology and Structural Features



File Name: Model Report_Regional Geology
Prepared by: CD
Checked by: RC

- **Table 2-2 – Stratigraphic Table of the Wittingham Coal Measures**

Super Group	Coal Measures	Subgroup	Formation	Seam
Singleton Super Group	Wittingham Coal Measures	*Denman Formation (sandstone and siltstone)*		
		Jerrys Plains Subgroup	**Mount Leonard Formation**	Whybrow Seam
			Allthorp Formation (claystone)	
			Malabar Formation	Redbank Creek Seam
				Wambo Seam
				Whynot Seam
				Blakefield Seam
			Saxonvale Member (siltsone and claystone)	
			Mount Ogilvie Formation	Glen Munro Seam
				Woodlands Hill Seam
			Milbrodale Formation (claystone)	
			Mount Thurney Formation	Arrowfield Seam
				Bowfield Seam
				Warkworth Seam
			Fairford Formation (claystone)	
			Burnamwood Formation	Mt Arthur Seam
				Piercefield Seam
				Vaux Seam
				Broonie Seam
				Bayswater Seam
		Archerfield Sandstone		
		Vane SubGroup	*Bulga Formation (sandstone and siltstone)*	
			Foybrook Formation	Lemington Seam
				Pikes Gully Seam
				Arties Seam
				Liddell- Ramrod Creek Seam
				Barrett Seam
				Hebden Seam
		Saltwater Creek Formation (sandstone and siltstone)		

The basal unit of the Wittingham Coal Measures is the Saltwater Creek Formation which comprises siltstones and sandstones and minor coal seams. The Saltwater Creek Formation resides at depth beneath most of the Hunter Valley, however it subcrops approximately 5 km northeast of LCO where it is upthrown between the Hebden and Hunter Thrusts.

Above the Saltwater Creek Formation, the remaining Wittingham Coal Measures can be divided into two coal bearing subgroups, the Vane Subgroup and the Jerrys Plains Subgroup with a marker bed known as the Archerfield Sandstone separating them. These two subgroups comprise up to six primary coal bearing units with each containing multiple seams (refer **Table 2-2**). The coal seams are separated by interburden units comprised of sandstone, siltstone, conglomerate, mudstone and shale. The Foybrook Formation is the basal coal-bearing unit of the Wittingham Coal Measures and forms the main subcropping and outcropping unit in the vicinity of LCO.

2.6 Hydrogeology

2.6.1 Aquifer Systems

Previous environmental assessments undertaken in the area (MER, 2001; ERM, 2008; Umwelt, 2006; Umwelt, 2008a; MER, 2011a; Aquaterra, 2009b) provide a consistent description of the local and regional hydrogeological regime being comprised of two distinct aquifer systems:

- Shallow unconfined aquifers of limited extent within the unconsolidated alluvium associated with the Hunter River and its tributaries, and
- A regional hard rock aquifer system associated with the Permian coal measures.

The alluvial aquifers associated with the Hunter River and its tributaries are generally characterized by unconsolidated deposits of silts, sands, and gravels of varying permeability. MER (2011a) describes the morphology of the alluvial deposits as a vertical succession of three distinct units, including basal coarse grained sand and cobble size deposits, finer grained levee deposits, and floodplain deposits. The basal coarse grained sand and gravel unit forms the main aquifer of the alluvium and in places may be confined by the overlying finer grained terrace deposits. These unconsolidated deposits support baseflow to surface water features in the region, with the varying morphology and extent of the deposits leading to complex and variable flow regimes (Aquaterra, 2009a).

The hard rock aquifer associated with the Permian coal measures exhibits varying levels of groundwater storage and transmission. The most permeable horizons are the coal seams themselves; non-coal interburden strata generally exhibit permeabilities at least one to two orders of magnitude less than the coal seams. Secondary porosity in the non-coal strata may be developed within fractures and joints, however the degree to which this occurs is quite variable and generally unpredictable.

Coal seams typically represent the more permeable hard rock strata through the presence of cleating and jointing, although there is little evidence of structure-related fracturing. Horizontal permeabilities (i.e. parallel to bedding) are generally significantly higher than vertical permeabilities within the coal seams, although subsidence-related cracking may enhance vertical permeabilities of both coal seams and interburden strata in areas of underground workings. Regionally, the coal seam aquifers are generally confined above and below by the interburden strata.

Groundwater in the coal measures moves downdip from areas of recharge where individual seams subcrop and outcrop in the north near the Hunter Thrust and in the west near Lake Liddell. Rates of recharge through unweathered Permian bedrock are very low, with estimates varying from near zero to no more than 1% of annual rainfall (MER, 2011b). Recharge can be expected to be slightly higher where more permeable rocks (i.e. coal seams) subcrop and outcrop.

2.6.2 Hydrogeological Properties

The hydrogeological properties that govern groundwater storage and flow in the region vary considerably between the unconsolidated alluvial systems and the confined hard rock aquifer system associated with the coal measures. Aquifer testing has been undertaken as part of previous environmental investigations for various mining projects in the region using a variety of techniques, including airlifting, packer tests, and laboratory core tests, with the majority of data collected for hard rock aquifers associated with the coal measures. **Table 2-3** provides a summary of hydraulic conductivity and storativity values reported in previous environmental assessments within the region. Recent slug test data collected from LCO monitoring bores targeting the Bowmans Creek alluvial aquifer are also included.

- **Table 2-3 – Range of Hydrogeological Properties**

Lithology	Hydraulic Conductivity (K_{xy}; m/day)	Storage[1]	Source
Alluvium	0.5 – 50	--	MER (2001)
	2.4	$S_s = 8.67 \times 10^{-2}$ $S_y = 0.25$	ERM (2008)
	10	$S_s = 1 \times 10^{-5}$ $S_y = 0.05$	MER (2011b)[2]
Alluvium (Hunter River)	50	$S_s = 1 \times 10^{-4}$ $S_y = 0.1$	Aquaterra (2009b)
	14.5	$S_s = 8.67 \times 10^{-2}$ $S_y = 0.25$	ERM (2008)
Alluvium (Bowmans Ck)	2×10^{-4} – 15	$S_s = 1 \times 10^{-4}$ $S_y = 0.05$	Aquaterra (2009b)
	1 – 60	--	LCC (2013)[3]
Alluvium (Glennies Ck)	0.04 – 80	--	Aquaterra (2009a)
	0.07 – 180	$S_s = 1 \times 10^{-4}$ $S_y = 0.05$	Aquaterra (2009b)
Coal Seams	1×10^{-5} – 1×10^{-1}	--	MER (2001)
	0.052	$S_s = 1.55 \times 10^{-3}$ $S_y = 0.02$	ERM (2008)
	0.04 – 7	--	Aquaterra (2009a)
	0.002 – 0.03	$S_s = 1 \times 10^{-4}$ $S_y = 0.005$	Aquaterra (2009b)
	1×10^{-4} – 2×10^{-2}	$S_s = 4 \times 10^{-6}$ $S_y = 0.002 – 0.1$	MER (2011b)[2]
Interburden / Overburden	0.007	$S_s = 2.25 \times 10^{-5} – 0.2$ $S_y = 0.02$	ERM (2008)
	1×10^{-6} – 8×10^{-3}	$S_s = 1 \times 10^{-5}$ $S_y = 0.005$	Aquaterra (2009b)
	4×10^{-6} – 5×10^{-3}	$S_s = 1 \times 10^{-6}$ $S_y = 3 \times 10^{-4} – 0.001$	MER (2011b)[2]

Notes
1) S_s = Specific Storage or Storativity (1/m); S_y = Specific Yield (dimensionless)
2) Modelled values
3) Calculated from slug test data collected by Larry Cook Consulting (LCC) for LCO monitoring bores ALV1L through ALV8L in March 2013

The range of hydraulic conductivity values reported in **Table 2-3** reflects the properties of the aquifer systems present in the region, with the permeability of the coal measures generally orders of magnitude lower than that of the alluvial aquifer system. Within the coal measures hydraulic conductivity values are higher for the coal seams compared to the intervening siltstones, shales, and sandstone units (interburden). Due to the laminar nature of the coal measures groundwater flow generally occurs within the stratigraphic layers, and vertical conductivity (K_z) has been reported to be orders of magnitude lower than horizontal hydraulic conductivity (K_{xy}) (ERM, 2008; Aquaterra, 2009b).

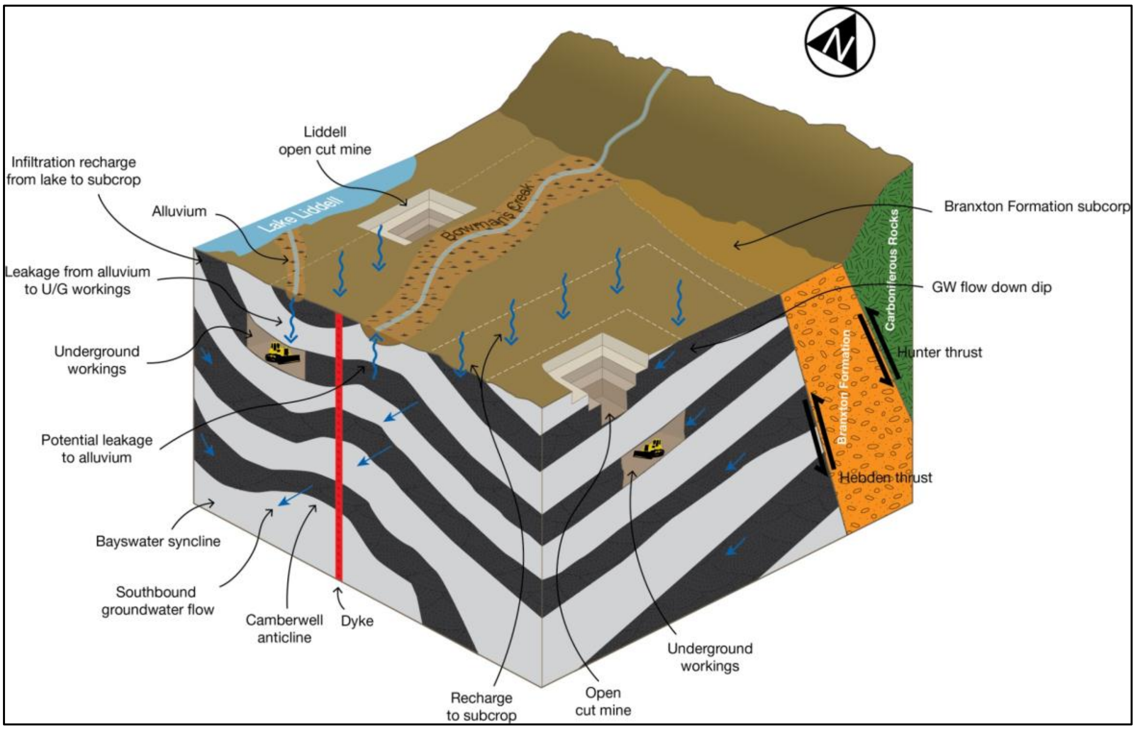
Hydraulic conductivity values reported for alluvial aquifers associated with different surface water features in the region reflect the varying morphology and depositional characteristics of the Hunter River and its tributaries. Reported hydraulic conductivity values for the Hunter River alluvium are higher than those for the tributaries Bowmans Creek and Glennies Creek (ERM, 2008), with investigations revealing a clear distinction between these alluvial deposits (Aquaterra, 2009b).

In March 2013, Larry Cook Consulting (LCC) undertook slug testing on selected observation bores within LCO's groundwater monitoring network that target the Bowmans Creek alluvial aquifer. Conductivity values determined from the slug test data ranged from 1 to 60 m/day, in agreement with previous environmental assessments (refer **Table 2-3**). The monitoring bores tested were installed by Mackie Environmental Research (MER) in 2001, and well completion details indicate the screened section of these alluvial bores targets the basal sand and gravel unit of the alluvium (MER, 2001). However the indicative stratigraphic log presented also indicates the sand and gravel unit extends below the bottom of the well screen and to the shallow bedrock (overburden) unit, with pebble diameters in this layer being larger than the screened section (MER, 2001). The hydraulic conductivity values determined therefore are considered to represent minimum ranges for the alluvial system.

2.6.3 Conceptual Model

Based on the geology and aquifer systems described above, a block diagram describing the conceptual hydrogeological model for XCN operations on either side of Bowmans Creek has been developed and is presented in **Figure 2-5**. This has been used to guide the development of a numerical groundwater flow model for the region.

▪ **Figure 2-5 – Conceptual Hydrogeological Model**



3. Groundwater Model Design

3.1 Confidence Level Classification

The *Australian Groundwater Modelling Guidelines* (Barnett et al., 2012) defines model confidence level classification as a means of rating models according to the confidence with which they can be used as a predictive tool. The classification depends on a number of factors including:

- The amount and quality of data on which the conceptualisation and model calibration are based,
- The manner in which the model is calibrated and the accuracy of the calibration,
- The objectives and requirements of the investigation, and
- The manner in which the predictions are formulated.

At the model planning stage it is important to decide on and document an appropriate target confidence level classification that reflects the expected modelling procedures and outcomes and takes account of the project requirements. In this case the salient aspects of the project that are likely to control the confidence level classification are:

- The level of expense associated with mine dewatering and water management infrastructure and the potential environmental consequences of adverse impacts would suggest that a high level of confidence in model predictions would be desirable.
- There is a reasonable level of regional hydrogeological data (including local scale geological information at the mine site) available for the study and hence the conceptualisation should be reasonably well founded.
- Calibration will be undertaken in steady state and transient mode to a limited data set. The available calibration data are limited to groundwater levels measured in bores in the vicinity of the mine site. There are no measured inflow rates to the mine during historic mining operations; in fact the exact history of mine development includes uncertainties. As a consequence calibration will provide limited constraints on the hydrogeological parameters that control the inflow to the mine and associated environmental impacts.

Given these issues and in consideration of the key indicators of model confidence level classification as described by the *Australian Groundwater Modelling Guidelines* (Barnett et al., 2012), the regional scale model has been targeted as a Class 2 (medium confidence) model. Additional confidence in model predictions (and an increase in confidence level classification) can be expected should additional calibration or validation data be obtained in the future. It is expected that such improvements can be realised if future modelling is tested against detailed observations of groundwater levels and inflows to the mine and further river gauging and baseflow estimates to help quantify the groundwater contribution to the major rivers and streams included in the model.

3.2 Model Description

The regional scale model is based on the existing model for the RUM (MER, 2011b) extended to the north and east to include LCO and the Mt Owen Complex and Glendell mines. The model was created using the Groundwater Vistas pre-processor with the MODFLOW-SURFACT (Version 4.0) finite difference code (Hydrogeologic, 2011) to allow for saturated and unsaturated conditions.

A MODFLOW-based model was chosen because it is well documented and widely used program, and is often used for open-cut and underground mining projects.

MODFLOW-SURFACT was chosen for the following reasons:

- The dewatering and re-saturation of rock and fill material is a major consideration for model simulations. Although not intending to accurately depict the unsaturated flow processes, the variable saturated flow options within MODFLOW-SURFACT add numerical stability to the de-saturation and re-saturation cycle that is likely to occur in and around the mining operations represented in the model.
- MODFLOW-SURFACT package has an automatic time stepping routine that allows for the calculation time increments to increase or decrease depending upon how many iterations are required to find a solution. This package has been shown to improve numerical stability when applied to mine dewatering applications.
- MODFLOW–SURFACT allows for time-varying material properties (TMP1 package), which is important for replicating the changes to hydrogeological parameters as a result of mining and placement of backfill.

As part of the conceptualisation and construction of the model, the following processes were not included:

- Private bores and any associated pumping;
- Flooding events or high river stage recharge; or
- Calibration to baseflow.

These processes were not explicitly included due to lack of available data or because they were assumed to represent relatively minor influences on the groundwater regime with respect to the modelling scope and objectives.

3.3 Model Domain

The model extent measures 20.5 km in the north-south direction and 27.4 km in the east-west direction, with the model origin (southwest corner) located at 305000 Easting and 6400000 Northing (GDA94 MGA Zone 56). Grid cells are 100 m by 100 m, resulting in a model grid of 205 rows and 274 columns.

The extent of the model domain is shown in **Figure 1-1**. Model cells were designated inactive in areas were coal seams belonging to the Vane Subgroup were not present, such as in the northwest and southeast corners of the model domain and north of the Hunter Thrust. In total the model contains 676,533 active cells.

3.4 Model Layers

The model includes 20 layers representing stratigraphy from the ground surface down to the Saltwater Creek Formation, with a description of each model layer provided in **Table 3-1**.

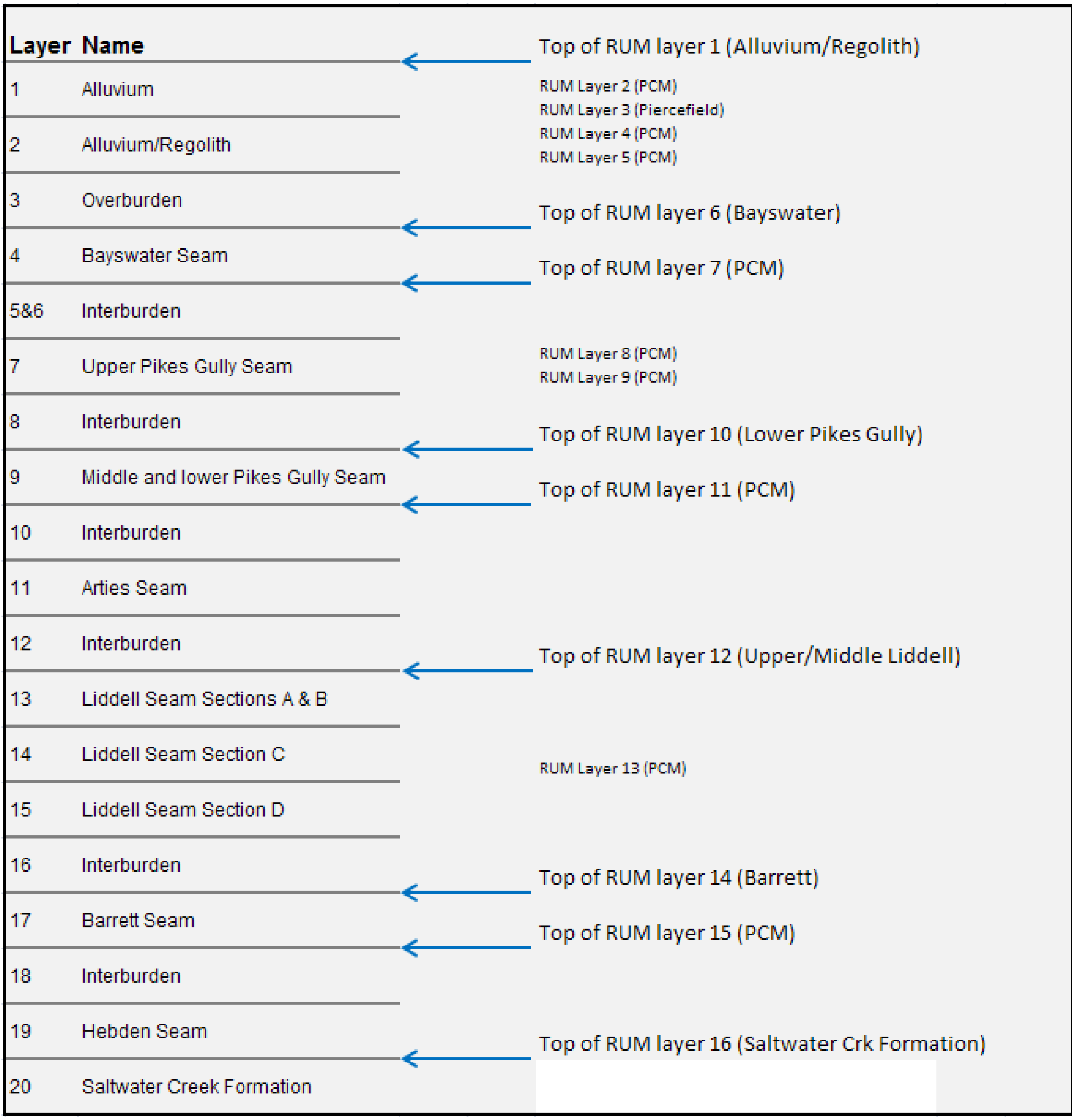
Table 3-1 – Model Layers

Layer	Name	Description
1	Alluvium	Alluvial deposits surrounding the major rivers.
2	Alluvium/Regolith	Basal Alluvial sediments surrounding the rivers and Regolith (weathered rock) elsewhere.
3	Overburden	Everything between the base of weathering and the top of the Bayswater Seam, can include seams, but mostly sandstone, claystone and/or siltstone.
4	Bayswater Seam	All the Bayswater Seams. Includes the upper Bayswater 1, upper Bayswater 2 and Lower Bayswater at Liddell. Also includes interburden between these seams.
5-6	Interburden	Everything between the base of the Bayswater Seam and the top of the Upper Pikes Gully Seam, includes Lemington Seam.
7	Upper Pikes Gully Seam	Upper Pikes Gully Seam.
8	Interburden	Everything between the base of the upper Pikes Gully Seam and the top of the middle Pikes Gully Seam.
9	Middle and Lower Pikes Gully Seam	Everything between the top of the middle Pikes Gully Seam and the base of the lower Pikes Gully Seam, includes interburden between the two seams.
10	Interburden	Everything between the base of the lower Pikes Gully Seam and the top of the Arties Seam.
11	Arties Seam	All the Arties Seams. Includes the Arties A, Arties B, Arties L1 and Arties L2 at Liddell.
12	Interburden	Everything between the base of the lower Pikes Gully Seam and the top of the Arties Seam.
13	Liddell Seam Sections A & B	All the Liddell Seams in Sections A and B. Includes the Liddell A1, Liddell Parting, Liddell B1, upper Liddell B2 and lower Liddell B2 at Liddell. Also includes interburden between these seams.
14	Liddell Seam Section C	All the Liddell Seams in Section C. Includes the upper Liddell C1, lower Liddell C1 at Liddell. Also includes interburden between the two seams.
15	Liddell Seam Section D	All the Liddell Seams in Section D. Includes the upper Liddell D1, lower Liddell D1 at Liddell. Also includes interburden between the two seams.
16	Interburden	Everything between the base of the Liddell Seam Section D and the top of the Barrett Seam.
17	Barrett Seam	All the Barrett Seams, including the Barrett A, upper Barrett B, middle Barrett B, lower Barrett B, Barrett C1, Barrett C2 and Barrett D seams. Also includes interburden between these seams.
18	Interburden	Everything between the base of the Barrett Seam and the top of the Hebden Seam.
19	Hebden Seam	All the Hebden Seams. Includes upper Hebden and lower Hebden at Liddell. Also includes interburden between the two seams.
20	Saltwater Creek Formation	This layer represents the basement below the Hebden Seam, its upper part is composed of the Saltwater Creek Formation.

A number of assumptions were made to create the surfaces that define the tops and bottoms of the model layers.

- For all areas outside the extents of Light Detection and Ranging (LIDAR) remote sensing data provided by XCN, the top of layer 1 (which represents the ground surface) is based on a 25 m digital elevation model (DEM) obtained from NSW Land and Property Information.
- Alluvial deposits are included in the uppermost layer of the model. In areas where alluvial deposits are present the thickness of the top model layer varies from 10 m in the upper reaches of Bowmans, Bayswater and Glennies Creeks, to 30 m along the Hunter River. These alluvial thicknesses are based on Probert and Stevenson (1970) and Beckett (1987) and represent the maximum thicknesses of alluvial sediments beneath the alignment of the rivers and creeks. The alluvium thickness was set to 1 m along the boundaries of the alluvium extent. This extent is based on the analysis of the latest available LIDAR data (personal communication with Col Mackie). Outside the areas where alluvium is present the top model layer is uniformly 1 m thick.
- Layer 2 of the model represents some areas of alluvial sediments within the river valleys and regolith elsewhere.
- The tops and bottoms of the model layers that represent the coal measures and interburden strata were based on surfaces from the Liddell Minescape Geological Model, the Ravensworth \ Glendell geological model, and the Mt Owen geological model. Beyond the XCN mine extents (Liddell, Ravensworth, Glendell and Mt Owen), layer elevations from the original RUM model (MER, 2011b) were used where correspondence exists between the RUM and regional scale model layering. The correspondence between the RUM model layers and the regional scale model layers is summarized in **Figure 3-1**.
- The subcrop locations for the individual seams are not known with accuracy outside the Liddell and Mt Owen geological models. The Bayswater Seam was assumed to subcrop where the Jerrys Plain Subgroup does, while the Pikes Gully, Arties, Liddell, Barrett and Hebden Seams were assumed to subcrop where the Vane Subgroup subcrops. The subcrop of the Jerrys Plain Subgroup and the Vane Subgroup were located according to the Hunter Coalfield Regional Geology map (NSW Department of Mineral Resources, 1993).
- The top of RUM model layer 10 (Lower Pikes Gully Seam) was assumed to be the top of the Middle Pikes Gully Seam in the regional model. This assumption is reasonable to the south of Liddell where the difference is less than 4 m, though it is recognized that greater discrepancies may occur further to the south.
- The division of the Liddell Seam between Sections A & B, C and D was based on their elevations at LCO. These seams separate further to the south of LCO, meaning that in the southern part of the model the three layers representing the Liddell Seam may incorporate significant thicknesses of interburden. In order to account for this stratigraphy lower hydraulic conductivity values are assigned to the model layers that represent the Liddell Seam in the south of the model.
- The bottom layer (basement) was assigned a constant thickness of 20 m.

- **Figure 3-1 – Relationship between the RUM and Regional Scale Model Layers**



The extent and depth of model layer 1 in the area of the Bowmans Creek alluvium was determined from LIDAR data and borehole logs, resulting in the alluvial layer shown in **Figure 3-2**. SKM was able to identify 41 bore logs that provided information on alluvial thickness, albeit with varying levels of confidence. The locations of the 41 boreholes used to define the Bowmans Creek alluvium are shown in **Figure 3-2**. Boreholes that do not fully penetrate the alluvium provided an indication of minimum alluvium thickness. A summary of the borehole data used is shown in **Table 3-2**. For grid development, at the outer extent of the alluvium the thickness was set to 0 m. The maximum alluvial thickness was assumed to occur at the centre of the alluvial valley and was based on previous interpretations of the Bowmans Creek alluvium (MER, 2011b).

- **Figure 3-2 – Model Thickness and Extent of Bowmans Creek Alluvium**

- **Table 3-2 – Boreholes Targeting Bowmans Creek Alluvium**

Borehole ID	Easting	Northing	Alluvial Thickness (m)*	Borehole ID	Easting	Northing	Alluvial Thickness (m)*
BC-SP01	317410	6411576	4.4	GNP-02	317564	6410201	>4
BC-SP02	317483	6411487	8.7	GNP-03	316946	6411686	2.8
BC-SP03	317547	6411405	>7.5	GNP-06	317605	6411062	>2
BC-SP04	317610	6411320	>6.5	GNP-07	316530	6412448	4.3
BC-SP06	317596	6411588	9.25	GW027690	316222	6412982	>5.5
BC-SP07	317681	6411448	10.15	GW028247	316275	6412952	>2.44
BC-SP08	317608	6411897	>5.9	GW046787	317205	6409241	>8
BC-SP09	317675	6411703	8.15	GW078054	317122	6409486	>10.8
BC-SP10	318080	6409400	6	RA10	317639.7	6404335	>13
BC-SP11	318137	6409337	9.4	RA14	317643.4	6404698	>11
BC-SP12	318201	6409265	6.3	RA15	317420.5	6404748	>10.5
BC-SP13	318253	6409210	3.5	RA17	317695.5	6404876	>10.5
BC-SP15	318182	6409484	5	RA30	317810.6	6406501	>9
BC-SP16	318290	6409376	4.6	T10	317683.6	6404450	>10
BC-SP17	318319	6409543	6.5	T1-A	318337.7	6406309	>7.9
BC-SP18	317350	6411325	3.8	T2-A	317583.3	6405217	>8.9
BC-SP19	317462	6411178	2.1	T3-A	317654.2	6404708	>9.9
BC-SP20	318184	6409118	4.5	T4-A	317685.8	6404323	>10
BC-SP21	318057	6409176	6.7	T5	317946.1	6406549	>8
BC-SP22	317992	6409051	6	T6	317975.1	6406675	>7
				T7	317717.4	6406336	>7

3.5 Boundary Conditions

3.5.1 General Head Boundaries

General head boundaries are assigned at active cells adjacent to model boundaries where the aquifer is known to extend beyond the limit of the model domain. Heads were adjusted for all boundaries during initial calibration and sensitivity assessments to produce a reasonable piezometric surface.

3.5.2 River Cells

River cells are assigned to replicate the surface water - groundwater interaction of the Hunter River and associated alluvium in the southern extents of the model area. The river bottom elevations are set to be 1 m below surface elevation and a uniform 0.1 m stage is assumed for all rivers.

3.5.3 Stream Routing Package

The Stream Routing Package (SRP) is used for replicating the surface water - groundwater interactions of Bowmans Creek. The advantage of using the SRP is that stream flow is estimated sequentially along the path of the stream boundary. An initial flow is assigned to the stream at the upstream end of the boundary string. For subsequent downstream cells, the flow entering the cell is equal to the flow entering the previous stream cell plus or minus any predicted baseflow input or river loss to groundwater. As a result a mass balance is kept on the stream. This feature is important for replicating ephemeral streams and for restricting the potential stream losses simulated in flow restricted streams such as Bowmans Creek.

LIDAR data was used to estimate bottom elevations for the SRP cells. Locations of cross-sections of the Bowmans Creek alluvium estimated from the LIDAR data are shown in **Figure 3-3**, and **Figure 3-4** shows the resulting estimated surface elevations at these cross-sections. **Figure 3-4** shows the Bowmans Creek channel can be clearly distinguished, however the coarse spacing of the model grid means the lowest points of the stream bottom are likely to be missed in the model discretization. As a result the stream bottom was set at 0.5 m below the lowest value estimated from the LIDAR data, and the stream stage was set at 0.5 m above the stream bottom. Where LIDAR coverage was not available the 25 m Digital Elavation Model (DEM) was used.

A profile of the Bowmans Creek alluvium model layer, including stream bottom, stage, model top and model bottom, is provided in **Figure 3-5**. The profile follows the meander of Bowmans Creek and illustrates the fluctuating thickness of alluvium as the creek winds from one side of the shallow alluvial deposit to the other. The inaccuracies of using the 25 m DEM compared to the LIDAR data can also be clearly seen in **Figure 3-5**. The upper reaches where LIDAR data are available (< 10,000 m chainage) have less areas where the base of alluvium is above the elevation of the river stage.

3.5.4 Non-Perennial Streams

Drain cells are assigned to non-perennial streams (e.g. Yorks, Bettys and Swamp Creeks) within the model domain, with the drain elevation assumed to be 0.1 m below the ground surface elevation. The drain cell conductance is set sufficiently high not to constrain flow to these cells.

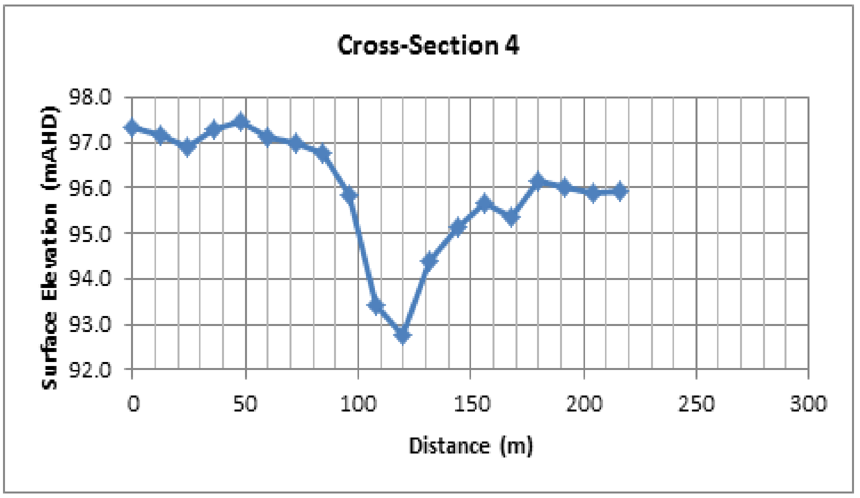
3.5.5 Wall Boundary Conditions

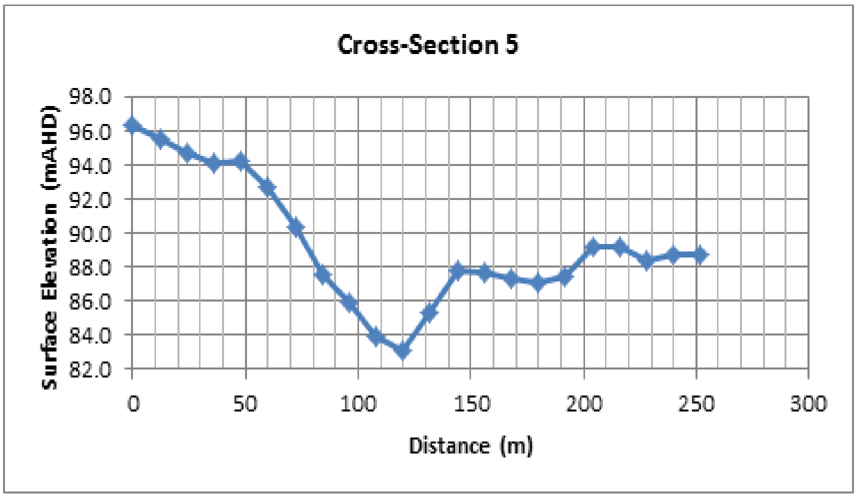
Structural features within the model domain that are known to act as horizontal flow barriers are represented in the model using the MODFLOW Wall boundary condition. Features such as the subsurface dyke and coal barrier in the southeast and east of the LCO Development Application (DA) boundary are replicated in the model using the wall boundary condition. The wall cells are defined along the mapped structures and conductance values assigned according to the feature properties. For example, the dyke in the southeast of the LCO DA boundary is assigned a conductance of 1×10^{-5} m^2/day, which was estimated during initial calibration runs to replicate the measured head gradient across the dyke. The wall cells used for the coal barrier are given a thickness based upon the designed thickness of the barrier and assigned a conductance equivalent to the hydraulic conductivity of coal seams.

▪ Figure 3-3 – Bowmans Creek Alluvium Cross-Section Locations

- **Figure 3-4 – Bowmans Creek Alluvium Cross-Sections**

- **Figure 3-4 – Bowmans Creek Alluvium Cross-Sections (cont.)**





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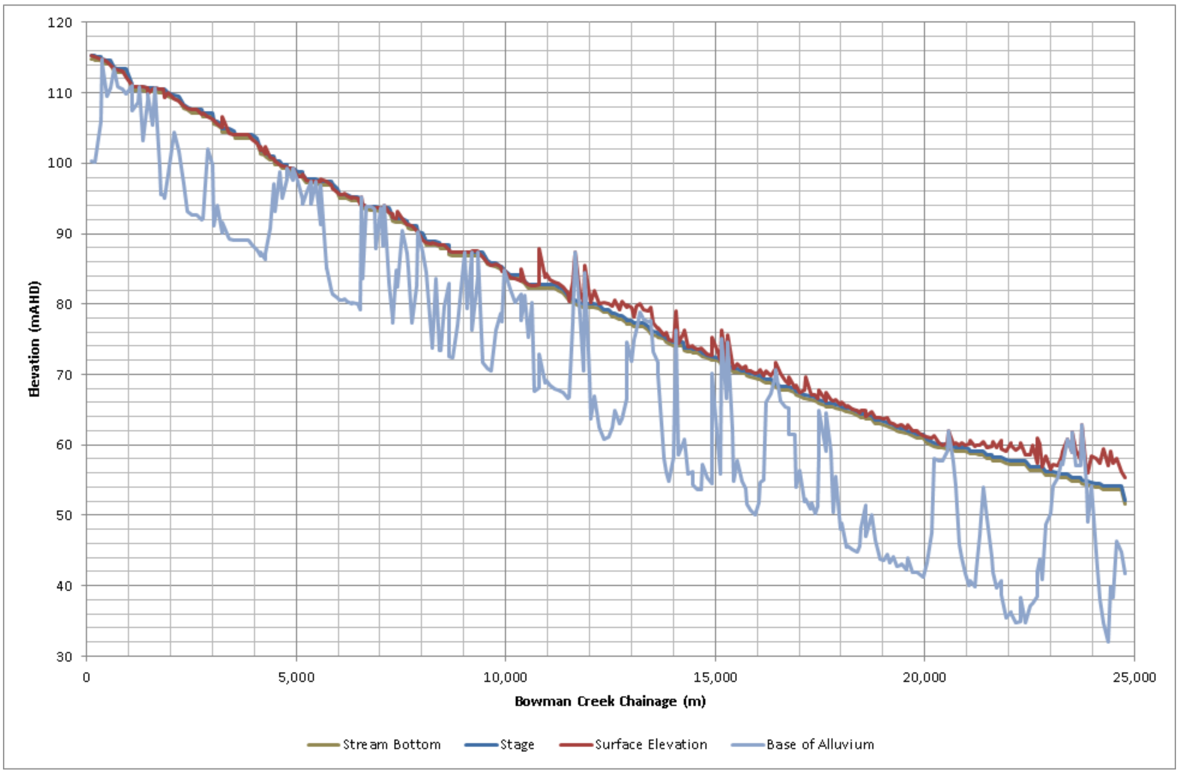
- **Figure 3-5 – Bowmans Creek Profile**



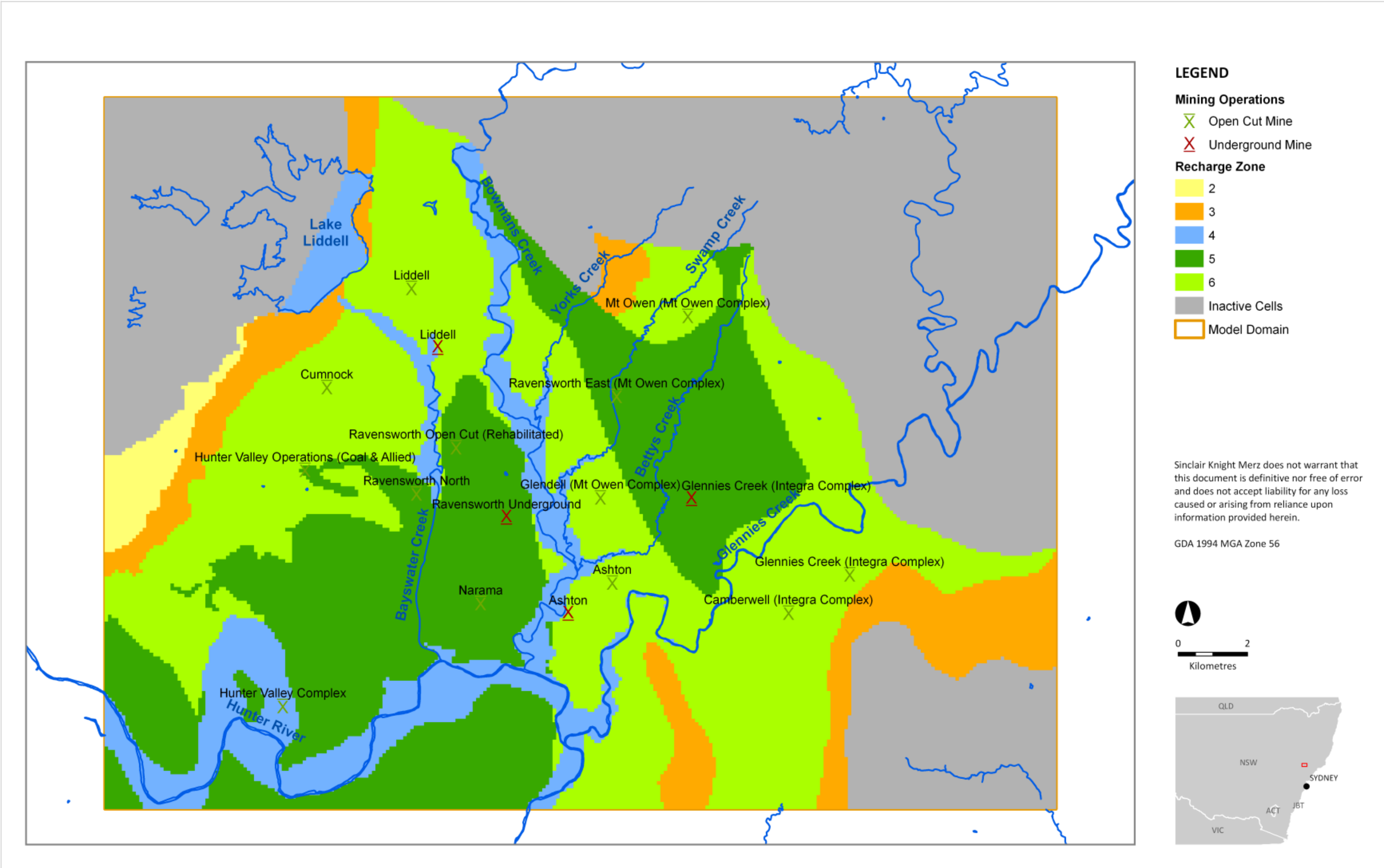
3.5.6 Recharge

Recharge is applied to the upper most active hydrogeological unit at a rate consistent with the surface geology characterisation shown in **Figure 2-4**. The resulting recharge zones in the model are shown in **Figure 3-6**, with the calibrated recharge rates for the zones provided in **Section 4.3**.

3.5.7 Evapotranspiration

Evapotranspiration is modelled with the MODFLOW EVT Package in which the maximum evapotranspiration rate is set to the corrected pan evaporation for the region (approximate 1460 mm/year) with an extinction depth of 2 m.

▪ Figure 3-6 – Model Recharge Zones



File Name: Model Report_Model Rch Zones
Prepared by: CD
Checked by: RC

3.6 Regional Mining Operations

The regional scale model incorporates historic and future mining operations that have already been approved. The operational mining sequences that fall within the calibration period (post-1990) are incorporated and have a significant influence on the calibration process. Underground mining prior to 1990 is represented in the model by increased hydraulic conductivity (both horizontal and vertical) as well as increased storage properties (specific yield). The post-1990 modelling stress periods incorporate both dewatering associated with underground and open cut operations through the use of drain boundary conditions. Post-dewatering re-saturation and groundwater recovery influenced by the final voids is modelled through the use of changing hydrogeological parameters, time varying evapotranspiration surfaces, and recharge rates.

3.6.1 Drain Cells

The mining operations and associated progressions included in the model come from a variety of sources and have been updated throughout the development of the model as additional information becomes available. Updates to the model are tracked through the model version protocol described in **Section 1.3**. A summary of the model updates and associated model version numbers to date are provided in **Table 1-1**.

Model representation of open cut mining operations comprises drain cells being assigned to the target seam layer and all model layers above it. For underground operations, drains are assigned to only the target seam layers. Where mining depth contour plans have been provided, drain elevations have been set to the pit floor elevation or layer bottom, whichever is higher. For areas where only the target seam(s) is known, the drain elevation is set to the bottom elevation of the target seam layer and layer bottom for layers above the target seam, where appropriate. The distribution of drain cells across the various model layers used to represent the various mining operations are presented **Appendix A**.

A sensitivity assessment on the conductance parameter assigned to drain cells representing mining operations was undertaken to ensure the conductance value was high enough to allow sufficient water removal but not so high as to lead to mass balance or numerical stability problems.

3.6.2 Hydrogeological parameters

An important feature of the regional scale model is the inclusion of changing hydrogeological parameters as a result of mining and backfill sequencing. The TMP1 package implemented in MODFLOW-SURFACT allows time-varying hydrogeological parameters to be incorporated into transient simulations. When changing the hydrogeological parameters using the TMP1 package there are two key inputs:

- The timing of the changes; and
- The multiplier to be applied to the parameter starting value.

The timing and magnitude of the changes are then tied spatially to the progression of the simulated mine operation. The areas used for the drain cells depicting mine operations were used to delineate Hydrostratigraphic Units (HSUs) within the model. HSUs are used in Groundwater Vistas to group cells so that their parameters can be changed together. The TMP1 package allows for hydrogeological parameters to be varied according to HSU zones.

Since HSUs are defined by both the timing of the change and the multiplier to be applied, many different zones are required to fully represent the aerial and vertical migration of pit growth and subsequent backfilling sequences. The changes to parameters used to replicate groundwater recovery post-mining are set to take effect the stress period after each drain cell becomes inactive. The multiplier for each HSU was calculated by dividing the new parameter(s) by the starting (i.e. calibrated) parameter(s).

Backfill was assumed to have a hydraulic conductivity of 1 m/day and a specific yield of 0.2 (Mackie, 2009). Multipliers for voids (air) were based on a hydraulic conductivity of 1000 m/day and a specific yield of one.

3.6.3 Recharge and Evapotranspiration

For model stress periods when the drain cells used to represent open cut mining operations are active (i.e. the open cut mine is operational), recharge to those drain cells is turned off. Post-mining backfill areas are assigned a recharge of 10% of the average annual rainfall.

Evapotranspiration rates are held constant throughout the model simulation. However the surface from which the extinction depth is calculated varies with time according to open cut mine progression and backfilling sequences. Extinction depths also vary according to the mine progressions. Extinction depths are set to 0.2 m in open cut pits during active mining, and then returned to 2 m for backfill areas. This adjustment is required to take account of the fact that there will be little or no vegetation present in areas where active mining is occurring and hence transpiration is negligible. It is assumed that vegetation, and associated transpiration processes, will be re-established in those areas once they have been backfilled. Extinction depths for final voids are kept at 0.2 m after mining activities cease.

4. Model Calibration

4.1 Monte Carlo Analysis

Calibration of the regional scale model was undertaken using Monte Carlo analysis to meet the following objectives:

- Establish datasets of model parameters that match measured groundwater levels within acceptable error limits. These parameter sets are reported collectively as the 'stochastic datasets'.
- Run the predictive simulations with the stochastic datasets to obtain an envelope of possible outcomes that also collectively represent the uncertainties associated with predictive modelling.

Model calibration using the stochastic approach employed here accounts for the inherent uncertainty associated with complex models based on many inter-related parameters. Each of the 'calibrated' datasets, or realisations that generate model results within the adopted calibration acceptance criteria, is considered equally plausible. The range of model results generated using these stochastic datasets provides a good indication of the uncertainties associated with predictive modelling. Such uncertainty analysis is important in any predictive modelling exercise and is recommended under the National Water Commission's recent *Australian Groundwater Modelling Guidelines* (Barnett et al., 2012).

The methodology followed for the Monte Carlo analysis comprised:

- Generation of the initial datasets;
- Model simulations using each dataset;
- Comparison of model results with historical groundwater levels;
- Establish the set of stochastic datasets; and
- Run predictive simulations for both the calibrated and stochastic datasets.

The initial input datasets for the Monte Carlo analysis comprised 10,000 unique combinations of model parameters generated automatically using a program developed by SKM. The program allows for the range of values for each parameter to be:

- Distributed as normal, log normal, random, or log random; and
- Constrained or tied to other parameters. For example, one parameter can be constrained so that it cannot exceed another parameter, or one parameter may be defined as a multiplier of another parameter (as commonly used to define a consistent level of anisotropy in hydraulic conductivity).

The generation of datasets in this method allows for flexibility in how parameters are defined and constrained, and also allows for multiple linking of parameters and constraints. For example, the horizontal conductivity of the regolith was not allowed to exceed that of the alluvium, while at the same time the vertical conductivity of the regolith was not allowed to exceed the horizontal hydraulic conductivity of the regolith, thus indirectly tying it to the horizontal conductivity of the alluvium. These checks and constraints are important in generating datasets to ensure that datasets are not created that violate our conceptual understanding of the system (e.g. vertical conductivities exceeding horizontal conductivities, or the hydraulic conductivity of the interburden exceeding that of the coal seams).

Table 4-1 summarizes of the range of values within which the model parameters were permitted to vary. The level of constraint for the parameter bounds was directly related to field-based and reference information available for the parameters. For instance, a comprehensive dataset is available for the range in expected hydraulic conductivity values of the coal seams and interburden material. Therefore the range in hydraulic conductivity values permitted for these layers is relatively small compared to the range permitted for the regolith and alluvium, units for which there was less site specific data available.

The ranges in parameters allowed does not necessarily reflect the expected or final values that will be selected for analysing potential inflows but are simply intended to:

- allow for a wide range of potential values and thus possibilities to be assessed through the calibration process; and
- evaluate the sensitivity and uncertainty in the parameterisation and calibration of the model.

Table 4-1 – Parameter Bounds Assigned for Monte Carlo Analysis

Parameter	Geologic unit	Minimum	Maximum	Constraints
Sy	Alluvium	1.00E-02	2.00E-01	
Sy	Regolith	5.00E-03	1.00E-01	
Sy	Interburden	5.00E-04	5.00E-02	
Sy	Pikes Gully Seam	5.00E-04	5.00E-02	
Sy	Liddell Seam	5.00E-04	5.00E-02	
Sy	Barrett Seam	5.00E-04	5.00E-02	
Sy	All other seams	5.00E-04	5.00E-02	
Sy	Underground workings (Pikes Gully)	5.00E-02	5.00E-01	
Sy	Underground workings (Hazeldene and Liddell)	5.00E-02	5.00E-01	
Kx (m/d)	Alluvium	1.00E-01	5.00E+02	
Kx (m/d)	Regolith	1.00E-03	5.00E+00	Could not exceed Alluvium (Kx)
Kx (m/d)	Interburden	1.00E-05	3.00E-02	Could not exceed coal seams (Kx)
Kx (m/d)	Pikes Gully Seam	9.00E-04	4.00E-01	
Kx (m/d)	Liddell Seam	1.00E-03	2.00E-01	
Kx (m/d)	Barrett Seam	1.00E-03	4.00E-01	
Kx (m/d)	All other seams	1.00E-03	5.00E-02	

Parameter	Geologic unit	Minimum	Maximum	Constraints
Kx (m/d)	Underground workings (Pikes Gully)	1.00E+01	5.00E+02	
Kx (m/d)	Underground workings (Hazeldene and Liddell)	1.00E+01	5.00E+02	
Kz (m/d)	Alluvium	1.00E-02	5.00E+00	Could not exceed Kx
Kz (m/d)	Regolith	1.00E-04	5.00E-01	Could not exceed Kx
Kz (m/d)	Interburden	1.00E-06	3.00E-03	Could not exceed Kx
Kz (m/d)	Pikes Gully Seam	9.00E-05	4.00E-02	Could not exceed Kx
Kz (m/d)	Liddell Seam	1.00E-04	2.00E-02	Could not exceed Kx
Kz (m/d)	Barrett Seam	1.00E-04	4.00E-02	Could not exceed Kx
Kz (m/d)	All other seams	1.00E-04	5.00E-03	Could not exceed Kx
Kz (m/d)	Underground workings (Pikes Gully)	1.00E+00	5.00E+01	
Kz (m/d)	Underground workings (Hazeldene and Liddell)	1.00E+00	5.00E+01	
River Conductance (m^2/d)	Layer 1	1.00E-05	1.00E+05	
Stream Conductance (m^2/d)	Bowmans Creek	1.00E-05	1.00E+05	
GHB Conductance (m^2/d)	Across multiple layers	1.00E-05	1.00E+05	
Recharge[1]	All other areas (zones 3-6)	0.001%	5%	
Recharge[1]	Alluvium	0.1%	20%	
[1] Percent of annual rainfall (Station # 61086) equal to 645 mm/yr (www.bom.gov.au)				

4.2 Calibration Target

For the model calibration, results of the Monte Carlo simulations were compared to measured groundwater levels at bores completed within the Bowmans Creek alluvium (the ALVx_L bores). The reasons these bores were used for model calibration include:

- Potential impacts of concern related to mining activities in the region are those associated with leakage and/or drawdown in the Bowmans Creek alluvium. As a result the replication of historical groundwater levels, and any associated constraints to calibration associated with matching the model results to these levels, was considered important.
- The number of available bores targeting the hard rock aquifer far exceeds those in the alluvium. Therefore if the data for the hard rock bores were included they would dominate the calibration statistics and potentially skew the calibration away from those parameters or realisations that best replicate the measured groundwater levels in the alluvium.

- The fluctuations in measured groundwater levels in hard rock bores far exceed those observed in the alluvium. The relative weight given to matching the magnitude of fluctuations in the bedrock could potentially reduce the ability of the model to replicate observed responses in the alluvial aquifers.

It should be noted that although the calibration target was limited to the measured data for the Bowmans Creek alluvial bores, the calibration statistics reported in **Section 4.3** include both hard rock and alluvial bore records.

The locations of the Bowmans Creek alluvial bores used for the calibration target data are summarized in **Table 4-2**. For each of these bores measured groundwater levels were averaged over the corresponding stress periods to create one target value per stress period.

Table 4-2 – Location of Bowmans Creek Alluvial Bores

Name	Easting	Northing	Model Layer
ALV1_L	315528	6417638	1
ALV2_L	316328	6414721	1
ALV3_L	315703	6417044	1
ALV4_L	315994	6416421	1
ALV7_L	316513	6413617	1
ALV8_L	316151	6413367	1

4.3 Calibration Results

The 10,000 simulations performed for the Monte Carlo analysis were undertaken in parallel across a dedicated modelling server at SKM and five other personal computers. The parallel computing was set up to allow for 71 simultaneous simulations to be running at any one time, thus allowing all 10,000 simulations to be completed and processed in less than 14 days.

During the Monte Carlo simulations the model runs were interrupted after 6,394 simulations. Of these 6,394 simulations, 794 converged for all transient stress periods. The results of this subset indicated a sufficient number of realisations that met the calibration statistical target criterion of less than or equal to 5% scaled root mean square (SRMS). Therefore, no more Monte Carlo calibration simulations were conducted.

The SRMS statistic was used as an indicator of how well each model run replicated the measured data over the calibration period. **Figure 4-1** summarizes the SRMS results for the 794 datasets (i.e. realisations) that converged, 37 of which resulted in an SRMS value less than the 5% calibration criterion.

The ranges in model parameters allowed in the Monte Carlo process do not necessarily reflect the expected or final parameter values because some of the ranges were allowed to exceed known data ranges or the conceptual understanding of the system. These parameter ranges were allowed to exceed the known data ranges in order to determine whether the calibration data and calibration process would constrain them, thereby providing an indication of the robustness of the model. Consequently SKM conducted a review of the 37 calibrated datasets to remove any datasets that contained parameterisations outside the system conceptualisation. Amongst these 37 datasets, only five realisations included recharge rates greater than 5% of average annual rainfall for the recharge zone representing alluvial aquifers (recharge zone 4 of **Figure 3-6**). Similar recharge rates for alluvial aquifers have previously been used in groundwater models for the region (MER, 2009; MER, 2011). These five realisations, or sets of model parameters, were considered the calibrated datasets available for predictive simulations. **Table 4-3** summarizes the range of values for model parameters within the calibrated datasets.

- **Figure 4-1 – Summary of Monte Carlo Simulation Results**

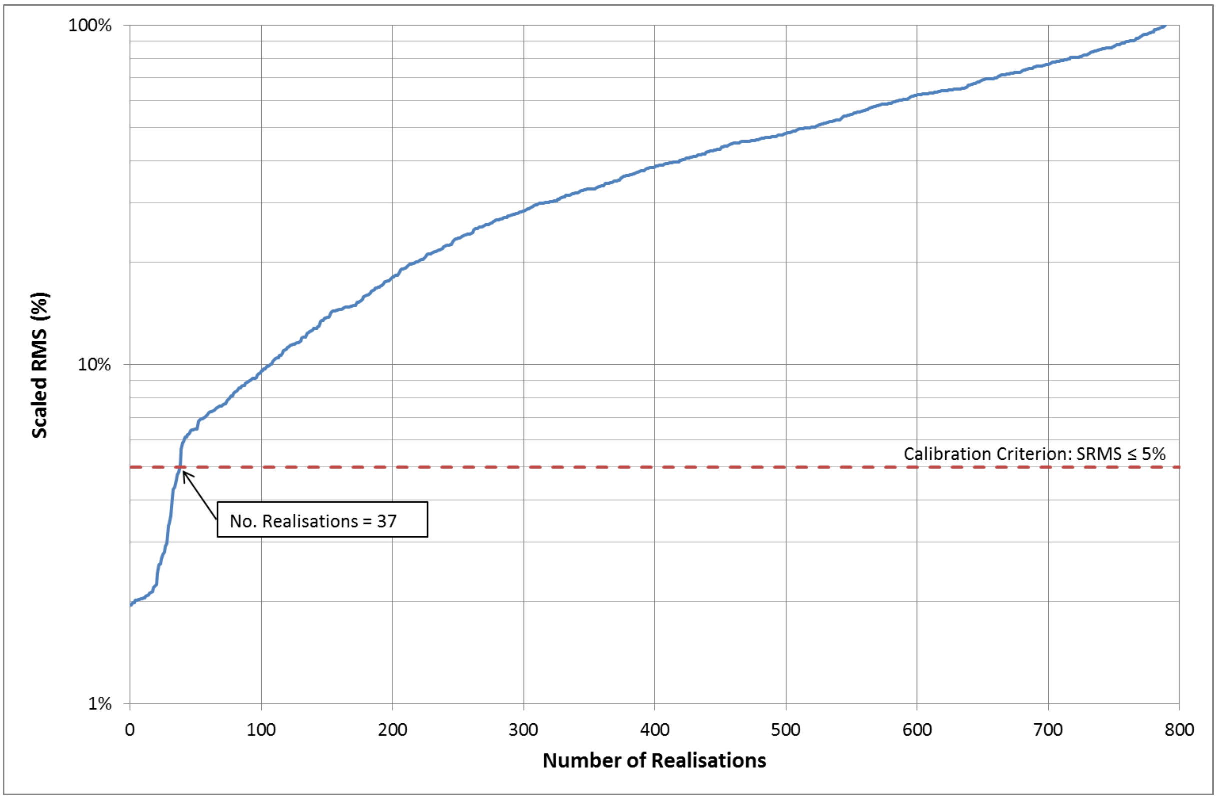


Table 4-3 – Range of Model Parameter Values for Calibrated Datasets

Parameter	Geologic unit	Minimum	Maximum
Sy	Alluvium	2.32E-02	1.73E-01
Sy	Regolith	9.72E-03	8.22E-02
Sy	Interburden	5.27E-03	4.98E-02
Sy	Pikes Gully Seam	6.32E-04	4.65E-02
Sy	Liddell Seam	8.53E-04	3.25E-02
Sy	Barrett Seam	5.48E-04	3.56E-02
Sy	All other seams	8.31E-04	9.25E-03
Sy	Underground workings (Pikes Gully)	5.26E-02	3.14E-01
Sy	Underground workings (Hazeldene and Liddell)	6.69E-02	2.85E-01
Kx (m/d)	Alluvium	7.48E+01	4.24E+02
Kx (m/d)	Regolith	7.28E-02	2.13E+00
Kx (m/d)	Interburden	3.75E-04	3.64E-03
Kx (m/d)	Pikes Gully Seam	5.66E-04	6.12E-02
Kx (m/d)	Liddell Seam	3.72E-02	9.54E-02
Kx (m/d)	Barrett Seam	5.12E-03	1.23E-01
Kx (m/d)	All other seams	6.63E-04	3.39E-02
Kx (m/d)	Underground workings (Pikes Gully)	4.82E+00	9.91E+01
Kx (m/d)	Underground workings (Hazeldene and Liddell)	2.51E+00	3.99E+02
Kz (m/d)	Alluvium	3.84E-02	1.13E+00
Kz (m/d)	Regolith	3.38E-03	3.39E-02
Kz (m/d)	Interburden	4.54E-05	9.86E-04
Kz (m/d)	Pikes Gully Seam	1.52E-05	1.89E-02
Kz (m/d)	Liddell Seam	4.87E-04	9.34E-03
Kz (m/d)	Barrett Seam	4.66E-04	8.96E-03
Kz (m/d)	All other seams	1.57E-04	9.68E-04
Kz (m/d)	Underground workings (Pikes Gully)	2.52E+00	4.14E+01
Kz (m/d)	Underground workings (Hazeldene and Liddell)	1.64E+00	8.56E+01
River Conductance (m^2/d)	Layer 1	1.36E-04	1.63E+05
Stream Conductance (m^2/d)	Bowmans Creek	4.43E+01	9.89E+02
GHB Conductance (m^2/d)	Across multiple layers	8.28E+02	4.53E+04
Recharge[1]	Alluvium	5.63%	16.21%
Recharge[1]	All other areas (zones 3-6)	0.003%	3.67%

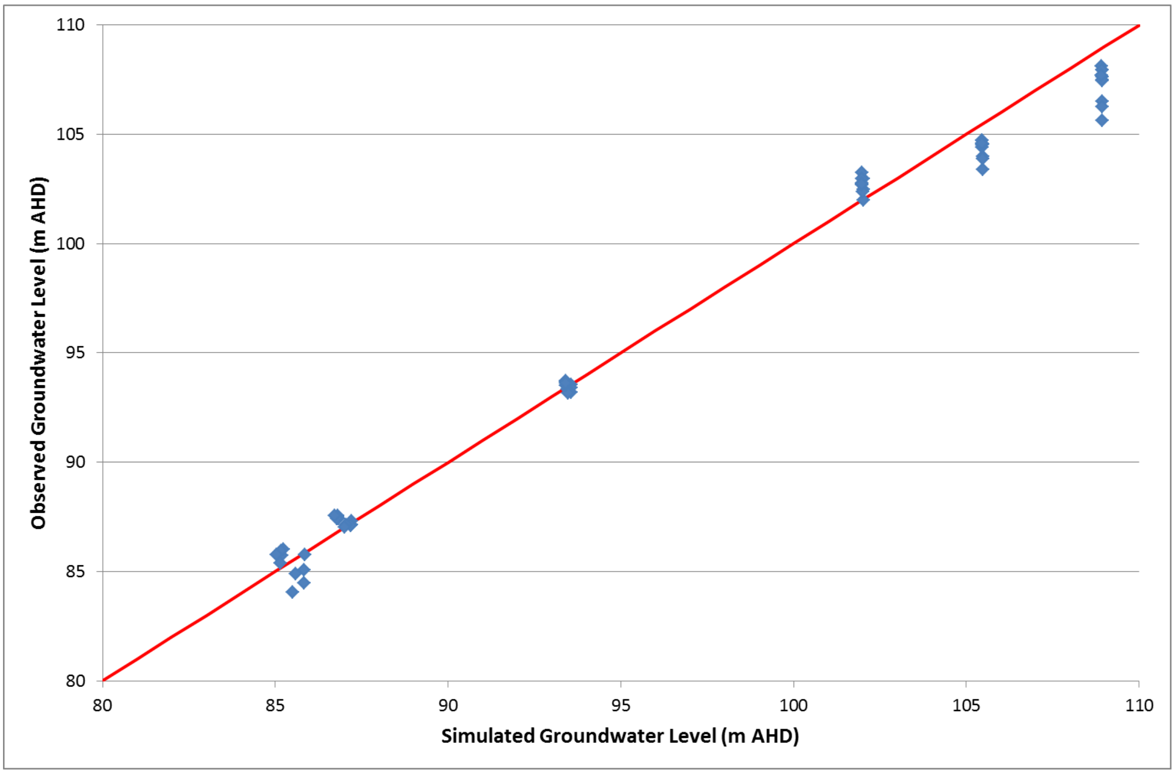
[1] Percent of annual rainfall (Station # 61086) equal to 645 mm/yr (www.bom.gov.au)

Table 4-4 provides a summary of statistical measures used to compare results from model simulations using the calibrated datasets with the observed data used as the calibration target (measured groundwater levels at Bowmans Creek alluvial bores; refer **Section 4.2**). A plot of the observed and simulated groundwater levels from one of the calibrated datasets is provided in **Figure 4-2**, and hydrographs of observed and simulated groundwater levels for the target calibration bores are presented in **Figure 4-3**. The simulated hydrographs shown in **Figure 4-3** are the 50th percentile of results from the five calibrated datasets, and error bars representing one standard deviation are included in the plot. The error bars cannot be discerned in the figure as the magnitude of the standard deviation for all bores is less than 0.1 m. The calibration statistics and figures show the simulated groundwater levels accurately replicate the observed data.

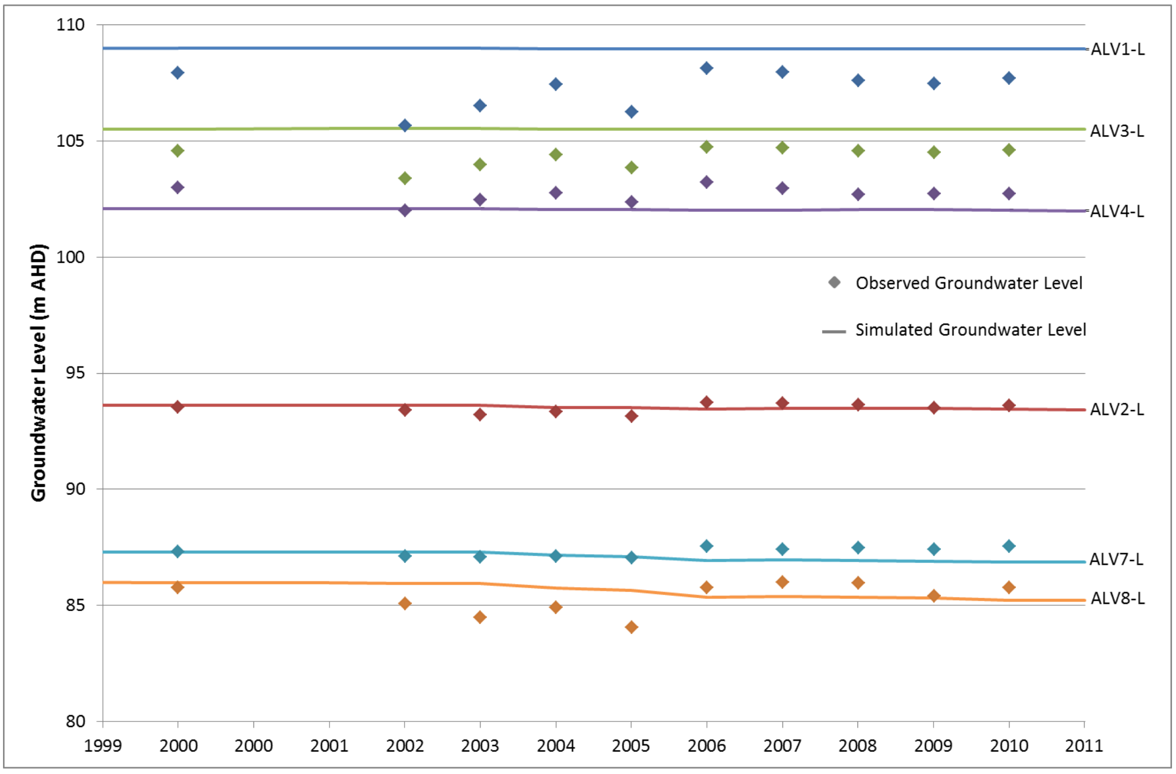
Table 4-4 – Summary of Calibration Statistics for Bowmans Creek Alluvium

Statistical Measure	Value Range
Residual Mean	0.4 – 0.5
Absolute Residual Mean	0.65 – 0.81
Residual Standard Deviation	0.77 – 0.98
Sum of Squares	46.6 – 66.7
RMS Error	0.88 – 1.05
Minimum Residual	-1.2 – -1.0
Maximum Residual	2.5 – 3.3
Number of Observations	60
Range in Observations	24.1
Scaled Standard Deviation	3.2% – 4.1%
Scaled Absolute Mean	2.7% – 3.4%
Scaled RMS	3.7% – 4.4%

- **Figure 4-2 – Observed vs Simulated Groundwater Levels for Bowmans Creek Alluvium**



- **Figure 4-3 – Observed vs Simulated Hydrographs for Bowmans Creek Alluvial Bores**



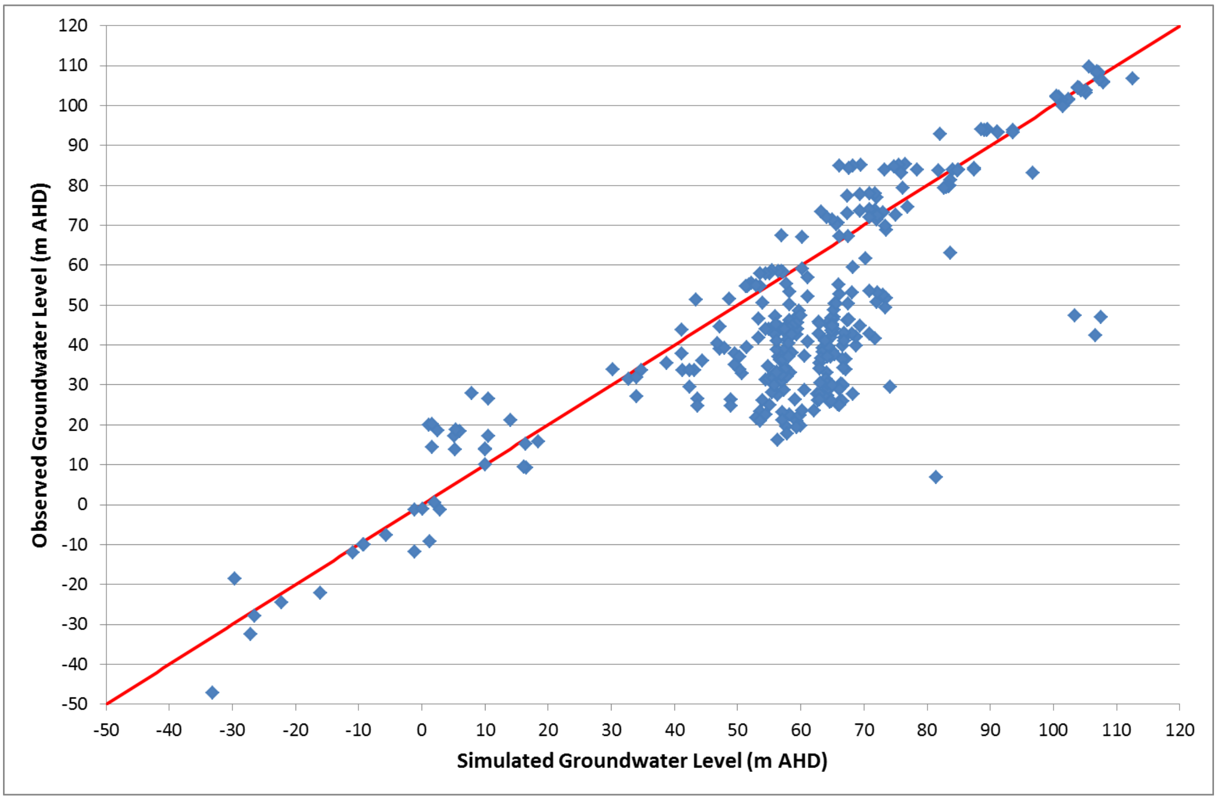
4.4 Calibration Statistics

In addition to comparing results of simulations using the calibrated datasets to measured groundwater levels at the Bowmans Creek alluvial bores, which were used as the calibration target data, groundwater data from other bores in the region, including those targeting the deeper hard rock aquifer, are available for comparison. **Table 4-5** provides a statistical summary of model results using the calibrated datasets relative to observed groundwater levels for other bores in the area, and **Figure 4-4** shows the observed versus simulated groundwater heads from one of the calibrated datasets. It is important to recognize that the measured groundwater levels used for the statistics in **Table 4-5** and shown in **Figure 4-4** were not used in the selection of calibration datasets, but are provided here as an indication of the model's ability to replicate groundwater levels and heads in other zones (both horizontally and vertically) within the model domain. Historical groundwater levels within the deeper hard rock aquifer, which includes the coal measures targeted by mining operations in the region, have been influenced by such mining activities and therefore result in greater disparity to the simulated data due to uncertainties and approximations in the model representation.

- **Table 4-5 – Summary of Calibration Statistics for Regional Bores**

Statistical Measure	Value Range
Residual Mean	10.4 – 29.3
Absolute Residual Mean	13.18 – 29.72
Residual Standard Deviation	15.42 – 27.7
Sum of Squares	1.37e+05 – 6.43e+05
RMS Error	18.61 – 40.3
Minimum Residual	-23.2 – -20.1
Maximum Residual	74.6 – 136
Number of Observations	396
Range in Observations	160.2
Scaled Standard Deviation	9.6% – 17.3%
Scaled Absolute Mean	8.2% – 18.6%
Scaled RMS	11.6% – 25.2%

▪ Figure 4-4 – Observed vs Simulated Groundwater Levels for Regional Bores



4.5 Sensitivity Analysis

Table 4-6 summarizes the range of values for model parameters within the calibrated datasets along with the percentage of the parameter range for all datasets that converged during the Monte Carlo simulations (794 datasets). These calibrated and converged parameter ranges are presented graphically in **Figure 4-5** through **Figure 4-8**. These figures and the percentage of the stochastic range provide an indication of the model's sensitivity to changes in the parameter values while also providing an indication of the parameter value's uncertainty. For the calibrated datasets model parameters with values that represent a lower percentage of the stochastic range indicate those parameters that will have a larger effect on the model predicted responses (i.e. the model is more sensitive to these parameters).

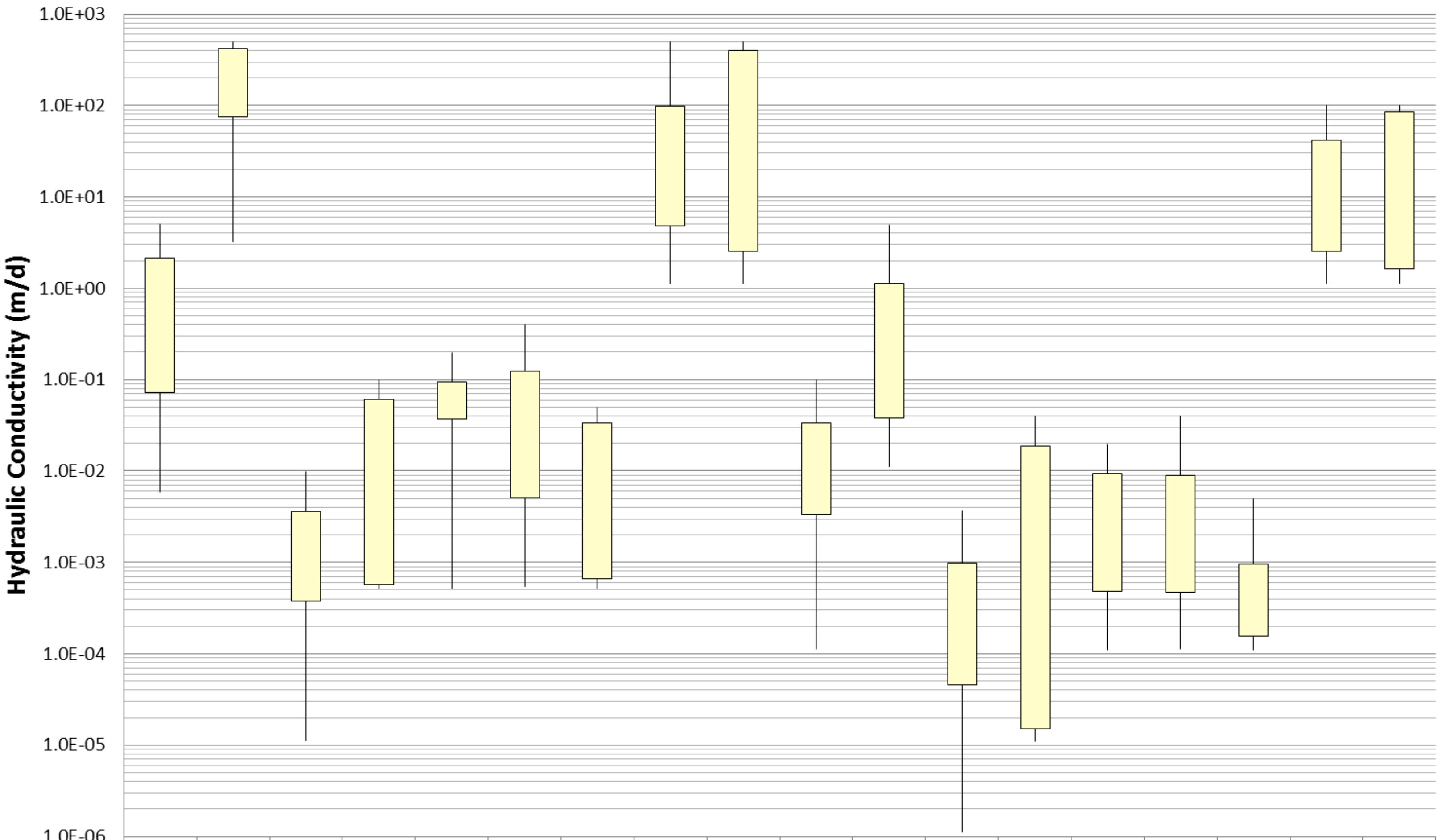
▪ Table 4-6 – Range of Model Parameter for Calibrated Datasets

Parameter	Geologic unit	Minimum	Maximum	% Stochastic Range
Sy	Alluvium	2.32E-02	1.73E-01	70%
Sy	Regolith	9.72E-03	8.22E-02	72%
Sy	Interburden	5.27E-03	4.98E-02	49%
Sy	Pikes Gully Seam	6.32E-04	4.65E-02	94%
Sy	Liddell Seam	8.53E-04	3.25E-02	79%

Parameter	Geologic unit	Minimum	Maximum	% Stochastic Range
Sy	Barrett Seam	5.48E-04	3.56E-02	91%
Sy	All other seams	8.31E-04	9.25E-03	53%
Sy	Underground workings (Pikes Gully)	5.26E-02	3.14E-01	78%
Sy	Underground workings (Hazeldene and Liddell)	6.69E-02	2.85E-01	64%
Kx (m/d)	Alluvium	7.48E+01	4.24E+02	35%
Kx (m/d)	Regolith	7.28E-02	2.13E+00	50%
Kx (m/d)	Interburden	3.75E-04	3.64E-03	34%
Kx (m/d)	Pikes Gully Seam	5.66E-04	6.12E-02	89%
Kx (m/d)	Liddell Seam	3.72E-02	9.54E-02	16%
Kx (m/d)	Barrett Seam	5.12E-03	1.23E-01	48%
Kx (m/d)	All other seams	6.63E-04	3.39E-02	86%
Kx (m/d)	Underground workings (Pikes Gully)	4.82E+00	9.91E+01	50%
Kx (m/d)	Underground workings (Hazeldene and Liddell)	2.51E+00	3.99E+02	83%
Kz (m/d)	Alluvium	3.84E-02	1.13E+00	56%
Kz (m/d)	Regolith	3.38E-03	3.39E-02	34%
Kz (m/d)	Interburden	4.54E-05	9.86E-04	38%
Kz (m/d)	Pikes Gully Seam	1.52E-05	1.89E-02	87%
Kz (m/d)	Liddell Seam	4.87E-04	9.34E-03	57%
Kz (m/d)	Barrett Seam	4.66E-04	8.96E-03	50%
Kz (m/d)	All other seams	1.57E-04	9.68E-04	48%
Kz (m/d)	Underground workings (Pikes Gully)	2.52E+00	4.14E+01	62%
Kz (m/d)	Underground workings (Hazeldene and Liddell)	1.64E+00	8.56E+01	88%
River Conductance (m^2/d)	Layer 1	1.36E-04	1.63E+05	92%
Stream Conductance (m^2/d)	Bowmans Creek	4.43E+01	9.89E+02	17%
GHB Conductance (m^2/d)	Across multiple layers	8.28E+02	4.53E+04	38%
Recharge[1]	Alluvium	5.63%	16.21%	20%
Recharge[1]	All other areas (zones 3-6)	0.003%	3.67%	72%

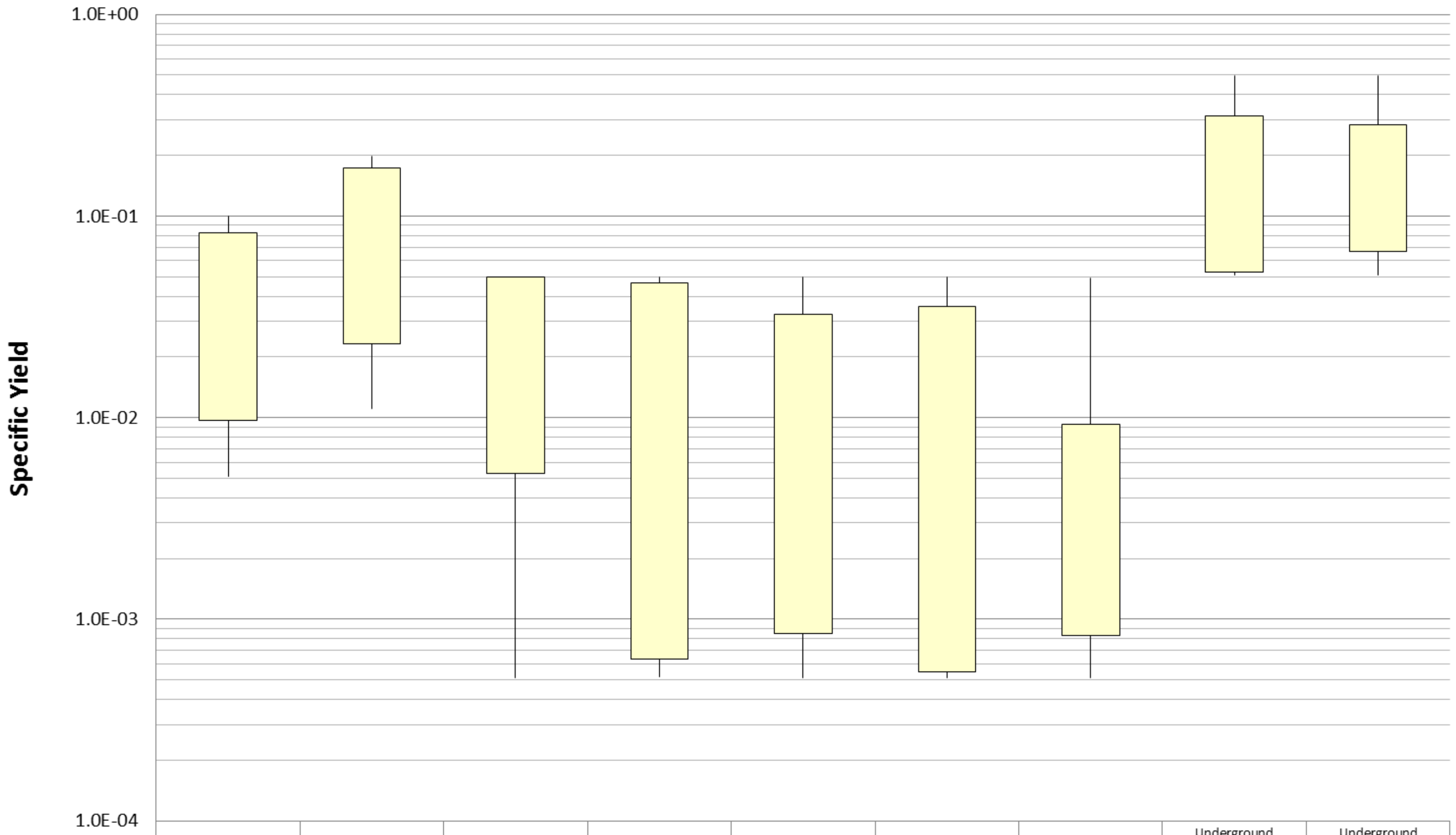
[1] Percent of annual rainfall (Station # 61086) equal to 645 mm/yr (www.bom.gov.au)

■ **Figure 4-5 – Model Parameter Sensitivity: Hydraulic Conductivities**



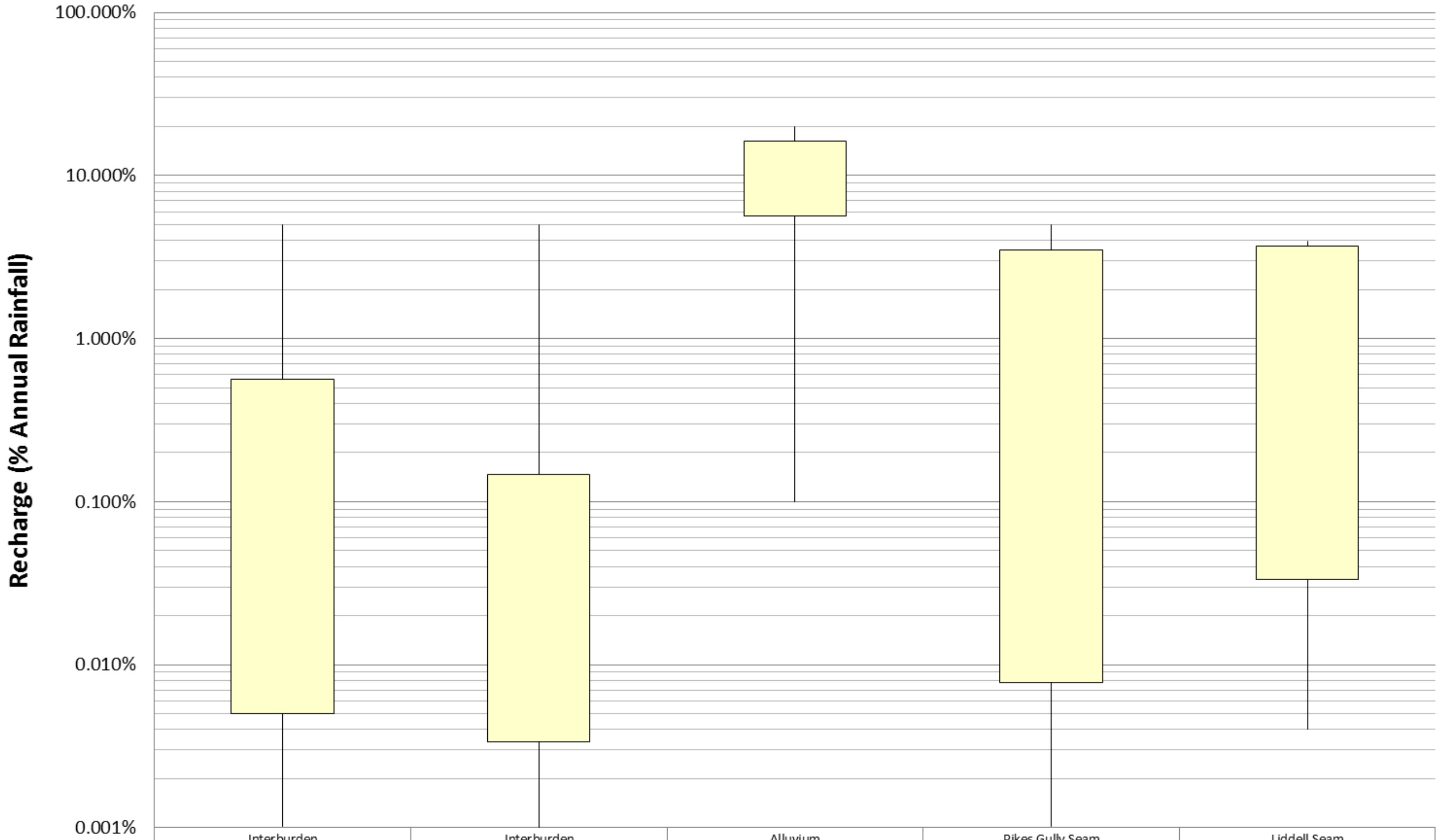
	Regolith (Kx)	Alluvium (Kx)	Interburden (Kx)	Pikes Gully Seam (Kx)	Liddell Seam (Kx)	Barrett Seam (Kx)	All other seams (Kx)	Underground workings (Kx)	Underground workings (Kx)	Regolith (Kz)	Alluvium (Kz)	Interburden (Kz)	Pikes Gully Seam (Kz)	Liddell Seam (Kz)	Barrett Seam (Kz)	All other seams (Kz)	Underground workings (Kz)	Underground workings (Kz)
Converged Maximum	5.0E+00	5.0E+02	9.9E-03	1.0E-01	2.0E-01	4.0E-01	5.0E-02	5.0E+02	5.0E+02	1.0E-01	5.0E+00	3.7E-03	4.0E-02	2.0E-02	4.0E-02	5.0E-03	1.0E+02	1.0E+02
Converged Minimum	5.8E-03	3.3E+00	1.1E-05	5.2E-04	5.2E-04	5.5E-04	5.1E-04	1.1E+00	1.1E+00	1.1E-04	1.1E-02	1.1E-06	1.1E-05	1.1E-04	1.1E-04	1.1E-04	1.1E+00	1.1E+00
Calibrated Maximum	2.13E+00	4.24E+02	3.64E-03	6.12E-02	9.54E-02	1.23E-01	3.39E-02	9.91E+01	3.99E+02	3.39E-02	1.13E+00	9.86E-04	1.89E-02	9.34E-03	8.96E-03	9.68E-04	4.14E+01	8.56E+01
Calibrated Minimum	7.28E-02	7.48E+01	3.75E-04	5.66E-04	3.72E-02	5.12E-03	6.63E-04	4.82E+00	2.51E+00	3.38E-03	3.84E-02	4.54E-05	1.52E-05	4.87E-04	4.66E-04	1.57E-04	2.52E+00	1.64E+00

▪ Figure 4-6 – Model Parameter Sensitivity: Specific Yield



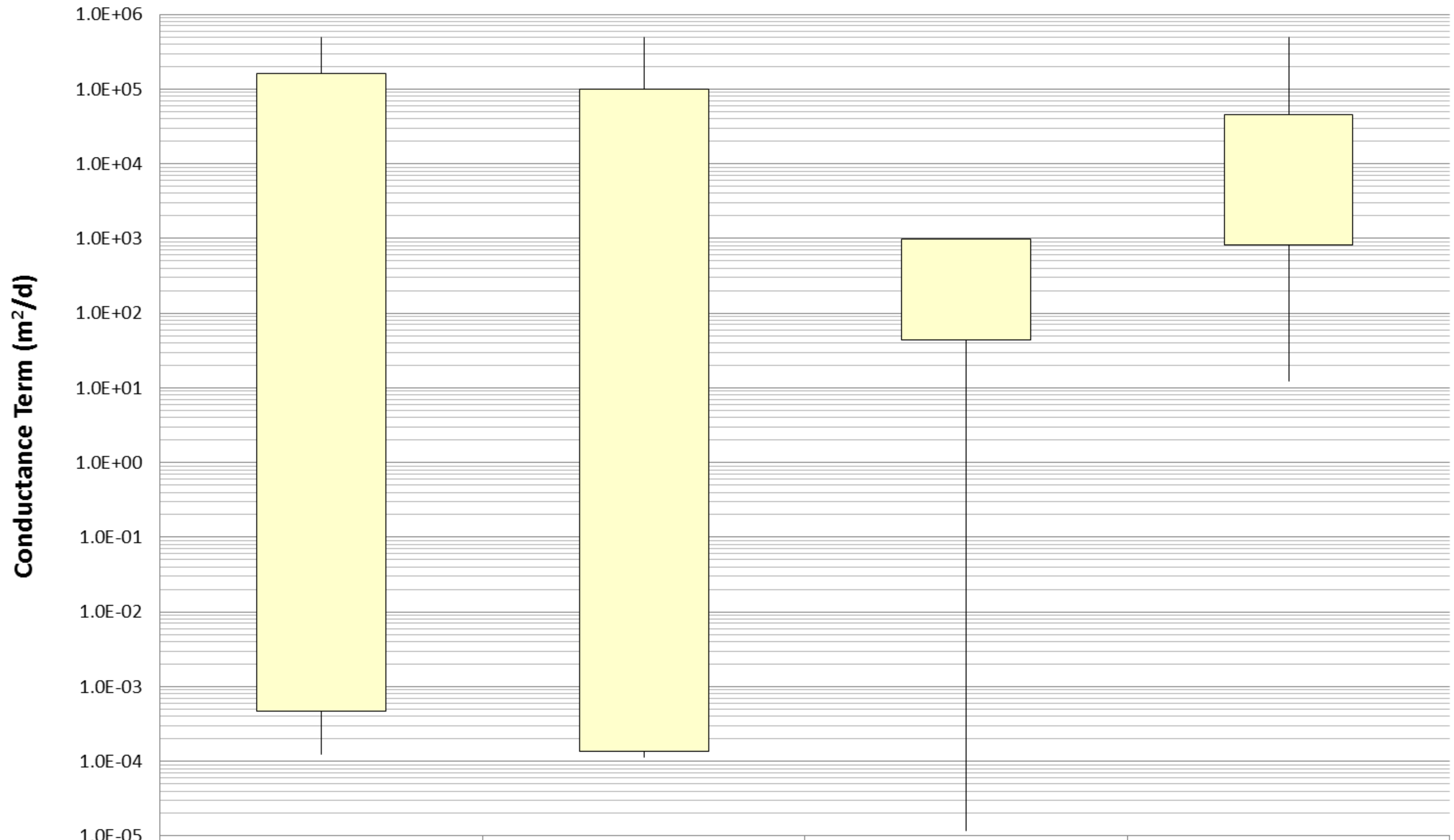
	Regolith	Alluvium	Interburden	Pikes Gully Seam	Liddell Seam	Barrett Seam	All other seams	Underground workings	Underground workings
Converged Maximum	1.0E-01	2.0E-01	5.0E-02	5.0E-02	5.0E-02	5.0E-02	4.9E-02	5.0E-01	5.0E-01
Converged Minimum	5.1E-03	1.1E-02	5.2E-04	5.2E-04	5.1E-04	5.2E-04	5.1E-04	5.1E-02	5.1E-02
Calibrated Maximum	8.22E-02	1.73E-01	4.98E-02	4.65E-02	3.25E-02	3.56E-02	9.25E-03	3.14E-01	2.85E-01
Calibrated Minimum	9.72E-03	2.32E-02	5.27E-03	6.32E-04	8.53E-04	5.48E-04	8.31E-04	5.26E-02	6.69E-02

- **Figure 4-7 – Model Parameter Sensitivity: Recharge**



	Interburden	Interburden	Alluvium	Pikes Gully Seam	Liddell Seam
Converged Maximum	5.00%	5.00%	19.95%	4.99%	3.96%
Converged Minimum	0.001%	0.001%	0.10%	0.001%	0.004%
Calibrated Maximum	0.56%	0.15%	16.21%	3.48%	3.67%
Calibrated Minimum	0.005%	0.003%	5.63%	0.008%	0.033%

- **Figure 4-8 – Model Parameter Sensitivity: Boundary Condition Conductance**



	River 1	River 2	Stream 1: Bowmans Creek	General Head Boundaries
Converged Maximum	5.0E+05	4.9E+05	9.9E+02	5.0E+05
Converged Minimum	1.2E-04	1.1E-04	1.2E-05	1.2E+01
Calibrated Maximum	1.63E+05	9.88E+04	9.89E+02	4.53E+04
Calibrated Minimum	4.71E-04	1.36E-04	4.43E+01	8.28E+02

5. Predictive Simulations

Following model calibration, the calibrated datasets are used to run predictive simulations of proposed mining activities and/or developments to investigate the potential impacts on local groundwater resources. The objectives of such predictive simulations are typically to estimate:

- Potential changes in groundwater flow and/or drawdown within specified aquifers resulting from the proposed mining activities and/or developments;
- The cumulative impacts of the proposed mining activities and/or developments within the context of regional mining operations;
- Pit inflows and dewatering requirements to accommodate mining activities; and
- Post mining equilibrium and the time period to reach equilibrium.

Predictive model simulations are specific to the proposed mining activities and/or developments for which the particular iteration of the model version is applied. Details of the predictive simulations are provided in the assessment reports (e.g. groundwater impact assessments) that utilize the regional scale model to evaluate the potential impacts of activities on local groundwater resources.

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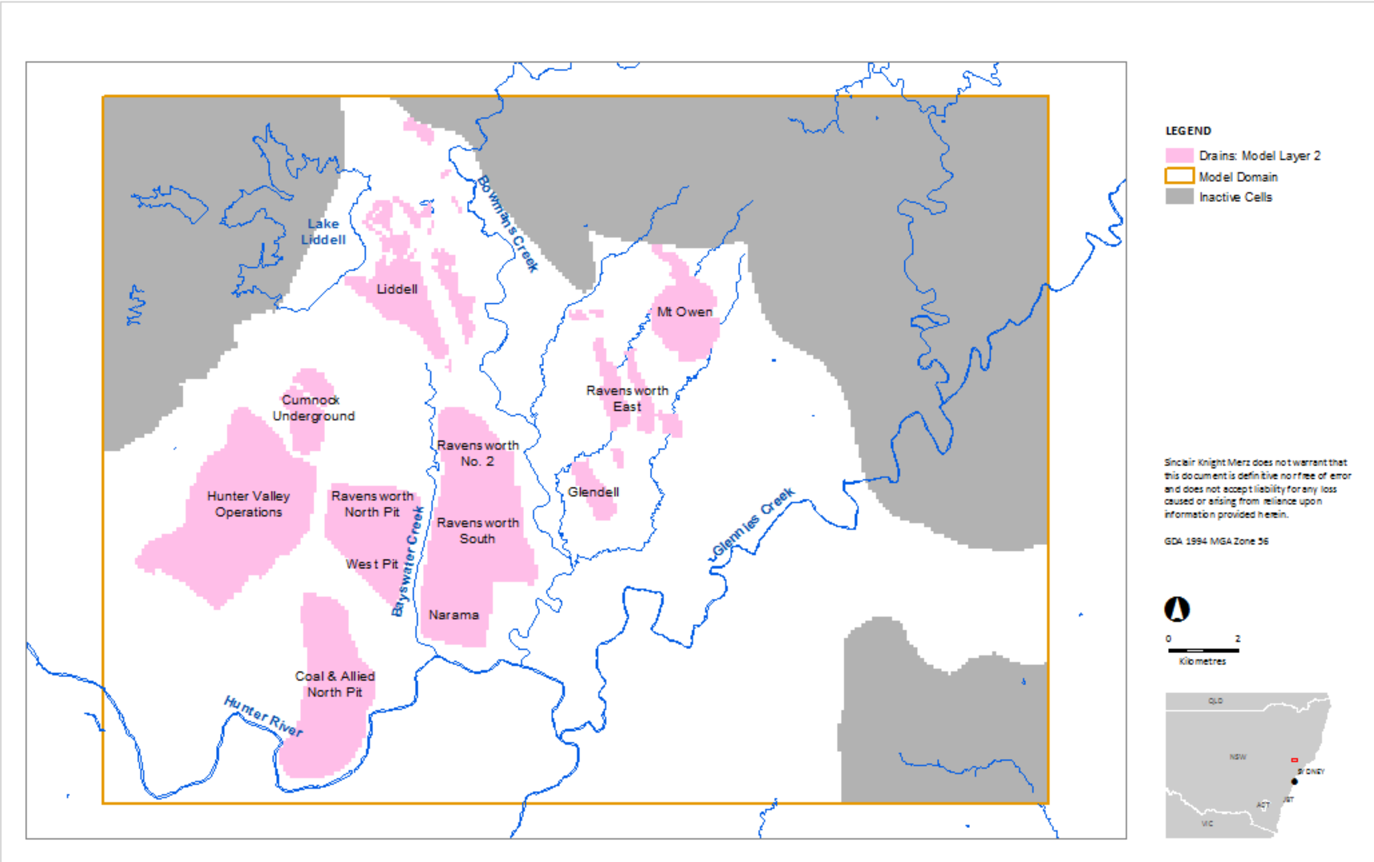
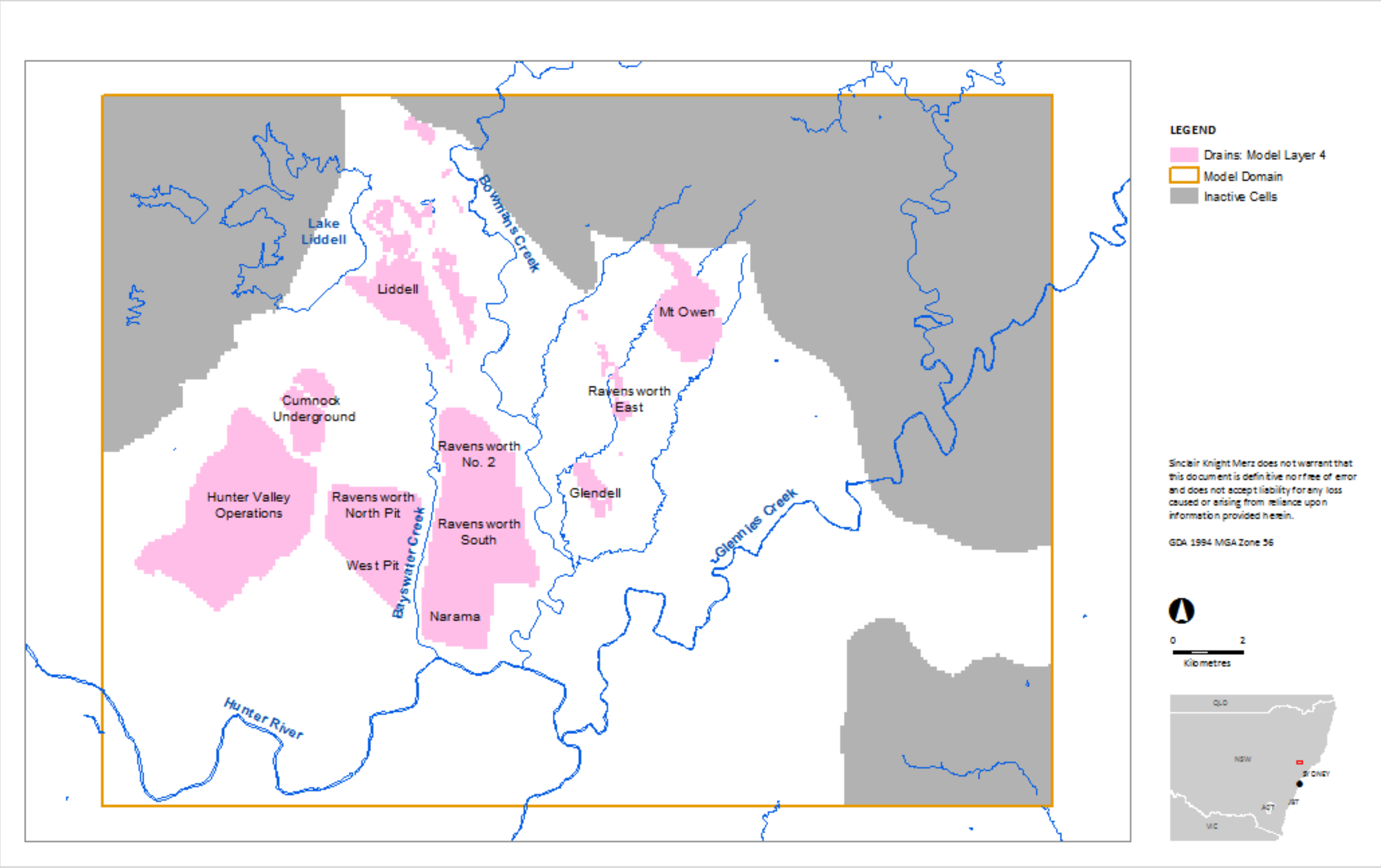
Appendix A Distribution of Model Drain Cells Representing Mining Operations

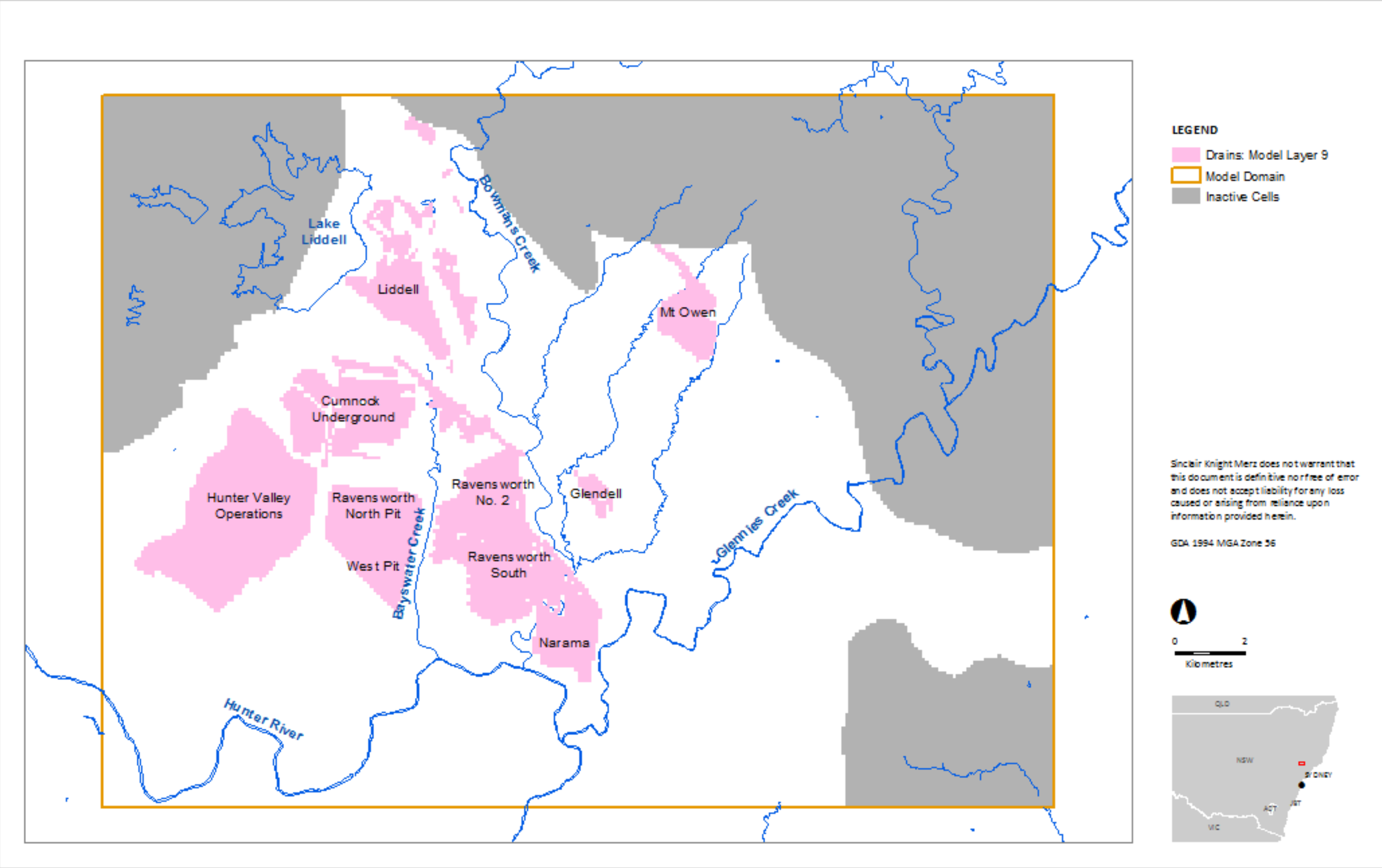
- **Figure A-1 – Model Drain Cells: Layer 2 (Alluvium / Regolith)**



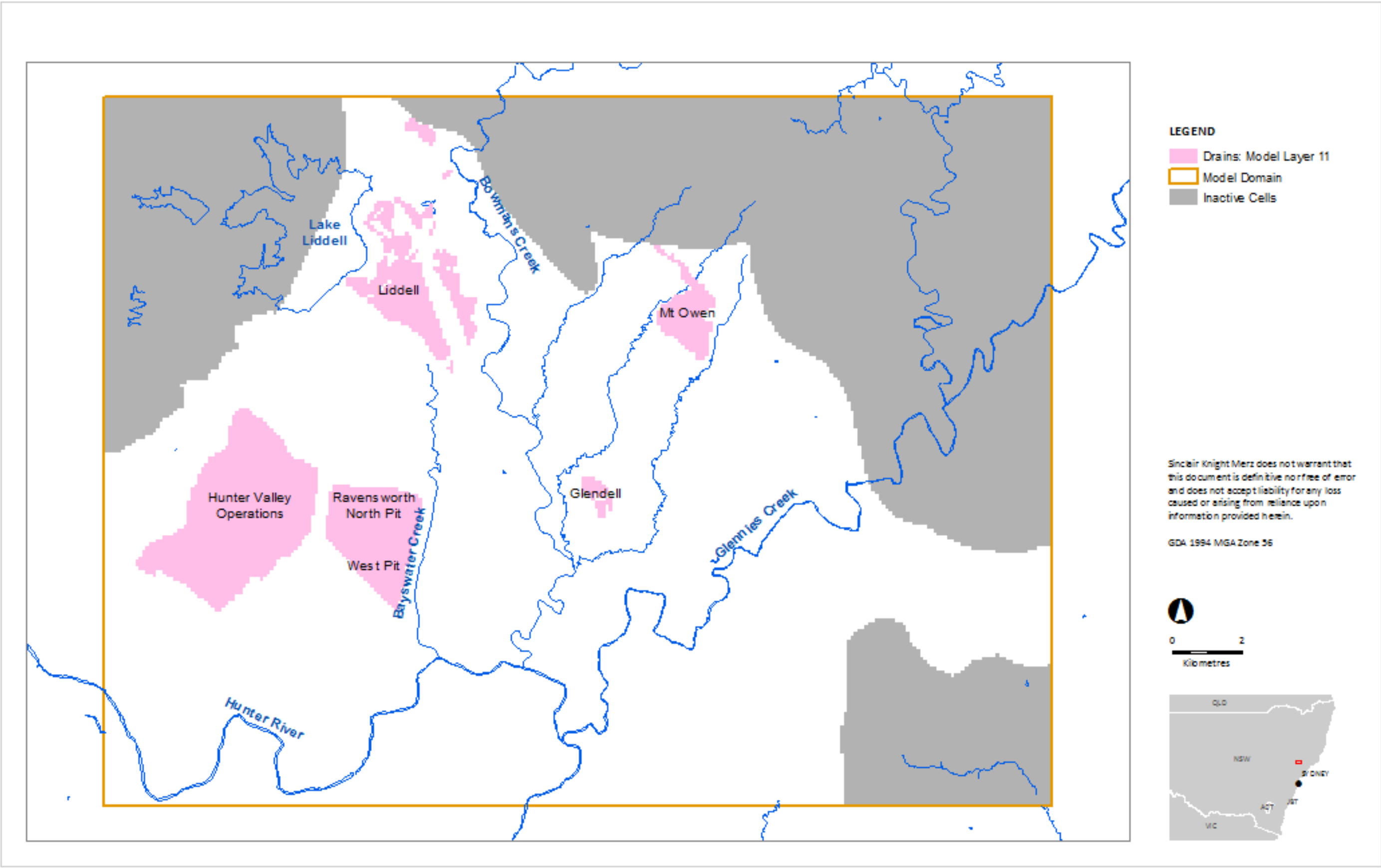
- **Figure A-2 – Model Drain Cells: Layer 4 (Bayswater Seam)**



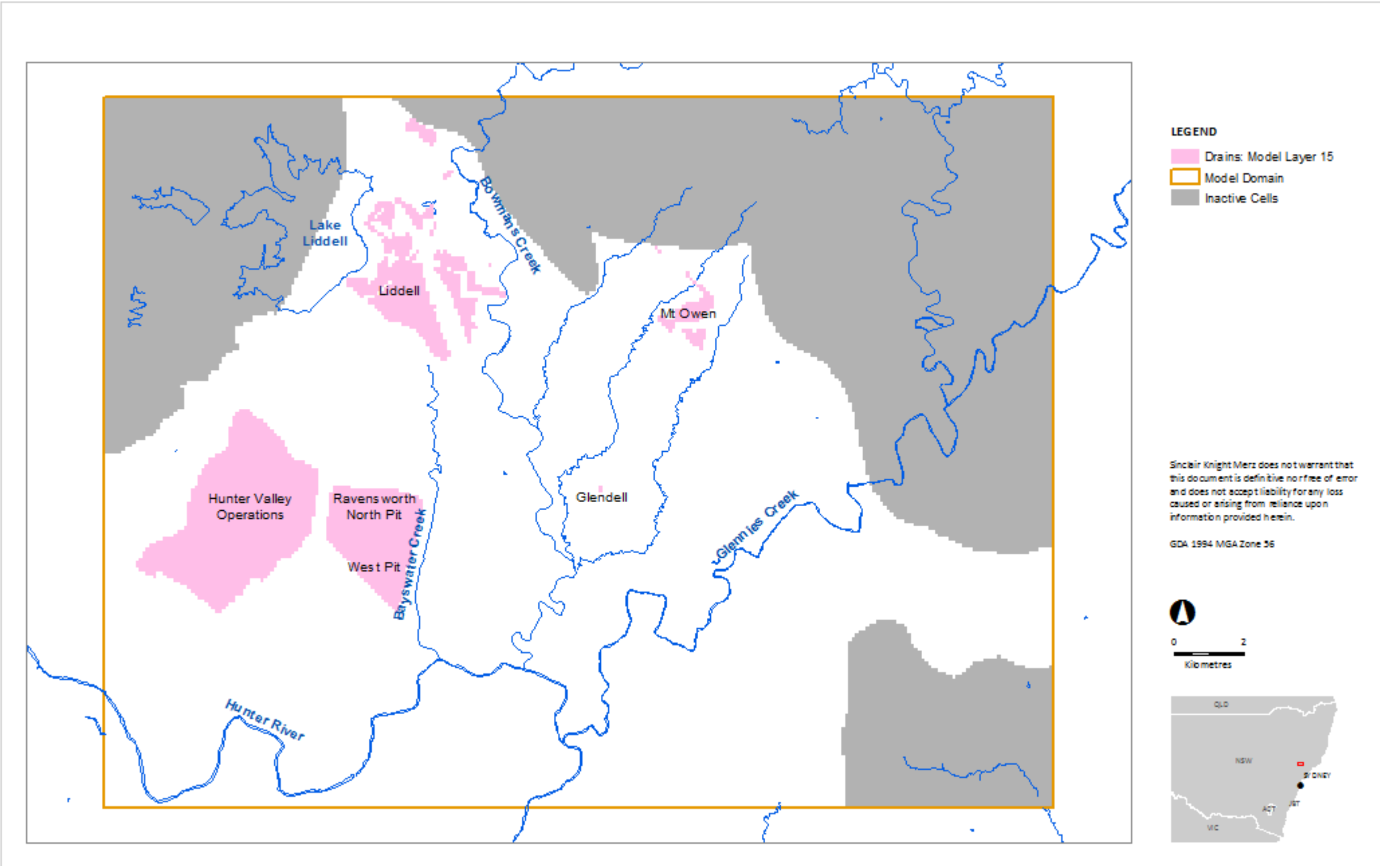
- **Figure A-3 – Model Drain Cells: Layer 9 (Middle and Lower Pikes Gully Seam)**



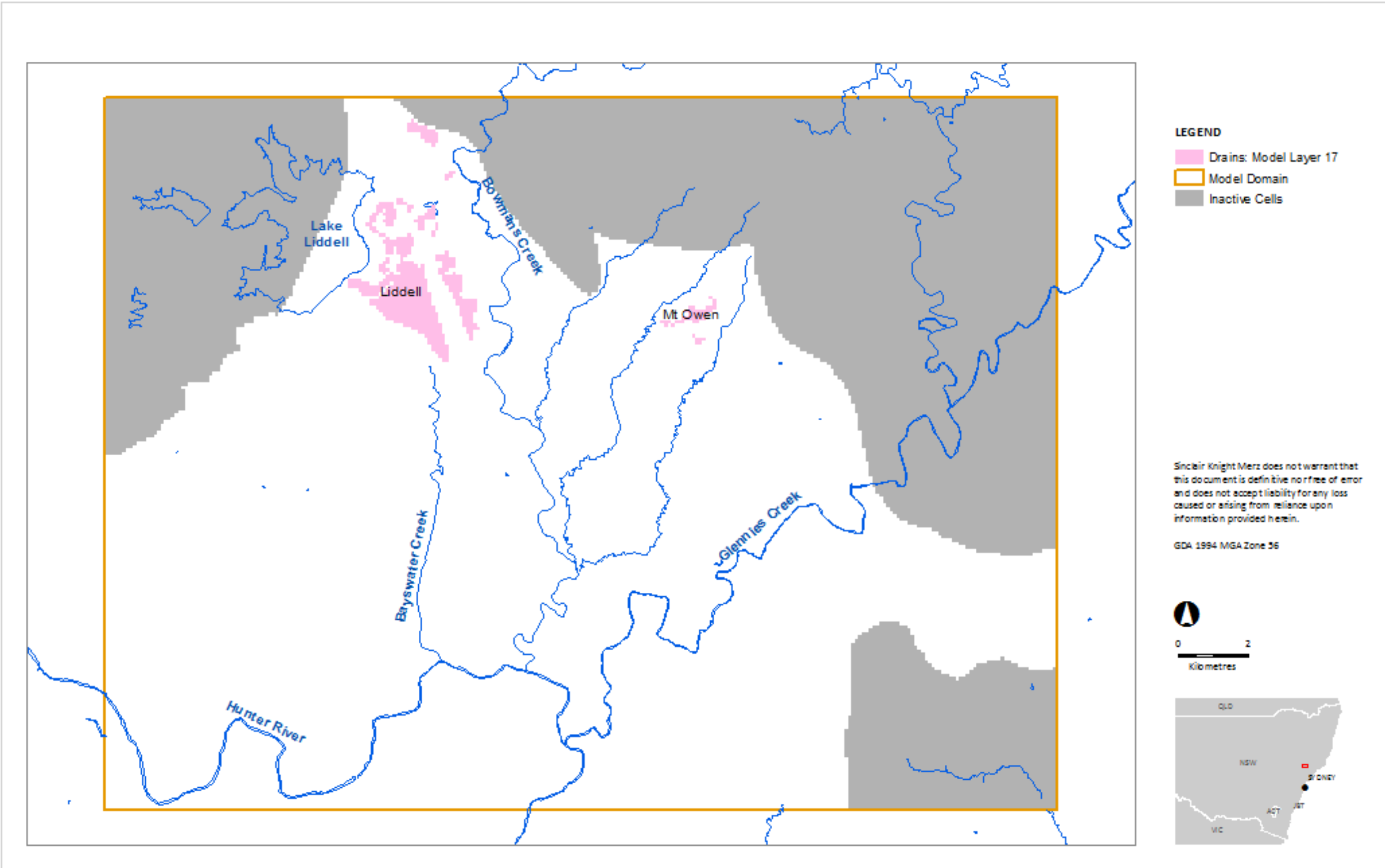
- **Figure A-4 – Model Drain Cells: Layer 11 (Arties Seam)**



- **Figure A-5 – Model Drain Cells: Layer 15 (Liddell Seam Section D)**



- **Figure A-6 – Model Drain Cells: Layer 17 (Barrett Seam)**



- **Figure A-7 – Model Drain Cells: Layer 19 (Hebden Seam)**