APPENDIX 10

Groundwater Impact Assessment

Mount Owen Continued Operations Project

UMWELT (AUSTRALIA) P/L FOR MOUNT OWEN P/L

Groundwater Impact Assessment

Revision D | Final - post-peer review

3109H

29 October 2014

Mount Owen Continued Operations Project

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Document history and status

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Mount Owen Continued Operations Project

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Executive Summary

Key messages

- A groundwater impact assessment has been carried out to evaluate the potential impacts to groundwater and its users from the proposed Mount Owen Continued Operations Project (the Project). Particular emphasis is placed on potential impacts to alluvial aquifer systems and to the minimal impact criteria specified in the NSW Aquifer Interference Policy (2012). A regional-scale numerical groundwater model was developed to allow assessment of cumulative as well as project-specific impacts on groundwater systems and to provide quantitative estimates of potential impacts to alluvial and hard rock aquifers.
- The groundwater modelling and impact assessment indicates that the Project will cause negligible impacts to the alluvial aquifers associated with Glennies Creek and Bowmans Creek.
- Estimated reductions in groundwater flow to alluvial aquifers associated with minor tributaries of Glennies Creek and Bowmans Creek as a result of the Project are less than 15 and six ML/year, respectively. Mount Owen Pty Limited (Mount Owen) currently holds sufficient licence allocations for the relevant water sources (Glennies and Jerrys, respectively) to accommodate the maximum predicted water take. The predicted reductions in groundwater input to these systems amount to less than 0.2% of current estimated baseflow contributions, and assessment of local stream flow conditions indicates that this amount will not result in a significant change to current surface water flow regimes.
- No groundwater dependent ecosystems will be impacted and there are no expected impacts to water quality in the alluvial aquifers.
- Drawdown of water tables in alluvial aquifers associated with minor tributaries of Glennies Creek and Bowmans Creek are predicted to locally exceed two metres. This triggered further assessment under the NSW Aquifer Interference Policy (2012). The predicted drawdown occurs within alluvium associated with Main Creek and Bettys Creek and is localised to small areas of the estimated alluvial extents. Further assessment indicates that the predicted drawdown does not impact on the long-term viability of any water-dependent asset.
- Dewatering requirements to enable safe mining operation are predicted to induce up to 165 metres drawdown in hydraulic pressure in the hard rock aquifer by the end of mining. The extent of this drawdown is entirely contained within the Project area and will not impact on neighbouring mining operations. Predicted impacts to the hard rock aquifer are unlikely to adversely affect groundwater quality. There are no groundwater users affected by these drawdowns.
- Estimates of groundwater extraction rates required to accommodate the Project are generally less than 500 ML/year, with a broad peak from 2022 through 2026 up to 750 ML/year. Mount Owen currently holds sufficient licences under Part 5 of the *Water Act 1912* to extract up to 1,160 ML/year groundwater from the regional hard rock aquifer and hence satisfies licensing criteria.
- Post-mining groundwater levels are predicted to return to levels equal to or above pre-approval levels. The final voids will not discharge to local alluvial aquifers, with the final voids at North Pit and the Ravensworth East Resource Recovery (RERR) Mining Area acting as long-term sinks for groundwater and the Bayswater North Pit (BNP) void predicted to be a source of water to the local hard rock aquifer. The BNP final void is predicted to discharge higher quality water than is currently observed in these aquifers and ultimately be a source of water to the RERR final void.

Background

Mount Owen Pty Ltd (Mount Owen) is seeking development consent to continue open cut mining operations at Mount Owen and Ravensworth East mines by extending mining of the North Pit to the south of the currently approved mining footprint and to undertake mining operations within the Bayswater North Pit (BNP), sequentially followed by mining of the Ravensworth East Resource Recovery (RERR) area. The Project will allow extraction of an additional 74 million tonnes (Mt) of run of mine (ROM) coal beyond currently approved operations at the North Pit and would extend the life of the mine to approximately 2030 (an additional 12 years beyond the current approved mining limit, currently expected to be completed in 2018), and an additional 18 Mt from Ravensworth East Mine.

Mount Owen is required to submit an Environmental Impact Statement (EIS) in support of its application for project approval under Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act). The EIS is intended to address the NSW Department of Planning and Environment (DP&E) Director-General's Requirements (DGRs) for the Project. The purpose of this Groundwater Impact Assessment report is to address the DGRs and specific issues outlined by other relevant government agencies for the assessment of potential impacts of the Project on local groundwater and connected surface water resources.

The methodology for the assessment is based on a framework that recognises 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 to such impacts. Risks or threats emerge from exposure pathways (where they exist) and adverse responses of receptors to potential direct impacts on groundwater systems. Accordingly, the impact assessment is presented within the following structure:

- Describe the *Context and Setting* of the operation (**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 scale numerical groundwater model was developed and interrogated to predict and evaluate potential impacts of the Project on local and regional groundwater resources (refer **Section** 3). Specifically, the model was used to determine the potential impacts to the shallow, alluvial Glennies and Jerrys Water Sources and the deeper, hard rock aquifers. Management of the shallow sources is governed under the NSW *Water Management Act (2000)* through Water Sharing Plans (WSP) for the *Hunter Regulated River Water Source* (2003) and the *Hunter Unregulated and Alluvial Water Sources* (2009), respectively. The deeper, hard rock aquifers are governed through licencing under the NSW *Water Act (1912).*

Assessment conclusions

Results of predictive model simulations and groundwater impacts assessment provide the following key conclusions:

- Predicted reductions in groundwater flow to the alluvial aquifers associated with Glennies Creek and Bowmans Creek are negligible (i.e. less than 1 ML/year) as a result of the Project. Predicted reductions in groundwater flows to the alluvial aquifers associated with their tributaries (Main Creek and Bettys Creek, respectively) are also minimal. The peak predicted water take from the Main Creek alluvium is less than 15 ML/year (from 2023). Predicted peak water take from the Bettys Creek alluvium is less than 6 ML/year (from 2022). Mount Owen currently holds sufficient water licence allocations under the applicable WSP for each water source to accommodate these maximum predicted water takes. The estimated reductions in groundwater flow to the alluvial aquifers represent less than 0.2 percent of estimated baseflow contributions to these surface water features.

- Negligible drawdown is predicted in the alluvial aquifers associated with Glennies Creek and Bowmans Creek as a result of the Project.

- Drawdown in alluvial aquifers associated with Main Creek and Bettys Creek, minor tributaries to Glennies Creek and Bowmans Creek respectively, is predicted to exceed the minimal impact criteria (greater than 2 m drawdown) for aquifer interference activities as specified in the NSW Aquifer Interference Policy (AIP – NSW, 2012). Further assessment requirements undertaken in accordance with the AIP (refer **Section 4.4**) were carried out and indicate the significance of these alluvial aquifers is limited, with both creeks having low volume, ephemeral surface water flow, and they largely act as drainage courses for local runoff. The assessment indicates no groundwater-dependent assets (i.e. groundwater users or environmental requirements) are impacted by the predicted drawdown.

- Estimates of groundwater extraction rates from the regional hard rock aquifer required to accommodate the Project are generally less than 500 ML/year, with a broad peak from 2022 through 2026 up to 750 ML/year. Mount Owen currently holds sufficient licences under Part 5 of the *Water Act 1912* to extract up to 1,160 ML/year from the regional hard rock aquifer.

- Post-mining, equilibrium simulations predict that the North Pit and RERR final voids will act as long-term groundwater sinks, while the BNP final void will act as a groundwater sink until the water level in that pit exceeds 37 m AHD, above which point water movement will be back into the hard rock aquifers and would flow through to emerge as inflow at RERR. It should be noted that the water quality in the receiving aquifers is poor and there are no groundwater users between the BNP and RERR Mining Area.

Assessments

Table ES-1-1 summarises the groundwater impact assessment for the Project, which focuses on the impacts of the Project on local and regional groundwater systems and receptors.

Table ES-1-1 – Assessment of Impacts to Groundwater Receptors

Potential Receptor	Direct Impact	Discussion
Alluvial aquifers associated with Glennies Creek, Bowmans Creek and their tributaries (including groundwater	Groundwater quantity	• Model simulations predict negligible reductions in groundwater flows and negligible drawdown in the Glennies Creek and Bowmans Creek alluvial aquifers as a result of the Project. • Estimated groundwater losses to Main Creek as a result of the Project are predicted to peak up to 15 ML/year between 2026 and 2030. Mount Owen currently holds sufficient licence allocations under the Hunter Regulated River WSP (2003) to accommodate the maximum predicted water take from the Glennies Creek alluvial aquifer as a result of the Project. Specifically, Mount Owen holds 1,000 unit shares with High Security licence, 192 unit shares with General Security and 9 unit shares for stock and domestic purposes for the Glennies Creek Source. • Predicted median groundwater losses for the Bettys Creek alluvial aquifer as a

Potential Receptor	Direct Impact	Discussion
dependent ecosystems)		result of the Project are less than 6 ML/year. Mount Owen currently holds licences under the Hunter Unregulated and Alluvial Water Sources WSP (2009) to extract up to 200 unit shares per year from the Jerrys Water Source. • Estimated drawdowns in the Main Creek and Bettys Creek alluvial aquifers as a result of the Project are predicted to locally exceed the minimal impact criteria for aquifer interference activities as specified in the AIP. The minor tributaries potentially affected are considered of limited significance due to low flow volumes and ephemeral conditions, and the limited extent, depth and condition of the alluvium within these tributaries. Further field assessment of the potential impacts of the predicted drawdown does not indicate the presence of any water-dependent asset, or user, as defined in the AIP.
	Groundwater quality	• Potential impacts to groundwater quality in alluvial aquifers are estimated to be limited as a result of the Project. • Post-mining equilibrium simulations undertaken by Umwelt (2014) predict the North Pit and RERR final voids will act as groundwater sinks. The Bayswater North void will ultimately act as a source, but will not discharge to the alluvial aquifers and adversely impact groundwater quality. Rather, it will discharge to the hard rock aquifer and thence to the RERR void.
	Surface Water – Groundwater Interaction	• Model simulations predict negligible reductions in groundwater flows and negligible drawdown in the Glennies Creek and Bowmans Creek alluvial aquifers as a result of the Project. • Estimated reductions in groundwater flow to the Main Creek alluvial aquifer, a minor tributary of Glennies Creek, represent less than 0.3% of estimated baseflow contributions to Glennies Creek. Predicted groundwater losses to the Bettys Creek alluvial aquifer, a minor tributary of Bowmans Creek, account for less than 0.2% of estimated baseflow to Bowmans Creek. • Main Creek and Bettys Creek are ephemeral surface water features that largely act as drainage courses for the local area. These ephemeral streams do not support high value aquatic ecosystems or riparian vegetation. The predicted leakage and resulting drawdown within these features is therefore unlikely to have a significant impact on surface water-groundwater interactions along Main Creek and Bettys Creek.
	Aquifer Impact	• The Project does not include modifications or works that will physically intercept alluvial aquifer systems. The continuation of the North Pit shell is never closer than 450 m from Main Creek and will not impact directly on its alluvial aquifer.
Neighbouring mining operations	Groundwater quantity	• Predicted depressurisation within the regional hard rock aquifer reaches a maximum of approximately 165 metres drawdown in the Bayswater seam at the end of mining (2030). Depressurisation of the regional hard rock aquifer caused by the Project is not predicted to adversely impact neighbouring mining operations.
	Groundwater quality	• Monitoring data collected as part of current mining operations at Mount Owen Complex indicate minimal impacts to groundwater quality of the regional hard rock aquifer. Predicted changes to groundwater flows and depressurisations as a result of the Project are unlikely to cause impacts to groundwater quality that would affect neighbouring mining operations.
	Surface Water – Groundwater	• Model predictions indicate the Project would have negligible impact on streamflow in Glennies Creek and Bowmans Creek, and their ephemeral tributaries Main Creek and Bettys Creek, respectively.

Potential Receptor	Direct Impact	Discussion
	Interaction	
	Aquifer Impact	• The proposed North Pit Continuation intercepts additional portions of the regional hard rock aquifer that contain the target coal reserves. 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 Project is not expected to adversely impact neighbouring mining operations.

Table ES-1-2 summarizes the assessment of the project within the context of relevant legislation and policies, namely the NSW *Water Management Act 2000,* NSW *Water Act 1912* and NSW Aquifer Interference Policy (2012).

Table ES-1-2 – Summary Regulatory Framework Assessment

Legislation / Policy	Requirement	Assessment
Water Management Act 2000 And *Water Act 1912*	Water Licences	• The peak median predicted water take from Main Creek is 15 ML/year. Mount Owen currently holds licence allocations under the Hunter Regulated River WSP (2003) totalling 1,000 unit shares of high security water, 192 unit shares of general security water and 9 unit shares of stock and domestic water. Such allocations are sufficient to accommodate the maximum predicted water take from the Glennies Creek alluvial aquifer, to which Main Creek and its alluvial aquifer is connected. • The maximum predicted water take from Bettys Creek as a result of the Project is 6 ML/year. Mount Owen currently holds licences to extract up to 200 unit shares per year from the Jerrys Water Source under the Hunter Unregulated and Alluvial WSP (2009), which includes the alluvial aquifers of Bowmans Creek and its tributaries. • Estimates of groundwater extraction rates required to accommodate the Project are generally less than 500 ML/year, with a broad peak from 2022 through 2026 up to 750 ML/year. • Mount Owen currently holds sufficient licences under Part 5 of the *Water Act 1912* to extract up to 1,160 ML/year groundwater from the regional hard rock aquifer.
NSW Aquifer Interference Policy (2012)	Level 2 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 any predicted water table variations. • Model simulations predict negligible drawdown within the Glennies Creek and Bowmans Creek alluvial aquifers. • Model simulations predict drawdown within the Main Creek and Bettys Creek alluvial aquifers greater than 2 metres. This exceeds the minimal impact criteria specified in the AIP, however further assessment in accordance with the Policy indicates the impacts would not adversely impact or prevent the long-term viability of any water-dependent asset. • The areal extent of predicted drawdown is localised to small reaches of Main Creek and Bettys Creek. No registered bores are located within the extent of predicted drawdown for either creek. Only monitoring bore NPZ3, which is part of the Mount Owen Complex groundwater monitoring network, is located within the extent of predicted drawdown. No groundwater users or water supply works are identified within the predicted extent of drawdown.

Legislation / Policy	Requirement	Assessment
		Water Pressure • Post-mining equilibrium simulations indicate groundwater levels within the Main Creek and Bettys Creek alluvial aquifers rapidly recover to levels equal to, or above, observed levels at the introduction of the WSPs. For Main Creek, the Hunter Regulated River WSP commenced in July 2004, and for Bettys Creek the Hunter Unregulated and Alluvial WSP commenced in August 2009. *Water Quality* • Model simulations provide no indication that the Project will alter the hydrogeologic regime in a manner that would adversely affect groundwater quality within the Main Creek and Bettys Creek alluvial aquifers.
	Level 2 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 predicted water table variations. • No water supply works have been identified within the zone of depressurisation predicted by the 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, the water balance assessment (Umwelt, 2014) predicts salinity in the North Pit final void will increase continuously over time, resulting in the potential for long term impacts to groundwater quality in the hard rock aquifer due to discharge of increasing salinity water to the surrounding aquifer. However, salinity modelling indicates that adverse impacts to the surrounding aquifer, which would occur when salinity levels in the final void are greater than the salinity of groundwater in the surrounding hard rock aquifer, are unlikely to occur for at least 200 years after the end of mining.

Proposed Management Strategy

An adaptive management approach is proposed for the monitoring and (if necessary) mitigation of any potentially unacceptable impacts to the Glennies Creek and Bowmans Creek alluvial aquifer systems. Based on the numerical model results and this groundwater impact assessment, key aspects of the proposed management strategy should include:

- Review, update and implement the existing groundwater monitoring plan for the Mount Owen Complex to include the additional monitoring locations installed from 2012 to 2014;
- Continued refinement and revalidatation of the groundwater model with additional monitoring data;
- If and where necessary, adjustment of mining and/or dewatering plans to mitigate unacceptable actual or predicted impacts on alluvial systems.

Based on the current level of knowledge and the results from predictive modelling of potential groundwater impacts, no actual mitigation for groundwater is deemed likely.

Important note about this report

The sole purpose of this report and the associated services performed by Jacobs is to provide a Groundwater Impact Assessment in accordance with the scope of services set out in the contract between Jacobs and the Client (Umwelt (Australia) Pty Limited *for* Mount Owen Pty Limited). That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

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1. Introduction

1.1 Background

Jacobs (*formerly* Sinclair Knight Merz Pty Ltd (SKM)) has been engaged by Umwelt (Australia) Pty Ltd (Umwelt), on behalf of Mount Owen Pty Ltd (Mount Owen), to carry out a Groundwater Impact Assessment for the Mount Owen Continued Operations Project.

The Mount Owen Complex is located within the Hunter Coalfields in the Upper Hunter Valley of New South Wales (NSW), approximately 20 kilometres north-west of Singleton, 24 kilometres south-east of Muswellbrook and to the north of Camberwell village (refer to **Figure 1-1**).

Mount Owen Pty Limited (Mount Owen), a subsidiary of Glencore Coal Pty Limited (formerly Xstrata Coal Pty Limited (Xstrata)) currently owns the three open cut operations in the Mount Owen Complex, Mount Owen (North Pit), Ravensworth East (West Pit and Bayswater North Pit (BNP)) and Glendell (Barrett Pit). The mining operations at the Mount Owen Complex include the integrated use of the Mount Owen coal handling and preparation plant (CHPP), coal stockpiles and the rail load-out facility.

The North Pit has an approved production rate of 10 million tonnes per annum (Mtpa) of run of mine (ROM) coal, and blended with Ravensworth East (4 Mtpa) and Glendell (4.5 Mtpa) ROM coal, feed the Mount Owen CHPP and associated infrastructure which has a total approved processing capacity of 17 Mtpa of ROM coal. Processed coal, both semi-soft and thermal coals, is transported via the Main Northern Rail Line to Port of Newcastle for export, or by rail or conveyor for domestic use.

Mount Owen expect, subject to market conditions, that mining will be completed within the currently approved area of the North Pit and the West Pit by 2018 and late 2014 respectively, and Glendell by 2022. Over the last few years, Mount Owen has been reviewing plans for the future of the Mount Owen and Ravensworth East Mines. Mount Owen has undertaken extensive exploration of its mining tenements as part of these plans and identified substantial additional mineable coal to the south of the currently approved North Pit and within an area currently approved for mining in the northern portion of the Ravensworth East Mine, referred to as the Bayswater North Pit (BNP). The previously identified Ravensworth East Resource Recovery (RERR) Mining Area is located immediately east of the West Pit and is now proposed to be mined sequentially after mining has been completed in the BNP, commencing in approximately 2022.

Mount Owen is seeking development consent for the Mount Owen Continued Operations Project (the Project) to extract this additional mineable coal through continued open cut mining methods. The Project proposes to continue the existing mining operations within the North Pit to the south beyond the current approved North Pit mining limit (the North Pit Continuation) and to undertake mining operations within the BNP, sequentially followed by RERR (refer to **Figure 1-2**).

The Project design has considered issues raised during extensive stakeholder consultation and outcomes of iterative impact assessment studies resulting in a Project design that reduces potential environment and community impacts. The Project avoids disturbance of Ravensworth State Forest and existing Offset Areas whilst maximising the use of existing disturbance areas and infrastructure.

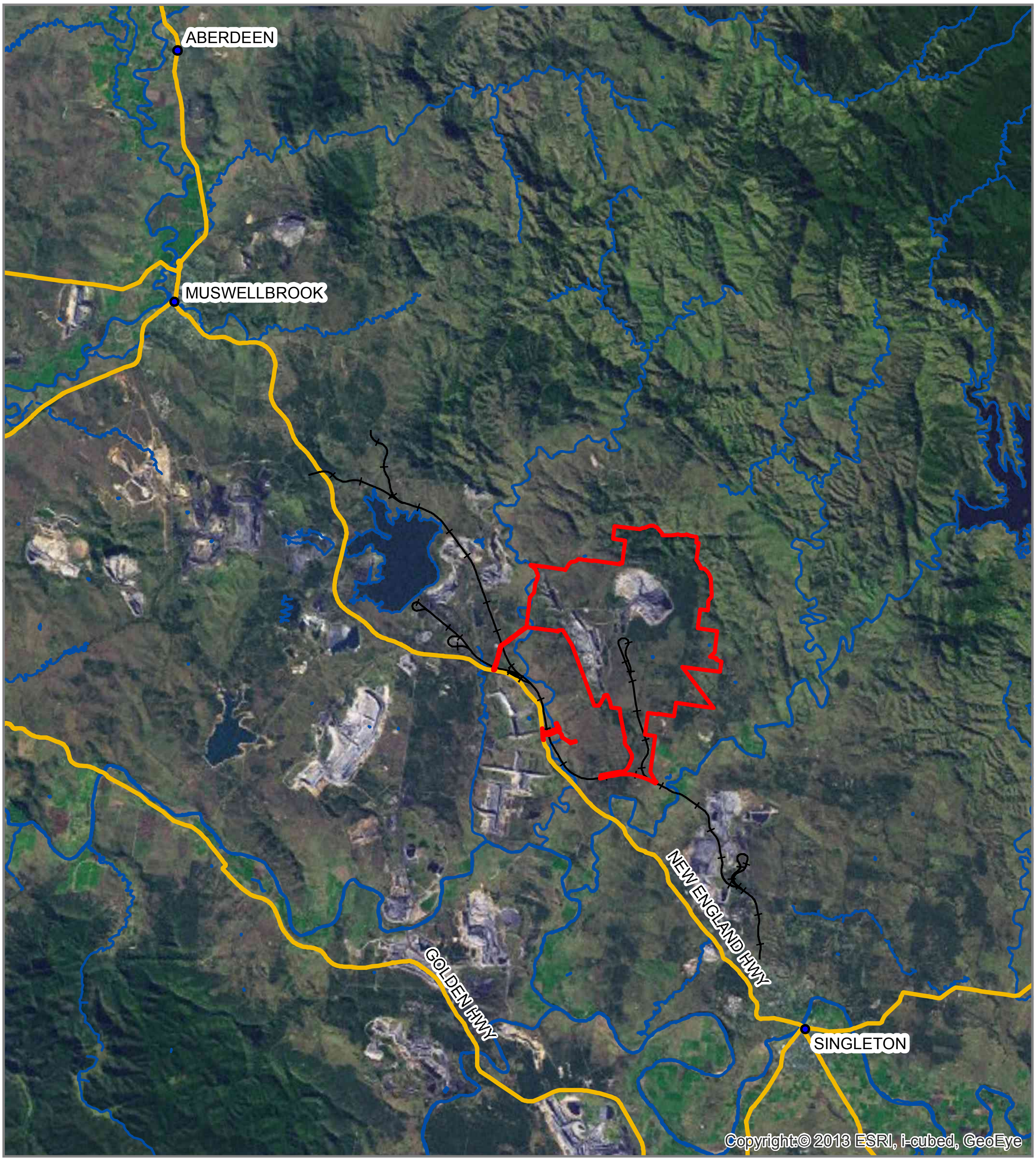
The Project seeks to maintain the current approved North Pit extraction rate of 10 Mtpa of ROM coal, extracting approximately 74 million tonnes (Mt) of ROM coal from the North Pit Continuation. The extraction of these additional mineable coal tonnes would continue the North Pit life to approximately 2030 (an additional 12 years). Additionally, the Project seeks to maintain the current approved Ravensworth East extraction rate of 4 Mtpa of ROM coal, and to extract approximately 12 Mt of ROM coal from the BNP. Mining within the BNP area would be undertaken from 2015 to 2022, with the mining in the RERR area to follow sequentially from 2022 to 2027 and extracting approximately 6 Mt of ROM coal.

The Project is also seeking approval for various infrastructure upgrades to support the mining operations. These include: expansion of the existing product stockpile to manage additional product types; upgrade and extension of the Mount Owen mine infrastructure area (MIA); additional rail line and turn-out to the west of the existing Mount Owen rail spur; a rail overpass and road upgrade at Hebden Road; extension of conveyor use to include Liddell Coal Operations and the Ravensworth Coal Terminal and revised tailings disposal for Glencore mines. These upgrades are all proposed within existing operational areas.

The Project will enable the consolidation of the Mount Owen and Ravensworth East Operations to provide for further operational efficiency by providing a single development consent for continued operations. The Project does not include any aspect of the ongoing operations at Glendell Mine, which will continue to operate in accordance with its current development consent.

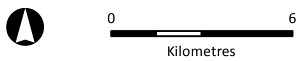
The Project is State Significant Development as defined by the provisions of the State Environmental Planning Policy (State and Regional Development) 2011 and requires development consent under Part 4 of the Environmental Planning and Assessment Act 1979 (EP&A Act). The Minister for Planning is the consent authority for the Project.

An Environmental Impact Statement (EIS) has been prepared for the Project to accompany a Project Application following Department of Planning and Environment (DP&E) issuing Director-General's Requirements (DGRs) for the Project in March 2013.



LEGEND

- Mount Owen Project Area
- Railway
- Main Highway
- Surface Water Features



Satellite Imagery: ESRI ArcGIS Online and data partners, including imagery from agencies supplied via the Content Sharing Program, Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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File Name: Figure 1-1 MOCO GIA_Locality
Prepared by: CD
Checked by: RC

Figure 1-1 Locality plan

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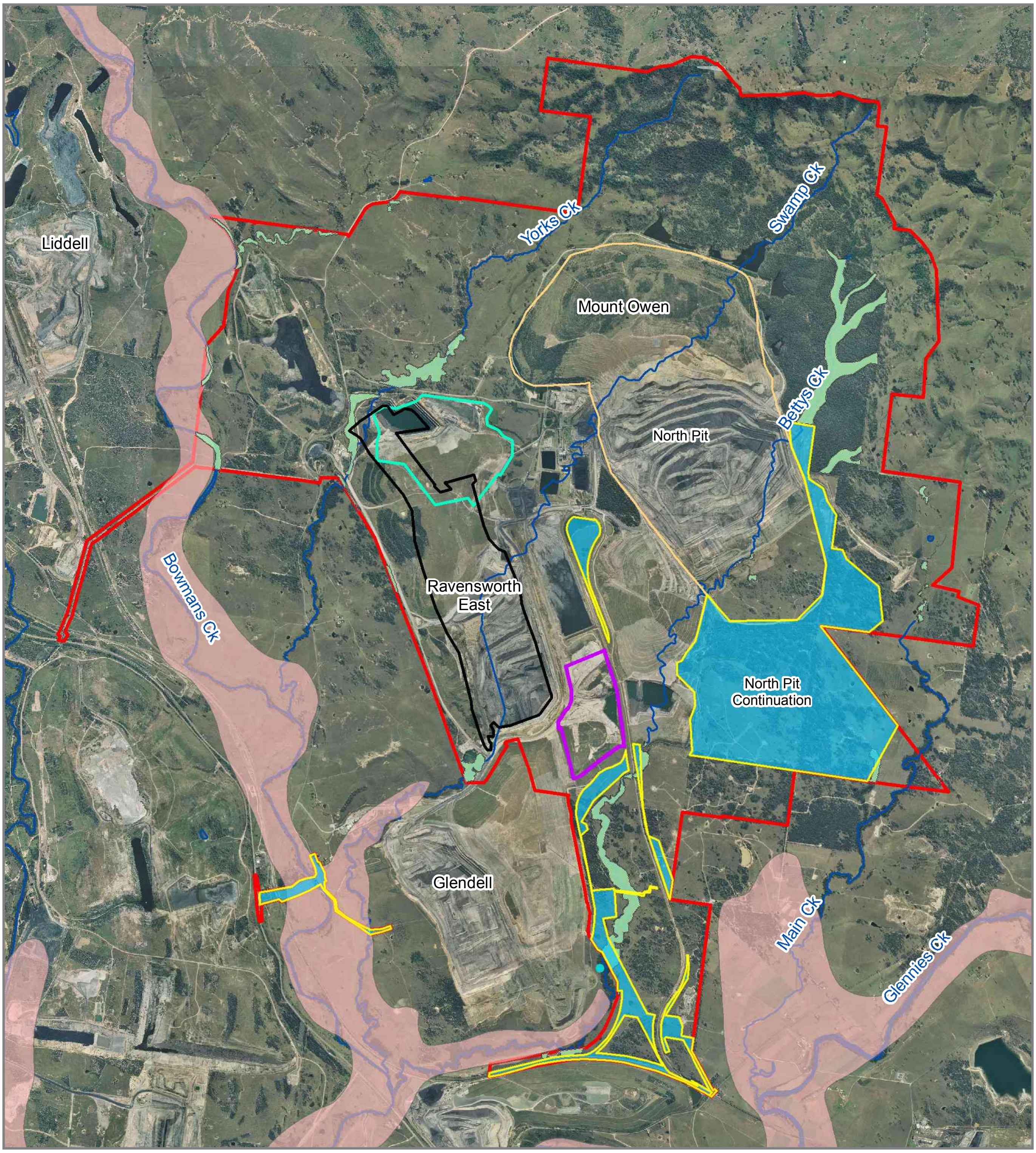

LEGEND

- Mount Owen Project Area
- Mount Owen Disturbance Areas
- West Pit
- Bayswater North Pit
- Approved North Pit Shell
- RERR Mining Area
- Surface Water Features
- BSAL
- Riparian Vegetation

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GDA 1994 MGA Zone 56

File Name: Figure 1-2 MOCO GIA_Proposed Extension
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Figure 1-2 Mine continuation area and proximity to NSW Biophysical Strategic Agricultural Land (BSAL)

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1.2 Purpose of this Report

The purpose of this Groundwater Impact Assessment report is to address the DGRs for the assessment of potential impacts of the Project on local groundwater and connected surface water resources. These issues are summarised in **Table 1-1** along with a reference to the relevant section of this report where the issue is addressed. In some cases, the potential impacts identified relate to surface water resources and/or the mine water balance. These are addressed in a separate report by Umwelt (2014) and reference is made accordingly in this report.

Table 1-1 – DGRs and Agency Comments Addressed in This Report

Director-General's Requirement	Relevant Section of Report
General Requirements	
▪ Detailed assessment of the key issues specified below, and any other significant issues including:	
- A description of the existing environment, using sufficient baseline data;	**Section** 2
- An assessment of the potential impacts of all stages of the development, including any cumulative impacts, taking into consideration relevant guidelines and policies; and	**Section 3.6**
- A description of the measures that would be implemented to avoid, minimise and if necessary, offset the potential impacts of the development, including proposals for adaptive management and/or contingency plans to manage any significant risks to the environment.	**Section** 5
Key Issues: Water Resources	
▪ Detailed assessment of the potential impacts (including cumulative impacts) on the quality and quantity of existing surface water and groundwater resources, including:	
- Detailed modelling of potential groundwater impacts, including any potential impacts on alluvial aquifers;	**Section** 3
- Impacts on affected licensed water users and basic landholder rights;	**Sections 4.2.1** and **4.3**
- Impacts on riparian, ecological, geo-morphological and hydrological values of watercourses, including environmental flows; and	**Sections 4.2.2** and **4.3**
- A flood assessment including identification of any necessary flood impact mitigation measures;	*see* Umwelt (2014a)
▪ A detailed site water balance, including a description of site water demands, water disposal methods (inclusive of volume, salinity and frequency of any water discharges), water supply infrastructure and water storage structures;	*see* Umwelt (2014a)
▪ An assessment of proposed water discharge quantities and quality against receiving water quality flows and objectives;	*see* Umwelt (2014a)
▪ Assessment of impacts of salinity from mining operations, including disposal and management of coal rejects and modified hydrogeology, a salinity budget and the evaluation of salt migration to surface and groundwater sources;	*see* Umwelt (2014a) and **Section 4.3**
▪ Assessment of groundwater impacts against the minimal impact	**Section 4.4**

considerations in the *NSW Aquifer Interference Policy*; ▪ Identification of any licensing requirements or other approvals under the *Water Act 1912* and/or *Water Management Act 2000*; ▪ Demonstration that water for the construction and operation of the development can be obtained from an appropriately authorised and reliable supply in accordance with the operating rules of any relevant Water Sharing Plan (WSP); ▪ A description of the measures proposed to ensure the development can operated in accordance with the requirements of any relevant WSP or water source embargo; ▪ A detailed description of the proposed water management system (including sewage), water monitoring program and measures to mitigate surface water and groundwater impacts; and ▪ Compliance with the Hunter River Salinity Trading Scheme.	**Section 5.3.2** *see* Umwelt (2014) **Section 5.3.2** *see* Umwelt (2014) *see* Umwelt (2014a)
NSW Office of Water Comments	**Relevant Section of Report**
Key Issue 1: Groundwater Resource Protection The Environmental Assessment is required to consider and respond to the following matters, as relevant: ▪ The objects and water management principles of the *Water Management Act 2000* ▪ Approval requirements under the NSW water legislation ▪ Full details of any existing licences and approvals under the *Water Management Act 2000* and/or *Water Act 1912* relating to the proposal ▪ Consistency with the rules of any Water Sharing Plan for the locality ▪ Relevant NSW government policies ▪ Relevant provisions of the NSW Aquifer Interference Policy ▪ The protection of surface water within the management regime of water management principles under the *Water Management Act 2000* ▪ The protection of groundwater sources including groundwater dependent ecosystems (GDE's) ▪ Identification of how a sustainable and efficient water supply is to be sourced and secured for the proposal having regard to any embargoes and water trading mechanisms ▪ Ensuring that any potential hydraulic connection between the proposed development and surface and groundwater sources is identified and mitigated ▪ Ensuring there is no adverse impact on surface and groundwater systems (including GDE's), basic landholder's rights and affected licensed water users ▪ Detailed explanation of potential groundwater volume, piezometric level, water table heights and the direction of flow and quality, through mine life and projections into the post-mine period ▪ Detailed explanation of groundwater drawdown or other impacts upon connected groundwaters associated with the Glennies Creek regulated water source, including any seepage flow	**Section 4.3** *see* Umwelt (2014a, b) **Section 4.1** **Section 4.3** **Sections 4.1, 4.2, 4.3 and 4.4, respectively** **Section 3.5** *see* Umwelt (2014a)

migrating into the proposed open cut extension ▪ Explanation of the site water balance for the proposed extension and total site operations, including any changes to water balance inputs from rainfall runoff and/or groundwater seepage to the open cut extension	*see* Umwelt (2014a)
▪ Detailed description of any proposed water supply system utilising groundwater as a source, and assessment of current licensing arrangements against this	**Section 4.4, 5.3** and Umwelt (2014a)
▪ Detailed analysis of the impacts of dewatering if required for the project, identifying the magnitude and duration of pumping, the area extent of water level drawdown, the likely quality of extracted groundwater, alterations to site water balance, and the monitoring and reporting protocols to be adopted to meet licensing requirements	**Section 0**
▪ Measures to prevent contamination of either the Glennies Creek regulated river water source, or its connected alluvium resulting from changes in groundwater tables	**Section 0**
▪ Details of the final landform and any rehabilitation plan	*see* Umwelt (2014c)
▪ Provision of surface water and groundwater monitoring plans	**Section 0**
▪ Provision of contingency strategies linked to monitoring and rehabilitation plans.	**Section 0**
General Environmental Risk Analysis Notwithstanding the above key assessment requirements, the Environmental Assessment must include:	
▪ An environmental risk analysis to identify potential environmental impacts associated with the project (construction and operation)	**Section 4.3**
▪ Proposed mitigation measures and potentially significant residual environmental impacts after the application of proposed mitigation measures; and	**Section** 5
▪ Where additional key environmental impacts are identified through this environmental risk analysis, an appropriately detailed impact assessment of these additional key environmental impacts.	**Section 4.3**
Key Issue 2: Landform or Void Rehabilitation The Environmental Assessment must include:	
▪ Justification of the proposed final landform with regard to its impact on local and regional groundwater systems,	*see* Umwelt (2014c)
▪ A detailed description of how the site would be progressively rehabilitated and integrated into the surrounding landscape,	*see* Umwelt (2014c)
▪ Detailed modelling of potential groundwater volume, flow and quality impacts of the presence of an inundated final void on identified receptors specifically considering those environmental systems that are likely to be groundwater dependent,	*see* Umwelt (2014a); *based on this report*
▪ A detailed description of the measures to be put in place to ensure that sufficient resources are available to implement the proposed rehabilitation; and	*see* Umwelt (2014c)
▪ The measures that would be established for the long-term protection of local and regional aquifer systems and for the on-going management of the site following the cessation of the	*see* Umwelt (2014c); *based on this report*

project.	
Additional general requirements Water Management Plan The Proponent shall discuss the methodology and data inputs and means to implement a Water Management Plan. The Environmental Assessment must include:	
▪ Existing and projected site water balance, including but not limited to details of water sources and security of water supply, site water use and management, off site water transfers, groundwater levels pre and post subsidence, measures to minimise water use and maximise reuse of saline and contaminated waters.	*see* Umwelt (2014a)
▪ Development and/or extension to a surface water monitoring program that includes:	
- detailed baseline data of surface water flows and water quality in the watercourses that could be affected by the project for a minimum of 2 years coinciding with the groundwater and ecological monitoring for Groundwater Dependent Ecosystems (GDE's);	*see* Umwelt (2013)
- surface water impact assessment criteria, including trigger levels for investigating potentially adverse surface water impacts for the project; and	*see* Umwelt (2013)
- a program to monitor surface water flows and quality in the watercourses that could be affected by the project.	*see* Umwelt (2013)
▪ Development and/or extension to a groundwater monitoring program that includes:	
- baseline data of groundwater levels, yield and quality in the region, and privately-owned groundwater bores, which could be affected by the project;	**Section 2.6.4** and **Section 2.6.5**
- groundwater impact assessment criteria, including trigger levels based upon analysis of baseline data for groundwater, surface water and ecology; and	**Section 4.3**
- development and/or extension to a surface and groundwater response plan which describes the measures and/or procedures that would be implemented to: o respond to any exceedances of the surface and groundwater assessment criteria; and o mitigate and/or offset any adverse impacts on groundwater dependent ecosystems or riparian vegetation located within and adjacent to the site.	**Section** 5
Groundwater Impact Assessment The Environmental Assessment must address impacts on alluvial and hard rock groundwater levels, groundwater gradients and quality, and:	
• include interpreted drawdown levels resulting from existing and/or ongoing mining operations of the project;	**Section 3.5**
• include trend analysis of alluvial and weathered/hard rock groundwater levels and those associated with groundwater dependent ecosystems against rainfall and mining operations for pre and post subsidence;	**Section 2.6.4**
• account for any drawdown loss of alluvial groundwater or river flows;	**Sections 3.5.1.1** and **4.1.1.1**

and • provide an assessment of depressurisation of coal measures will be undertaken by a suitable qualified hydrogeologist and results reported in the Annual Environmental Monitoring Report (AEMR).	**Section** 5
Groundwater management ▪ In respect to the Preliminary Groundwater Dependent Ecosystem Monitoring, the Environmental Assessment is to: - Include the presence and likelihood of groundwater dependent ecosystems; - Demonstrate the adequacy of monitoring bore network of groundwater quality and groundwater levels for GDE's which are located within the cone of depressurisation for the mining proposal, and - Include analysis of monitored surface water and groundwater quality monthly and groundwater levels daily for a minimum of 2 years in all bores coinciding with surface water and ecology monitoring. ▪ In respect to Site Water Supply and Balance, the Environmental Assessment is to, in addition to site water balance in the water management plan, include: - A discussion on comparison between the reporting period site water balance inflow and outflows for the existing and extended mining operation. This is to include an assessment on any measured or predicted increases / decreases in inflows and outflow to and from the mining operation and Glennies Creek alluvium, means to devise comparisons between measured and predicted inflows, and a detailed analysis of any water use efficiency measures which may be incorporated into the mining extension proposal, and - Monitoring and reporting measures to be implemented of review of management and best use of segregated contaminated, sediment laden and clean water volumes.	*see* Umwelt (2014b) **Section 4.2** **Section 2.6.4** and **Section 2.6.5** *see* Umwelt (2014a)
NSW Environment Protection Authority (EPA) Comments	**Relevant Section of Report**
Specific Issues: Water Describe Proposal 1. Describe the proposal including position of any intakes and discharges, volumes, water quality and frequency of all water discharges. 2. Demonstrate that all practical options to avoid discharge have been implemented and environmental impact minimised where discharge is necessary. 3. Where relevant include a water balance for the development including water requirements (quantity, quality and source(s)) and proposed storm and wastewater disposal, including type, volumes, proposed treatment and management methods and re-use options. Background Conditions 4. Describe existing surface and groundwater quality. An assessment needs to be undertaken for any water resource likely	*see* Umwelt (2014a) *see* Umwelt (2014a) *see* Umwelt (2014a) **Section 2.6**

to be affected by the proposal.	
Impact Assessment	
5. Describe the nature and degree of impact that any proposed discharges will have on the receiving environment.	**Section 4.3**
6. Assess impacts against the relevant ambient water quality outcomes. Demonstrate how the proposal will be designed and operated to: - Protect the Water Quality Objectives for receiving waters where they are currently being achieved; and - Contribute towards achievement of the Water Quality Objectives over time where they are not currently being achieved.	**Section 4.3** and Umwelt (2014a)
7. Where a discharge is proposed that includes a mixing zone, the proposal should demonstrate how wastewater discharged to waterways will ensure the ANZECC (2000) water quality criteria for relevant chemical and non-chemical parameters are met at the edge of the initial mixing zone of the discharge, and that any impacts in the initial mixing zone are demonstrated to be reversible.	*see* Umwelt (2014a)
8. Assess impacts on groundwater and groundwater dependent ecosystems.	**Section 4.3**
9. Describe how storm water will be managed both during and after construction.	*see* Umwelt (2014a)
Monitoring	
10. Describe how predicted impacts will be monitored and assessed over time. For relatively large and/or high risk developments, proponents should develop a water quality and aquatic ecosystem monitoring program to monitor the responses for each component or process that affects the Water Quality Objectives that includes, for example: - adequate data for evaluating compliance with water quality standards, environment protection licence limits and Water Quality Objectives - measurement of pollutants identified or expected to be present in any discharge.	**Section** 5
11. Water quality monitoring should be undertaken in accordance with the *Approved Methods for the Sampling and Analysis of Water Pollutant in NSW* (2004)	**Section** 5

1.3 Assessment Methodology

To understand the extent and magnitude of potential impacts posed to groundwater and connected surface water systems as a result of the Project, it is necessary to consider how activities 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 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 can been identified (Brereton and Moran, 2008). They are:

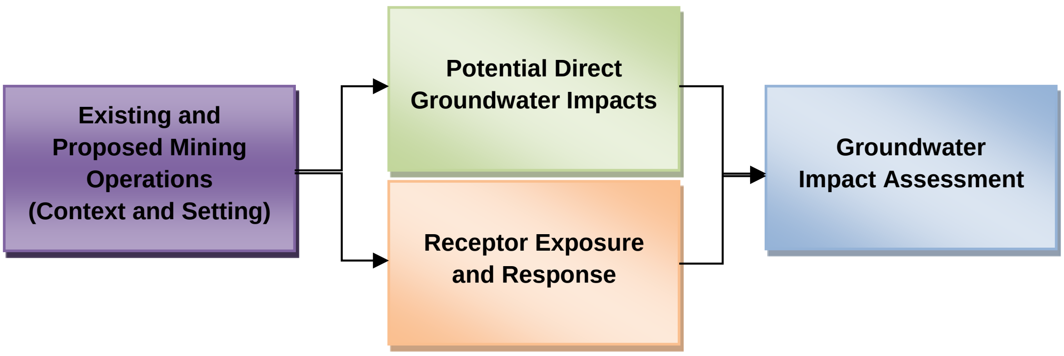
- *Groundwater quantity* – including consideration of changes to groundwater levels / pressures and flux;
- *Groundwater quality* – including consideration of salinity and concentrations of other important water quality constituents (such as metals, pH, nutrients and radionuclides);
- *Groundwater – surface water interactions* – including consideration of changes to the level of interaction between groundwater and surface water systems (such as stream baseflow); and
- *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 (GDEs) such as aquatic ecosystems that are maintained to some extent by creek baseflow, and terrestrial vegetation that utilises groundwater to meet some or all of its water requirements
- *Economic*: including agricultural and aquaculture activities that rely on groundwater (*e.g.* for irrigation or stock watering), as well as 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, 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 (mine site) to regional (catchment) 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 continuation 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 Project.

- *Potential Direct Groundwater Impacts* (**Section 4.1**): Identifies potential direct impacts to the groundwater system arising from the proposed mine continuation.
- *Potential Receptors* (**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.

1.4 Legislative Framework

The following is a review of applicable legislative and statutory requirements applicable to the groundwater assessment.

1.4.1 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 the State's 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 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 WSPs relevant to the operations (at Mount Owen for the Project) are the *Water Sharing Plan for the Hunter Regulated River Water Source* (2003) and the *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources* (2009). The Hunter Regulated River WSP (2003) applies to the rivers regulated by the Glenbawn and Glennies Creek Dams, including the Hunter River from the upper reaches of Glenbawn Dam to upstream of Maitland, and Glennies Creek downstream of Glennies Creek Dam. The Hunter Unregulated and Alluvial WSP (2009) covers 39 different water sources including unregulated rivers and creeks, highly connected alluvial groundwater, and tidal pool areas within the Hunter region. The Hunter Regulated River WSP commenced on 1 July 2004 before being suspended on 29 December 2006, after which it recommenced on 20 February 2009. The Hunter Unregulated and Alluvial WSP commenced in August 2009.

Glennies Creek and its associated alluvial sediments downstream of Glennies Creek Dam are part of the Hunter Regulated River Water Source, and as such are subject to the rules and allocation limits set out in the Hunter Regulated River WSP (2003). All water extractions from this water source, other than basic landholder rights extractions (e.g. domestic and stock rights and native title rights), must be authorised by an access licence. Each access licence specifies a share component of the total entitlement of approximately 217,000 unit shares (DWE, 2009a) according to specific purposes (e.g. local water utility, major utility, or domestic and stock) or as high security, general security and supplementary water access licences. An embargo on applications for new commercial access licences has been in place for the Hunter Regulated River water source since 1982 (DIPNR, 2004).

Bowmans Creek and its associated alluvial aquifer is located within the Jerrys Management Zone of the Hunter Unregulated and Alluvial WSP (2009). 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 the Hunter Unregulated and Alluvial WSP (DWE, 2009b).

Groundwater within the regional hard rock aquifer associated with the Wittingham Coal Measures is not currently regulated by a WSP under the *Water Management Act 2000*.

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 Regulated River WSP (July 2004) and 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 licences. Conditions at the commencement of the WSP may, therefore, be considered a baseline against which to assess the on-going and future water extraction licence requirements.

1.4.2 NSW Strategic Regional Land Use Policy (2012) and Aquifer Interference Policy (2012)

In September 2012, the NSW Government released the Upper Hunter Strategic Regional Land Use Plan (SRLUP) to set out a range of initiatives to better balance growth in mining and coal seam gas industries with the need to protect important agricultural land and water. Under this policy, the NSW Government mapped Strategic Agricultural Land across the region, and the alluvial aquifers of the Hunter and its major tributaries (including Bowmans and Glennies Creeks) were classified as BSAL. As the Project is located in proximity to land mapped as BSAL under the SRLUP (**Figure 1-2**), a site verification of land within the proposed disturbance area was undertaken as part of the Agricultural Impact Assessment (Umwelt 2014c). This assessment determined that there was no BSAL within the proposed disturbance area.

The AIP was established to objectively define the process by which development applications are assessed to determine their potential impacts on aquifers, to clarify the requirements for obtaining water licences 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 AIP clarifies water licensing 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 AIP, the assessment of impacts on water sources and GDEs is based on the project proponents' ability to demonstrate:

1. The capacity to obtain the necessary licences to account for the take of water from a given source, or if licences are unavailable, that the 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 AIP 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, studies would be required to fully assess these impacts.

1.4.3 Water Licensing

Mount Owen currently holds several different licences to extract groundwater from water sources. These licences include allocations to extract groundwater from the Glennies Creek alluvium, regulated by the Hunter Regulated River WSP (2003), and the Jerrys Water Source, which is regulated under the Hunter Unregulated and Alluvial WSP (2009), as well as licences to extract water from the deeper regional hard rock aquifer under the *Water Act 1912*. **Table 1-2** provides a summary of the current water licences held by Mount Owen. Current licensing allocations include 1,000 unit shares of high security water, 192 unit shares of general security water and 9 unit shares of stock and domestic water allocations from Glennies Creek under the Hunter Regulated River WSP (2003). Mount Owen hold a licence for 200 unit shares per year from the Jerrys Water Source under the Hunter Unregulated and Alluvial WSP (2009), as well as licences under Part 5 of the *Water Act 1912* to extract up to 1,160 ML/year from the regional hard rock aquifer.

Table 1-2 – Summary of Groundwater Bore Licences held by Mount Owen

WAL / Reference No.	Water Source	Purpose / Use	Share (units or ML per year)	Status / Notes
WAL18310 / 20AL210992	Jerrys Water Source	-	200	Unregulated River
WAL7814 / 20AL200722	Hunter Regulated River	-	1,000	Regulated River (High Security)
WAL613 / 20AL200389	Hunter Regulated River	-	192	Regulated River (General Security)
WAL7823 / 20AL201676	Hunter Regulated River	Domestic and Stock	9	Domestic and Stock
20BL169337	Hard Rock Aquifer	Extraction	140	Mount Owen dewatering
20BL170294	Hard Rock Aquifer	Extraction	220	Mount Owen dewatering
20BL170295	Hard Rock Aquifer	Extraction	800	Mount Owen dewatering

2. Context Setting

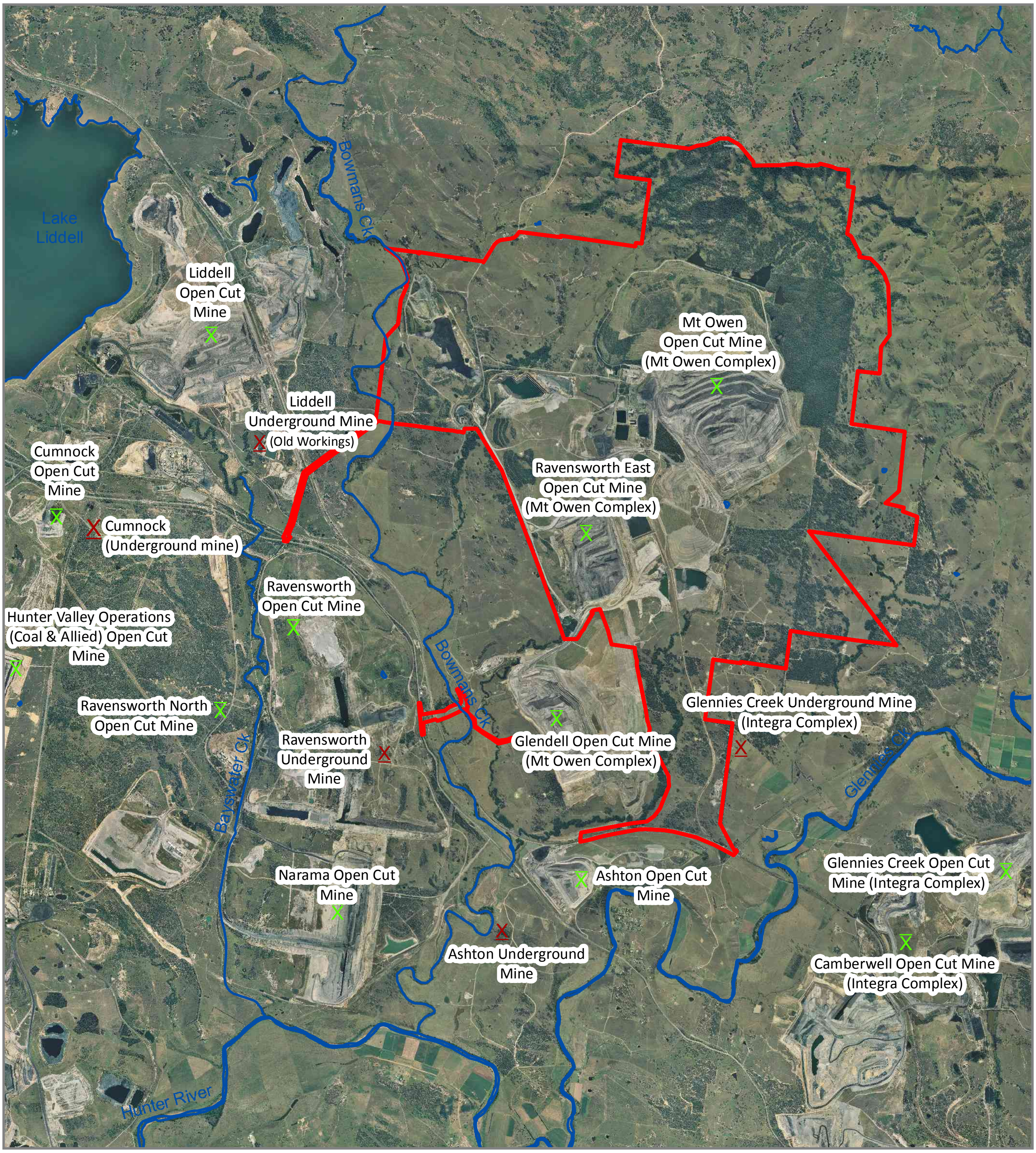
2.1 Regional Mining Activities

The Project area is located approximately 20 km north-west of Singleton and 24 km south-east of Muswellbrook in the Upper Hunter Valley region of New South Wales. The region surrounding Mount Owen has been subject to extensive underground and open cut coal mining since the early 20th century which has extensively altered the physical features and environmental setting, including the surface water and groundwater systems. The location of 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 Mount Owen Complex

The Mount Owen Complex is located to the east of Bowmans Creek and north of Glennies Creek and includes three adjacent open cut coal mines: Mount Owen, Ravensworth East and Glendell. The Mount Owen Mine comprises the North Pit, tailings and overburden emplacement areas and associated infrastructure. Current mining operations at Mount Owen Mine are permitted under development consent DA 14-1-2004 until 2025, though under current estimated extraction rates, mining in the North Pit is expected to reach its currently approved limit by 2018. The Ravensworth East Mine recommenced operations in 2000 under development consent DA 52-03-99 and comprises West Pit and several tailings and overburden emplacement areas. Development consent for the Ravensworth East mine lapses in 2021, and approved reserves in the currently operational West Pit are estimated to be extracted in quarter 1 of 2014. The Glendell Mine comprises the currently operating Barrett Pit, which operates under development consent DA 80/952 and is planned to cease mining in 2024.

The North Pit (Mount Owen Mine) and West Pit (Ravensworth East) currently mine or have previously mined coal seams from the Bayswater seam down to the Hebden seam at depths of more than 250 m below ground level (bgl). The Barrett Pit (Glendell) mines coal from the Bayswater to the Barrett seam to an approximate depth of 200 m bgl. Mount Owen manages water for the Mount Owen Complex through an integrated Water Management Plan. The Mount Owen Complex is part of the Greater Ravensworth Water Sharing Scheme (GRWSS) including the Cumnock, Ravensworth Operations, Narama, Ravensworth Underground and Liddell mining operations, which allows flexibility in water management requirements for mines in the region. Under normal to dry rainfall conditions, Mount Owen Complex is currently predicted to operate with a water deficit, with water shortages being met via transfers from other mines via the GRWSS (MOC, 2013).



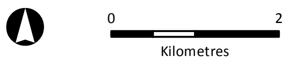
LEGEND

Mining Operations

X Open Cut Mine

X Underground Mine

Mount Owen Project Area



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GDA 1994 MGA Zone 56

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Prepared by: CD
Checked by: RC

Figure 2-1 Regional mining operations

JACOBS

2.1.2 Liddell Coal Operations

To the west of Mount Owen Complex and Bowmans Creek, Liddell Coal Operations (LCO) has been mining continuously 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 to produce up to 8 Mtpa of ROM coal (GSS, 2011; AECOM, 2012). A current Modification to this DA has been submitted (July 2013) to allow progression of the existing South and Entrance Pits to enable mining to continue through to 2022. The Liddell DA is included within the modelling framework of this assessment.

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. The coal seams undergoing mining 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. Current mining operations result in LCO being a net water producer, with excess water being discharged to surrounding mines in the area via the GRMWSS (GSS, 2011) and discharged offsite via the Hunter River Salinity Trading Scheme (HRSTS).

2.1.3 Ravensworth Operations

Located to the south of LCO, Ravensworth Surface Operations received project approval in February 2011 and consolidates the Narama and Ravensworth West open cut pits, the Cumnock No. 1 open cut and underground operations, surface facilities for 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.

The former Ravensworth No. 2, Ravensworth South and Narama 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. RUM is located beneath the old Ravensworth No. 2, Ravensworth South and Narama open cut pits and currently extracts coal from the Pikes Gully seam via long wall panels in a south-westerly direction. RUM has development approval to undertake future long wall mining in the underlying Liddell and Barrett seams (MER, 2011b), though is currently expected to go into care and maintenance in November 2014.

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) and entered into a period of care and maintenance in September 2014. The Integra Underground Mine comprised longwall mining in the Middle Liddell seam, with development works and approval for expansion to mine the Hebden and Barrett seams. Underground operations entered into a period of care and maintenance, however, in May 2014.

Coal from the Integra Mine Complex was handled and processed at the Integra CHPP prior to transport by rail to Newcastle for export. Sufficient water was typically available from mining operations such that Integra acted 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 south of the Mount Owen Complex. Ashton open cut operations commenced in 2004 and mined coal from the Pikes Gully seam down to the Barrett seam. The underground operations extracted longwall panels in the Pikes Gully seam and is now progressing longwall extraction from the underlying Liddell seams. A requirement of continued underground workings was to develop two significant diversions of Bowmans Creek south of the existing open cut operations. This has been undertaken to allow secure underground mining which has commenced beneath the southern mine area.

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 Mount Owen 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

The Hunter Valley's climate is 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 18 km southwest of Mount Owen Complex, and Bowmans Creek, 11 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 Mount Owen Complex). Rainfall at Jerrys Plains averages 645 mm/year 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 35% higher than Jerrys Plains at 871 mm/yr. This higher rainfall is due to higher land elevations on the flanks of the Hunter Valley.

Potential evaporation generally exceeds rainfall in all except early winter months across the region.

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	77.1	73.1	59.7	44.0	40.7	48.1	43.4	36.1	41.7	51.9	61.9	67.5	**645.9**
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 Greater Ravensworth Region (the region) highlighted by two distinct landforms: the gently undulating alluvial plains associated with the Hunter River Valley and its major tributaries, and the steeper, elevated ranges delineating the flanks of the valleys. Within the Hunter River valley, ground elevations generally range between 50 and 150 m above sea level (Australian Height Datum – AHD), rising to elevations up to 500 m AHD following the northwest to southeast trending ridgeline to the north of the region which marks the surficial expression of the Hunter Thrust. The Hunter Thrust is a significant geological feature associated with faulting that brings outcrops of older Carboniferous rocks up against younger Permian Coal Measures 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 terms of physical size and flow rate, with its catchment area covering approximately 22,000 square kilometres.

The Project Area is located within sub-catchments of the Hunter River catchment associated with Bowmans Creeks and Glennies Creek, as shown in Figure **2-3**. The eastern portion of the Project area lies within the Glennies Creek catchment, while the majority of the project area falls within the Bowmans Creek catchment.

Bowmans Creek drains an area of approximately 250 square kilometres, and has an almost perennial flow regime (Umwelt, 2006). Glennies Creek is a perennial stream regulated by Glennies Creek Dam approximately 12 km east of the Project area. In addition to these perennial surface water features, several ephemeral tributary creeks drain the Project area. These are comprised of Yorks Creek, Swamp Creek and Bettys Creek (tributaries of Bowmans Creek), and Main Creek (tributary of Glennies Creek). Bettys Creek and Swamp Creek have been subject to extensive diversion works associated with previous mining activities (Umwelt, 2014a).

Flow duration curves extracted from stream gauges on the Hunter River (stations 210126 and 210127), Glennies Creek (stations 210084 and 210044), Bowmans Creek (station 210130), Yorks Creek (station 210049) and Swamp Creek (station 210050), shown in **Figure 2-4**, reflect the relative quantity of streamflow and the percentage of time flow occurs for each volume at each station. Four distinct flow regimes may be identified:

- The flow rates and duration profiles recorded at gauging stations 210126 and 210127 show the dominance of the Hunter River as the major surface water feature in the region.
- The stream gauge on Bowmans Creek (station 210130) indicates near perennial flow, albeit at flow rates generally less than 5 ML/day.
- Stream flow data for Glennies Creek (stations 210084 and 210044) reflect the regulated flows on the creek controlled by Glennies Creek Dam, with flows generally exceeding 10 ML/day.
- Flow duration curves for stream gauges on Yorks Creek and Swamp Creek reflect the ephemeral nature of these tributaries, where lack of flow often results in sampling from stagnant pools when surface water quality monitoring is undertaken (Umwelt, 2013). These creeks essentially act as drainage courses during periods of higher rainfall. Stream gauge data for both these creeks are for the period 1958 to 1968, prior to commencement of mining operations in the area, illustrate the natural behaviour of these creeks prior to extensive mining activities.

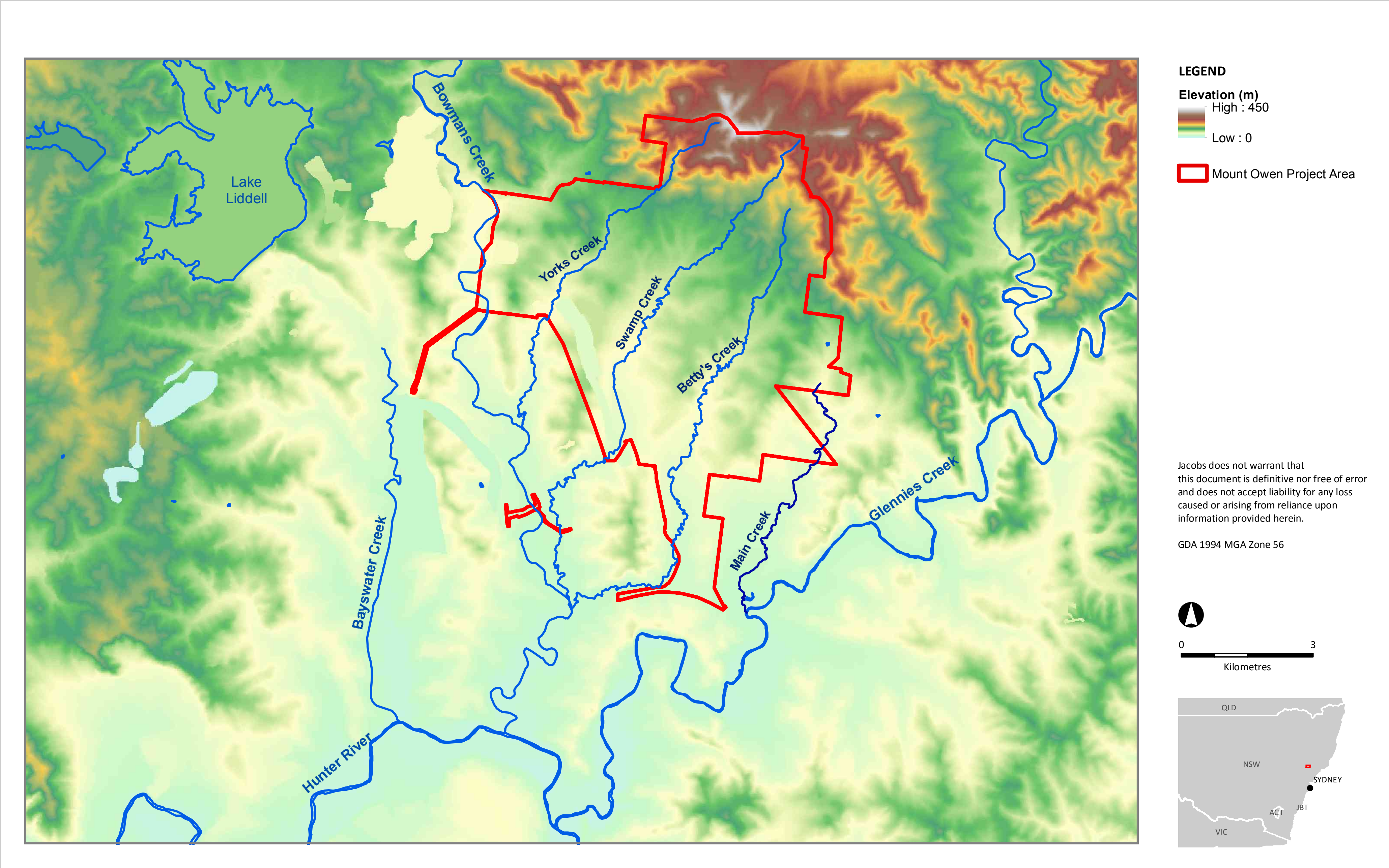

Figure 2-2 Regional natural topography and drainage in relation to the Project Area

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File Name: Figure 2-2 MOCO GIA_Regional Topography
Prepared by: CD
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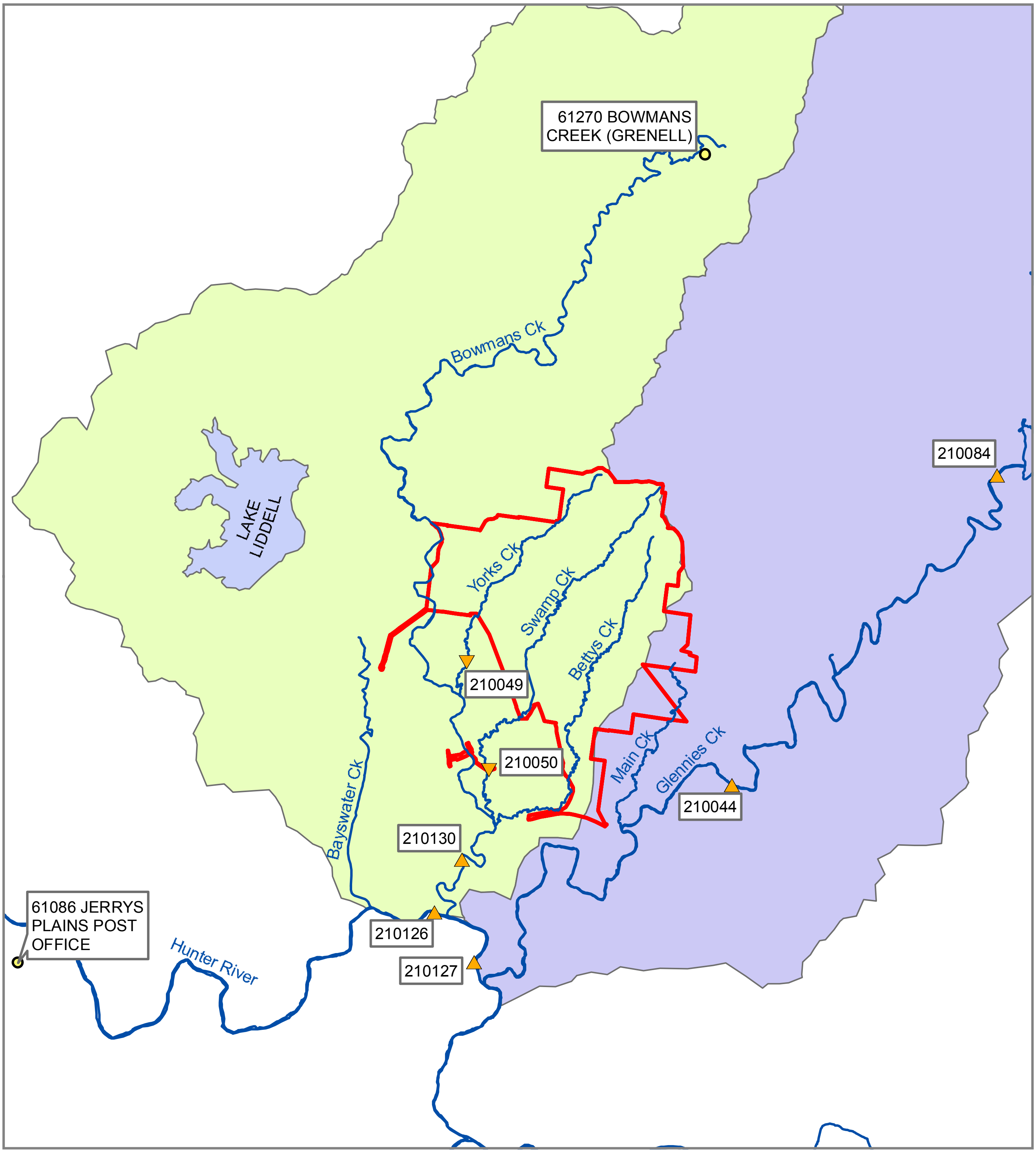

LEGEND

Stream Gauging Stations

- Open
- Closed
- Weather Stations
- Bowmans Creek and Bayswater Creek Catchment
- Glennies Creek Catchment
- Mount Owen Project Area

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Kilometres

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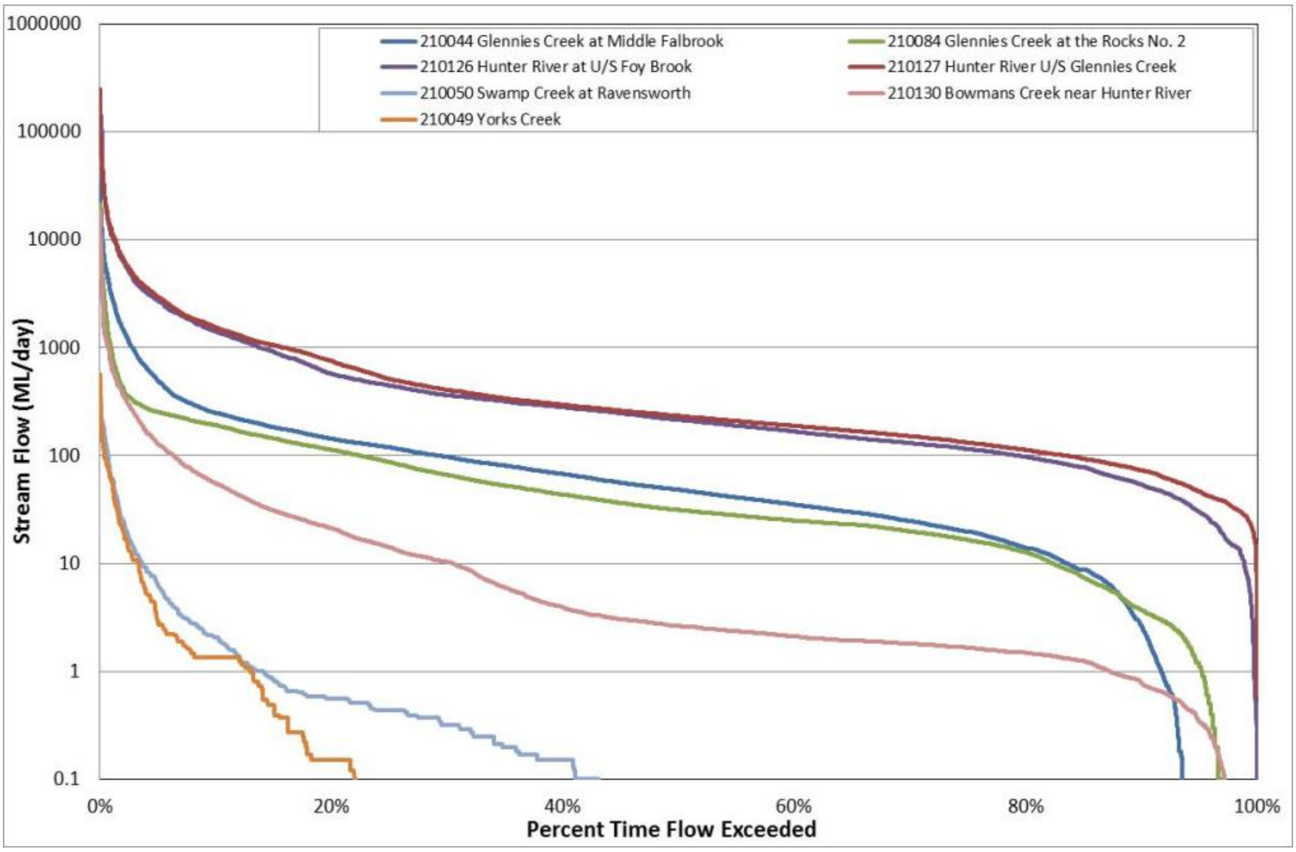
File Name: Figure 2-3 MOCO GIA_SW Catchments
Prepared by: CD
Checked by: RC

Figure 2-3 Local surface water features, and stream gauging and weather stations

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



Note: Foy Brook is now known as Bowmans Creek

The DGRs make specific reference to assessing the potential impacts of the Project on the Glennies Creek alluvial groundwater source. Potential groundwater impacts relate directly to the impact on groundwater contributions to stream flow, known as the baseflow component of the flow regime. In order to evaluate such potential impacts, historical stream flow and climatic data can be used to estimate contributions of groundwater baseflow to the creek. Stream flow data was analysed using a digital recursive filter (BaseJumper®, Murphy, et al., 2008) to estimate the groundwater contribution to streamflow (i.e. baseflow).

A good understanding of local conditions that may influence baseflow contributions to stream flow is important when using flow analysis software and interpreting its outputs (Murphy et al., 2008). Flow regulating structures such as upstream dams and reservoirs can generate low flow signals that can be misinterpreted as baseflow at gauges downstream, and as a result the use of digital recursive filters is generally not recommended for regulated streams. Glennies Creek is currently regulated by Glennies Creek Dam upstream of gauges 210084 and 210044, and is hence unsuitable for current stream flow and climatic data analysis since construction between 1980 and 1983. Stream flow data is available prior to 1980, however, and analysis can still be undertaken to estimate natural historic baseflow contributions to Glennies Creek.

The approach to estimating baseflow contributions to stream flow relies on a number of assumptions that are important to consider if the baseflow estimates are used to verify outputs from any models. The recursive filter approach estimates the proportion of stream flow that can be attributed to *slow* flow, that is, the proportion of stream flow that occurs during low flow conditions (such as dry weather conditions). BaseJumper® assumes that slow flow is synonymous with baseflow, however such an assumption is not always applicable, notably where regulating structures modify the natural flow regime.

BaseJumper's estimate of slow flow also represents a net volume, meaning any outflow to groundwater (i.e. leakage to groundwater) in the river reach above the gauge is combined with any groundwater discharge to the stream (i.e. baseflow). The estimate of slow flow is derived at the gauge site, but represents an integration of surface water and groundwater interactions along the river reach above the gauge. **Table 2-2** summarises the data record for stream gauges along Glennies Creek available to determine baseflow estimates.

Table 2-3 shows the estimated annual slow flow contributions for stream gauges 210084 and 210044 prior to 1980 and after 1983 (when Glennies Creek Dam was completed). Using the data record prior to 1980 provides an indication of baseflow contributions to stream flow along Glennies Creek, with baseflow estimates of 6,930 ML/year and 9,221 ML/year determined at gauges 210084 and 210044, respectively. These estimates amount to approximately 10% of the total stream flow in Glennies Creek, and the increase in estimated baseflow contributions between the two gauges suggests the creek is a gaining reach (i.e. groundwater contributes baseflow to the creek) between these locations.

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

Stream Gauge	210084	210044
Start of Record	6/11/1969	27/01/1956
End of Record	9/12/2012	13/10/2009
Number of days over record	15,740	19,619
Number of years over record	43.1	53.8
Number of days with data	15,226	19,162
Number of days missing data	514	457
% missing	3.3%	2.3%
Number of days with zero flow	462	949
% of time zero flow	3.0%	5.0%

Table 2-3 – Baseflow Estimates[2] for Gauges on Glennies Creek

Stream Gauge	210084	210044
Pre-1980 Data Record		
Average Streamflow (ML/day)	200	247
Average Streamflow (ML/year)	73,003	90,140
Estimated Baseflow (ML/day)	19	25
Estimated Baseflow (ML/year)	6,930	9,221
Percent Streamflow as Baseflow	9.5%	10.2%
Post-1983 Data Record		
Average Streamflow (ML/day)	64	146
Average Streamflow (ML/year)	23,435	53,428
Estimated Baseflow (ML/day)	20	37
Estimated Baseflow (ML/year)	7,271	13,655
Percent Streamflow as Baseflow	31.0%	25.6%

Comparison with the estimated slow flow contributions to stream flow after completion of the Glennies Creek Dam (post 1983) reflects the influence on stream flow caused by flow regulation. Average streamflow has been significantly reduced and the post-1983 slow flow estimates suggest that a much larger contribution of baseflow

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

to stream flow due to the regulation of the creek by Glennies Creek Dam. As a result, the estimated baseflow contributions for this period should not be considered definitive estimates, and comparison of such baseflow estimates to other analytical or simulated estimates of baseflow (such as groundwater contributions to the alluvial aquifers estimated by numerical models, or through surface water-groundwater interaction studies) should be considered approximations (*see* **Section 3.3.6**).

2.5 Geology

The Project Area is located within the Hunter Coalfield of the Permian and Triassic Sydney Basin. The geology comprises Permian coal measures and associated inter-seam sedimentary sequences, overlain by Triassic sediments. This sequence is faulted against the Carboniferous New England Block to the east and northeast. An eroded valley through the Triassic sediments has been in-filled with Quaternary to Recent alluvium associated with the Hunter River and its tributaries (Beckett, 1988). To the west and southwest of the Hunter River floodplain is steeply incised terrain of the younger Triassic Narrabeen Group. The Permian depositional environment is interpreted as a varying cyclic pattern of fluvial to marine deltaic conditions (Mackie, 2009).

The areas of the Hunter Valley adjacent to the floodplain are comprised 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. To the north and northeast of the Project Area 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.

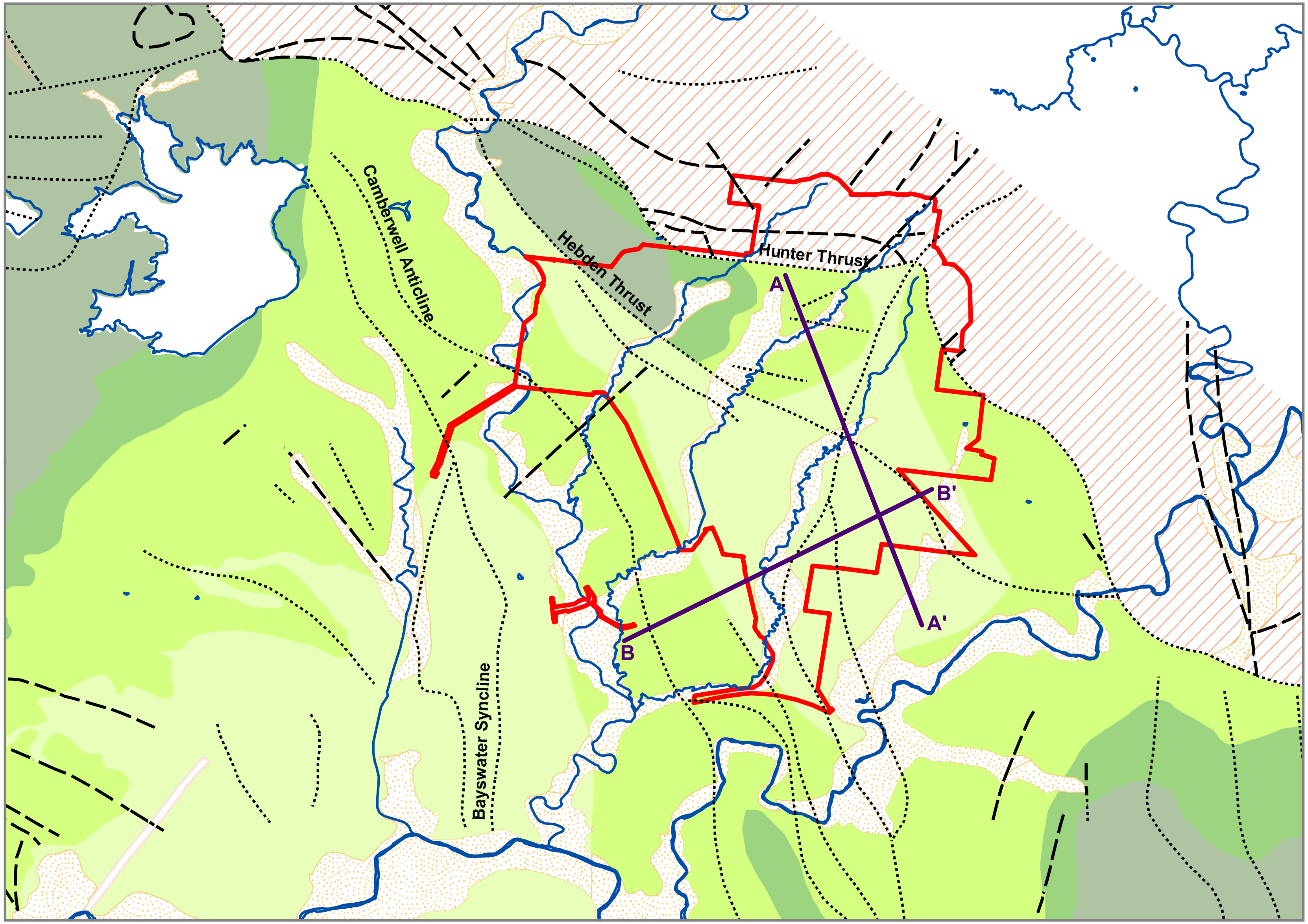
Figure 2-5 illustrates the geology and the locations of major structural features within the region.

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.

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, whilst the middle and upper units are generally between 1 m and 3 m thick and are commonly terraced (Beckett, 1987).

The unconsolidated alluvial deposits associated with Glennies Creek are up to 14 m thick (Geoterra, 2009 *and validated through the additional standpipe installation carried out as part of assessment – see* ***Section 2.6.4*** and **Figure 2-8**). Tributaries to Glennies Creek, such as Main Creek, constitute sheet-wash drainage lines through surficial colluvium and are ephemeral features of the landscape.



LEGEND

Surface Geology

- Quaternary Alluvium
- Triassic Narrabeen Group
- Newcastle Coal Measures
- Jerrys Plains Subgroup
- Vane Subgroup
- Saltwater Creek Formation
- Maitland Group
- Greta Coal Measures
- Carboniferous (undif)
- Volcanics (various)
- Faults
- Folds
- Mount Owen Project Area

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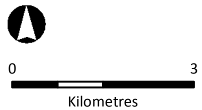


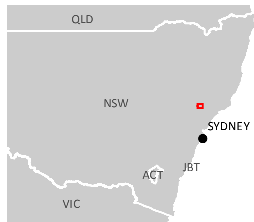


Figure 2-5 Regional geology and structural features

File Name: Figure 2-5 MOCO GIA_Regional Geology
Prepared by: CD
Checked by: RC

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 and these are summarised in **Table 2-4**. 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).

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 lies at depth beneath most of the Hunter Valley, however it sub-crops in the northern part of the Project area where it is up-thrown between the Hebden and Hunter Thrusts.

Table 2-4 – Stratigraphic Table of the Wittingham Coal Measures

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 (siltstone 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 Sub-Group	*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)		

Above the Saltwater Creek Formation, the 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 each containing multiple seams (refer **Table 2-4**). The coal seams are separated by interburden units comprised of sandstone, siltstone, conglomerate, mudstone and shale.

Stratigraphic cross sections have been developed for the Project area based on data extracted from the geological model developed by Mount Owen. The locations of the cross sections are shown in **Figure 2-5** and the cross sections are presented in **Figure 2-6** and **Figure 2-7**.

Figure 2-6 – Geologic Cross Section A – A'

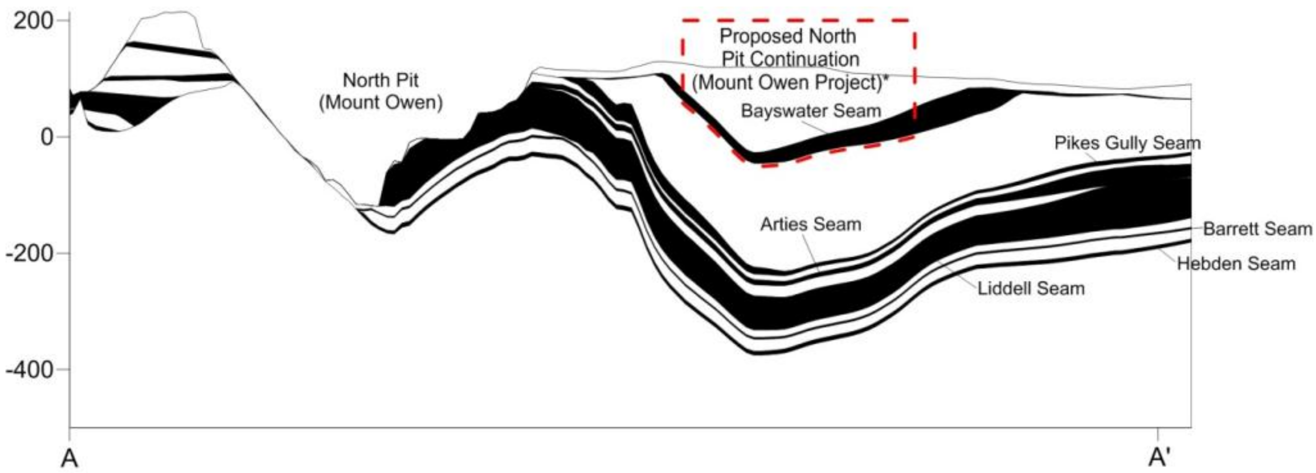
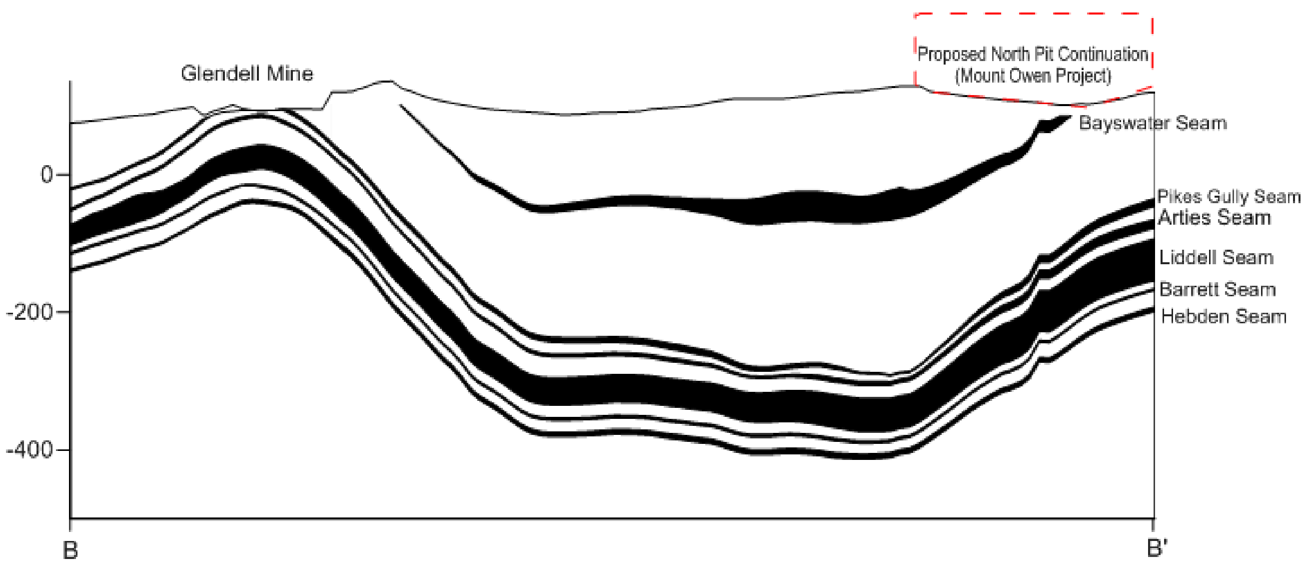


Figure 2-7 – Geologic Cross Section B – B'



* Notes:

- Extent of proposed North Pit Continuation approximate only
- Vertical exaggeration of 4:1 is used for both cross sections
- Coal seam thickness shown include all sub-seams and associated interburden

2.6 Hydrogeology

2.6.1 Aquifer Systems

Previous environmental assessments undertaken in the area (MER, 2001; MER, 2003; ERM, 2008; Umwelt, 2006; 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 characterised by unconsolidated deposits of silts, sands, and gravels of varying permeability. The morphology of the alluvial deposits comprises 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 alluvial aquifer and in places may be confined by the overlying finer grained terrace deposits. These unconsolidated aquifers discharge groundwater to surface water features in the region, with their varying morphology and extent leading to complex and variable surface water interactions (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. Enhanced transmission will develop over underground workings where induced cracking above the goaf will increase porosity and permeability. Independent studies of the extent and magnitude of this enhanced cracking have been used to establish a relationship for increased transmissivity above underground workings for the Upper Hunter Valley area.

Coal seams typically represent the more permeable hard rock strata due to 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 enhances vertical permeabilities of both coal seams and interburden strata in areas of underground workings. In the Upper Hunter Valley, the coal seam aquifers are generally semi-confined above and below by the interburden strata.

Groundwater in the regional hard rock aquifer moves down dip and down gradient from areas of recharge where individual seams sub-crop 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) sub-crop and outcrop.

2.6.2 Registered Bores

A search of NSW Office of Water’s PINEENA GW database (2010) identified 39 registered groundwater bores within 4 km of the Project area. **Figure 2-8** shows the location of these bores, and **Table 2-5** summarises bore information from the database. Whilst several of the registered bores are listed under private ownership in the NOW database, all bores within 4 km of the Project boundary are now owned, or are on, mine lands, or are inactive. The nearest active private water supply bores are over 4 km from the Project boundary (Umwelt, 2014b).

Table 2-5 – State Registered Groundwater Bores

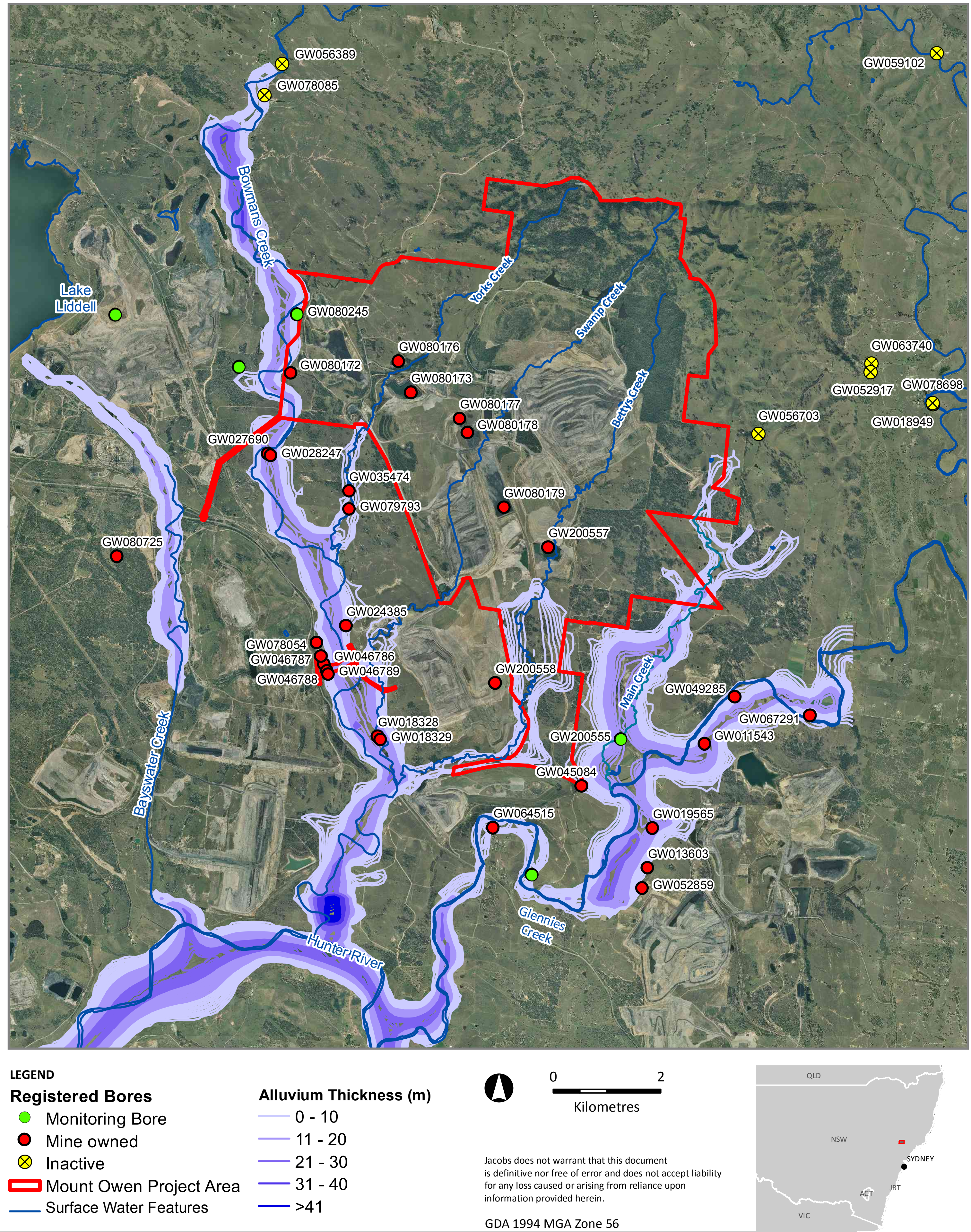
Work No.	Licence	Owner[3]	NOW registered purpose[4]	Date Completed	Depth (m)
GW027690	20BL020923	Liddell Tenements	Irrigation	1/01/1966	6
GW028247	20BL020924	Liddell Tenements	Irrigation	1/01/1962	2
GW080212	20BL168065	Liddell Tenements	Monitoring	31/05/2002	--
GW080245	20BL168066	Liddell Tenements	Monitoring	7/08/2002	--
GW080213	20BL168064	Liddell Tenements	Monitoring	31/05/2002	--
GW080172	20BL168209	Mount Owen Pty Ltd	Industrial	28/03/2002	--
GW078085	20BL166608	--	Stock†	23/06/1997	13
GW080725	20BL168240	Cumnock No 1 Colliery Pty Ltd	Mining	10/08/2000	130
GW080176	--	--	Unknown	4/02/2002	--
GW080173	--	--	Unknown	4/02/2002	--
GW035474	20BL028920	Private	Exploration	--	--
GW079793	--	--	Mining	--	3
GW056389	20BL122309	Private	Domestic†	1/01/1950	7.3
GW024385	20BL017861	Enex Foydell Ltd (Liddell)	Stock†	1/01/1926	4.6
GW078054	20BL166290	-	Industrial	-	16.2
GW046787	20BL107141	Private	Domestic	-	6.2
GW046786	20BL107142	Private	Domestic	1/01/1972	6.9
GW046788	20BL107143	Private	Domestic	-	6.1
GW046789	20BL107144	Private	Domestic	-	6.9
GW018328	20BL010403	Private	Unknown	1/01/1959	5.8
GW018329	20BL010402	Private	Unknown	1/01/1959	4.9
GW200558	20BL169574	Mines	Test Bore	19/04/2005	36
GW080177	-	-	-	2/04/2002	-
GW080178	-	-	-	2/04/2002	-
GW080179	-	-	-	2/04/2002	-
GW200557	20BL169571	Mines	Test Bore	19/04/2005	49.2
GW064515	20BL136766	Private	Domestic	1/01/1919	5.5
GW080968	20BL170105	Dept. of Water and Energy	Monitoring	13/10/2005	30
GW045084	20BL104306	Private	Domestic	1/03/1976	-
GW052859	20BL114996	Private	Stock	-	9.1
GW013603	20BL009051	Private	Irrigation	1/01/1938	12.8
GW019565	20BL012970	Private	Domestic	1/11/1962	7.3
GW200555	20BL167917	Mines	Monitoring	6/08/2005	11
GW049285	20BL109471	Private	Farming	1/01/1979	9.1
GW011543	20BL004898	Private	Stock	1/01/1925	5.5
GW067291	20BL142106	-	Stock	-	-

[3] Bores listed under private ownership are owned by mines in the area (Umwelt, 2013).
[4] As listed in the NOW database

Work No.	Licence	Owner[3]	NOW registered purpose[4]	Date Completed	Depth (m)
GW056703	20BL123557	Private	Stock†	1/10/1981	22.9
GW052917	20BL121779	Private	Stock†	1/10/1981	15.2
GW059102	20BL117760	Private	Irrigation	1/10/1981	-
GW063740	20BL135390	Private	Stock†	1/10/1986	39.6

Source: NSW Office of Water's PINEENA GW database, version 3.2 (October 2010), http://waterinfo.nsw.gov.au/pinneena/gw.shtml
- denotes no information from NOW database
† inactive

Plate 1 Groundwater monitoring bore GW200555 near Main Creek



File Name: Figure 2-8 MOCO GIA_Registered Bores

Prepared by: CD

Checked by: RC

Figure 2-8 Registered groundwater bores within 4 kilometres of the Project Area

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2.6.3 Hydraulic Properties

The hydraulic properties that govern groundwater storage and flow across 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 airlift pumping tests, 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 monitoring bores targeting the Bowmans Creek alluvial aquifer (*by L Cook & Associates in, 2013*) are also included.

Table 2-6 – Range of Hydraulic Properties

Lithology	Horizontal Hydraulic Conductivity (m/day)	Storage[1]	Source
Alluvium	0.5 – 50	--	MER (2001)
	2.4	S_s = 8.67 x 10^{-2} S_y = 0.25	ERM (2008)
	10	S_s = 1 x 10^{-5} S_y = 0.05	MER (2011b)[2]
Alluvium (Hunter River)	50	S_s = 1 x 10^{-4} S_y = 0.1	Aquaterra (2009b)
	14.5	S_s = 8.67 x 10^{-2} S_y = 0.25	ERM (2008)
Alluvium (Bowmans Ck)	2 x 10^{-4} – 15	S_s = 1 x 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 x 10^{-4} S_y = 0.05	Aquaterra (2009b)
Coal Seams	1 x 10^{-5} – 1 x 10^{-1}	--	MER (2001)
	0.052	S_s = 1.55 x 10^{-3} S_y = 0.02	ERM (2008)
	0.04 – 7	--	Aquaterra (2009a)
	0.002 – 0.03	S_s = 1 x 10^{-4} S_y = 0.005	Aquaterra (2009b)
	1 x 10^{-4} – 2 x 10^{-2}	S_s = 4 x 10^{-6} S_y = 0.002 – 0.1	MER (2011b)[2]
Interburden / Overburden	0.007	S_s = 2.25 x 10^{-5} – 0.2 S_y = 0.02	ERM (2008)
	1 x 10^{-6} – 8 x 10^{-3}	S_s = 1 x 10^{-5} S_y = 0.005	Aquaterra (2009b)
	4 x 10^{-6} – 5 x 10^{-3}	S_s = 1 x 10^{-6} S_y = 3 x 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 monitoring bores ALV1L through ALV8L in March 2013

The range of hydraulic conductivity values reported in **Table 2-6** reflects the variability of the properties of the aquifer systems present in the region, with the hydraulic conductivity 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 hydraulic conductivity (K_z) is presumed 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 observed between the Hunter River alluvial sediments and that in 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 the alluvial deposits associated with the Hunter River and Glennies Creek (Aquaterra, 2009b).

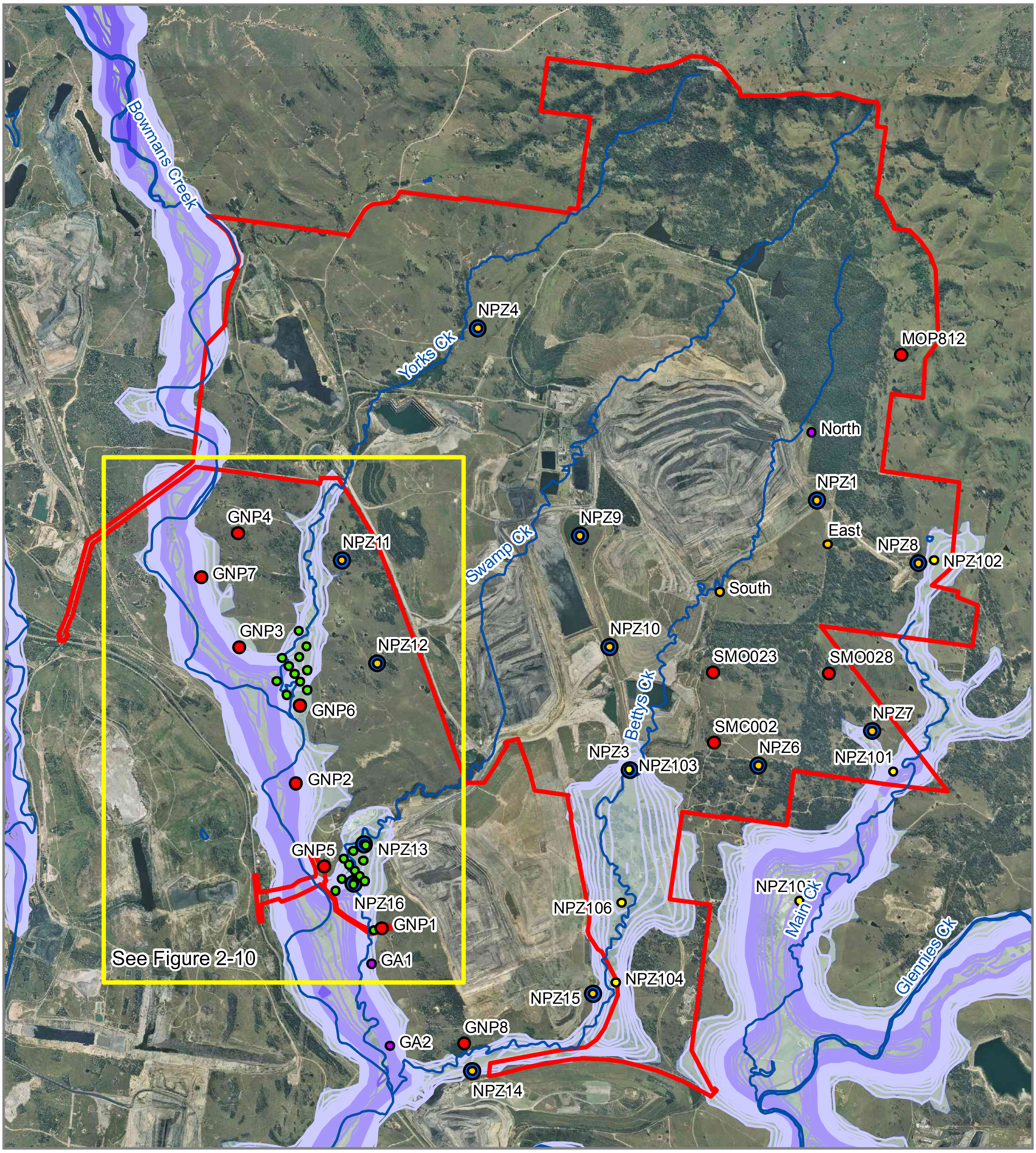
2.6.4 Groundwater Levels and Flow Patterns

Groundwater level data for Mount Owen Complex is available from the existing groundwater monitoring network identified in the *Mount Owen Complex Groundwater Monitoring Plan*, plus additional locations installed between 2012 and 2014 to supplement the existing network. The existing monitoring network, shown in **Figure 2-9** and summarised in **Table 2-7**, includes a series of nested piezometers (the NPZ-series bores) previously reported to target both the alluvium and deeper hard rock aquifers. However the reported drilled depths for these nested bores (refer **Table 2-7**) indicate that the shallow piezometers were drilled to depths typically beneath the alluvial deposits. In addition the locations of several of the bores (refer **Figure 2-9**) are well away from any surface water or drainage features likely to be associated with alluvium. Bore logs and well construction details were not available for the NPZ-series bores, however, making it difficult to determine the stratigraphic layer(s) and associated aquifer being targeted. Given the location and drilled depth of the shallow bores within the NPZ-series piezometers, and taking into account water level data (see below), the shallow piezometers likely target the shallow bedrock overburden immediately underlying the alluvium or weathered regolith, while the deeper piezometers target the deeper bedrock interburden and/or coal seams. All NPZ bores are therefore considered to be constructed entirely within the regional hard rock aquifer. Monitoring bores for which the drilled depth is unavailable (*e.g.* North, East, South, GA1, GA2) have been assumed to monitor the target lithology specified.

Between 2012 and 2014, SKM and Mount Owen installed additional groundwater monitoring bores to supplement the existing network, including:

2012: a series of shallow piezometers targeting the alluvial aquifers of Yorks Creek, Swamp Creek and Bowmans Creek, and deeper bores targeting the regional hard rock aquifer beneath Bowmans Creek (locations GNP1 through GNP8) and to the south of the currently operating North Pit (locations SMC002, SMO023 and SMO028) (SKM, 2012). An additional hard rock bore (MOP812) was installed in the northeast of the Project area to assess groundwater pressures north of the Hunter Thrust fault. The bores targeting the alluvial aquifers were installed as standpipe piezometers, and the deeper hard rock bores were installed with vibrating wire piezometers (VWPs) to provide continuous water pressure data for the regional hard rock aquifer. The additional monitoring locations installed in 2012 are shown in **Figure** 2-10, and details are summarised in **Table 2-8**.

2013 - 2014: a series of standpipes were installed targeting the alluvial aquifers of Main Creek, Bettys Creek and Glennies Creek to provide additional information on alluvial geometry in these creeks as well as on-going groundwater level and water quality data. The locations of these bores are shown in **Figure 2-9**, with details summarised in **Table 2-8**.



LEGEND

Existing Monitoring Network
- Alluvium
- Shallow Hard Rock
- Deep Hard Rock

2012 Monitoring Network
- Alluvium
- Deep Hard Rock

2014 Monitoring wells
- Alluvium

- Surface Water Features
- Mount Owen Project Area

Alluvium Thickness (m)
- 0 - 10
- 11 - 20
- 21 - 30
- 31 - 40
- >41

0 1.5
Kilometres

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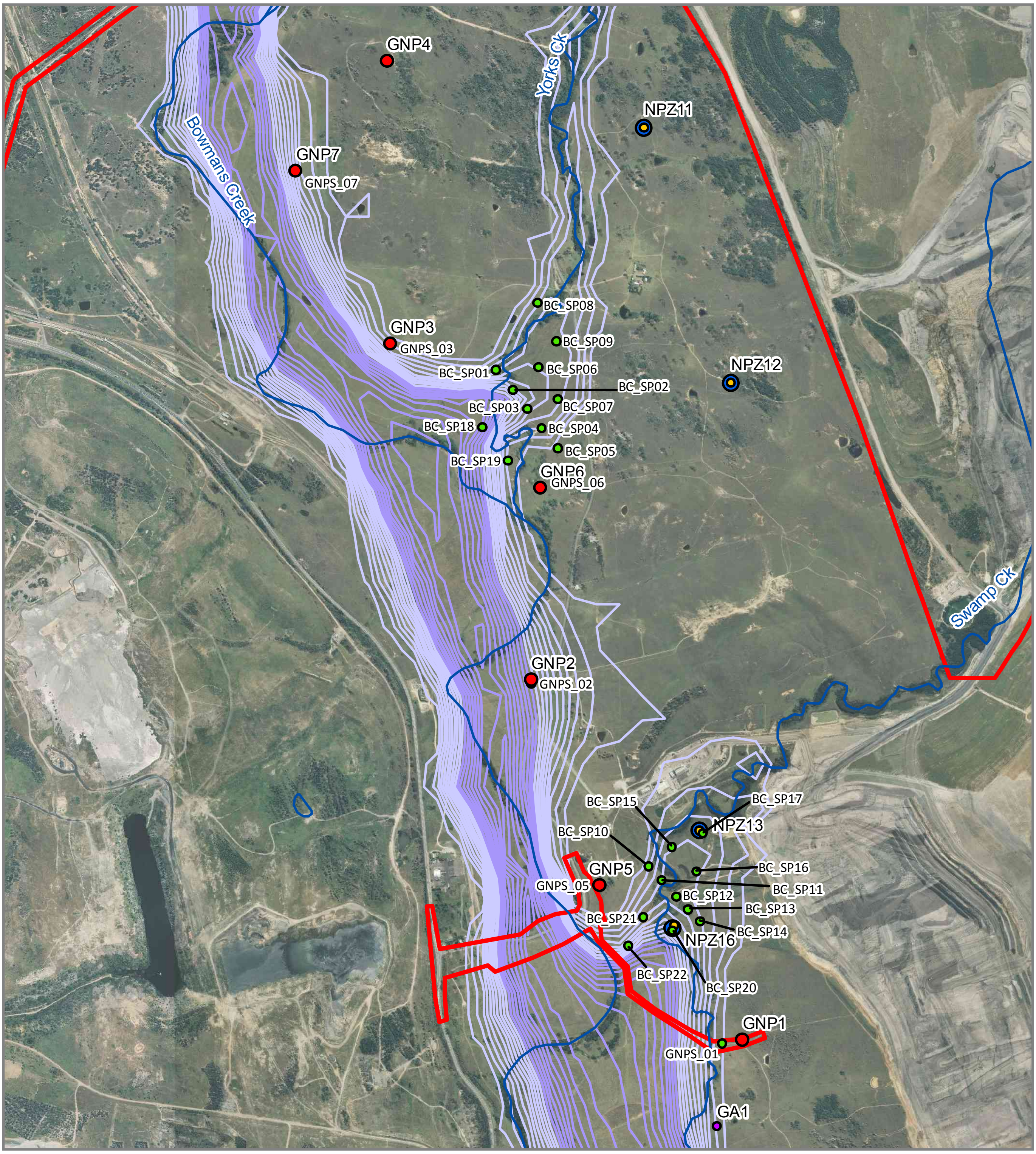
GDA 1994 MGA Zone 56

QLD
NSW
SYDNEY
ACT
JBT
VIC

File Name: Figure 2-9 MOCO GIA_MOC Existing Monitoring Network
Prepared by: CD
Checked by: RC

Figure 2-9 Mount Owen Complex groundwater monitoring network (inset: Figure 2-10)

JACOBS



LEGEND

Existing Monitoring Network
- Alluvium
- Shallow Hard Rock
- Deep Hard Rock

2012 Monitoring Network
- Alluvium
- Deep Hard Rock

- Surface Water Features
- Mount Owen Project Area

Alluvium Thickness (m)
- 0 - 10
- 11 - 20
- 21 - 30
- 31 - 40
- >41

0 0.6
Kilometres

GDA 1994 MGA Zone 56

File Name: Figure 2-10 MOCO GIA_Monitoring Network_Inset
Prepared by: CD
Checked by: RC

Figure 2-10 Mount Owen Complex groundwater monitoring network (detail inset)

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Table 2-7 – Pre-2012 Mount Owen Complex Groundwater Monitoring Network

Monitoring Location	Easting	Northing	Elevation	Drilled Depth	Target Aquifer / Lithology
North	323156	6414020	140.65	--	Bettys Creek Alluvium
East	323332	6412810	153.49	--	Hard Rock Aquifer
South	322157	6412294	110.93	--	Hard Rock Aquifer
NPZ1 NPZ1a	323213	6413286	126.2	60 m 130 m	Shallow Hard Rock Aquifer Deep Hard Rock Aquifer
NPZ3 NPZ3a	321182	6410365	93.53	30 m 60 m	Shallow Hard Rock Aquifer Deep Hard Rock Aquifer
NPZ4 NPZ4a	319534	6415151	124.84	60 m 110 m	Shallow Hard Rock Aquifer Deep Hard Rock Aquifer
NPZ6 NPZ6a	322577	6410410	125.74	65 m 102 m	Shallow Hard Rock Aquifer Deep Hard Rock Aquifer
NPZ7 NPZ7a	323811	6410786	95.38	62 m 110 m	Shallow Hard Rock Aquifer Deep Hard Rock Aquifer
NPZ8 NPZ8a	324761	6412715	120.02	60 m 130 m	Shallow Hard Rock Aquifer Deep Hard Rock Aquifer
NPZ9 NPZ9a	320643	6412905	113.86	22 m 50 m	Shallow Hard Rock Aquifer Deep Hard Rock Aquifer
NPZ10 NPZ10a	320961	6411696	116.62	27 m 61 m	Shallow Hard Rock Aquifer Deep Hard Rock Aquifer
NPZ11 NPZ11a	318061	6412639	100.68	61 m 102 m	Shallow Hard Rock Aquifer Deep Hard Rock Aquifer

Monitoring Location	Easting	Northing	Elevation	Drilled Depth	Target Aquifer / Lithology
NPZ12 NPZ12a	318439	6411522	112.25	48 m 97 m	Shallow Hard Rock Aquifer Deep Hard Rock Aquifer
NPZ13 NPZ13a	318297	6409571	77.98	70 m 134 m	Shallow Hard Rock Aquifer Deep Hard Rock Aquifer
NPZ14 NPZ14a	319468	6407091	74.59	51 m 91 m	Shallow Hard Rock Aquifer Deep Hard Rock Aquifer
NPZ15 NPZ15a	320785	6407938	81.6	59 m 130 m	Shallow Hard Rock Aquifer Deep Hard Rock Aquifer
NPZ16 NPZ16a	318181	6409127	75.7	60 m 173 m	Shallow Hard Rock Aquifer Deep Hard Rock Aquifer
GA1	318468	6408316	73.1	--	Swamp Creek Alluvium
GA2	318667	6407429	69.53	--	Swamp Creek Alluvium

Table 2-8 – Supplemental Monitoring Network (2012 to 2014)

Monitoring Location	Easting	Northing	Elevation (mAHD)	Drilled Depth (m)	Target Aquifer / Lithology	Construction Details
2012						
GNP1	318491.93	6408640.89	76.75	231	Hard Rock Aquifer	Vibrating Wire Piezometer (VWP)
GNP2	317563.62	6410219.84	78.26	270	Hard Rock Aquifer	VWP
GNP3	316945.51	6411691.07	84.96	237	Hard Rock Aquifer	VWP
GNP4	316930.70	6412932.21	111.44	282	Hard Rock Aquifer	VWP
GNP5	317864.69	6409316.69	86.26	285	Hard Rock Aquifer	VWP
GNP6	317604.61	6411061.15	80.81	216	Hard Rock Aquifer	VWP

Monitoring Location	Easting	Northing	Elevation (mAHD)	Drilled Depth (m)	Target Aquifer / Lithology	Construction Details
GNP7	316530.74	6412451.70	89.57	255	Hard Rock Aquifer	VWP
GNP8	319387.7	6407393	82.89	120	Hard Rock Aquifer	VWP
SMC002	322098.3	6410658.3	113.01	213	Hard Rock Aquifer	VWP
SMO023	322088.1	6411418	110.85	219	Hard Rock Aquifer	VWP
MOP812	324128.6	6414863.5	199.73	300	Hard Rock Aquifer	VWP
SMO028	323345.7	6411410.5	109.65	183	Hard Rock Aquifer	VWP
BC-SP01	317410	6411576	85.16	4.4	Yorks Creek and Bowmans Creek Alluvium	Standpipe piezometer
BC-SP02	317483	6411487	83.51	8.7	Yorks Creek and Bowmans Creek Alluvium	Standpipe piezometer
BC-SP03	317547	6411405	82.94	7.5	Yorks Creek and Bowmans Creek Alluvium	Standpipe piezometer
BC-SP04	317610	6411320	82.27	8.9	Yorks Creek and Bowmans Creek Alluvium	Standpipe piezometer
BC-SP05	317680	6411232	84.36	9.0	Yorks Creek and Bowmans Creek Alluvium	Standpipe piezometer
BC-SP06	317596	6411588	85.71	9.3	Yorks Creek Alluvium	Standpipe piezometer
BC-SP07	317681	6411448	86.28	10.2	Yorks Creek Alluvium	Standpipe piezometer
BC-SP08	317592	6411869	88.68	8.5	Yorks Creek Alluvium	Standpipe piezometer
BC-SP09	317675	6411703	87.12	8.2	Yorks Creek Alluvium	Standpipe piezometer
BC-SP10	318080	6409400	77.43	6.0	Swamp Creek Alluvium	Standpipe piezometer
BC-SP11	318137	6409337	76.00	9.4	Swamp Creek Alluvium	Standpipe piezometer
BC-SP12	318201	6409265	76.18	6.3	Swamp Creek Alluvium	Standpipe piezometer
BC-SP13	318253	6409210	76.18	3.5	Swamp Creek Alluvium	Standpipe piezometer
BC-SP14	318305	6409158	76.06	5.9	Swamp Creek Alluvium	Standpipe piezometer
BC-SP15	318182	6409484	76.35	5.0	Swamp Creek Alluvium	Standpipe piezometer
BC-SP16	318290	6409376	76.10	4.6	Swamp Creek Alluvium	Standpipe piezometer
BC-SP17	318319	6409543	77.00	6.5	Swamp Creek Alluvium	Standpipe piezometer

Monitoring Location	Easting	Northing	Elevation (mAHD)	Drilled Depth (m)	Target Aquifer / Lithology	Construction Details
BC-SP18	317350	6411325	82.08	3.8	Bowmans Creek Alluvium	Standpipe piezometer
BC-SP19	317462	6411178	80.90	2.1	Bowmans Creek Alluvium	Standpipe piezometer
BC-SP20	318184	6409118	74.87	4.5	Swamp Creek and Bowmans Creek Alluvium	Standpipe piezometer
BC-SP21	318057	6409176	76.08	6.7	Swamp Creek and Bowmans Creek Alluvium	Standpipe piezometer
BC-SP22	317992	6409051	74.15	6.0	Bowmans Creek Alluvium	Standpipe piezometer
GNPS-01	318403	6408621	74.013	3.0	Bowmans Creek Alluvium	Standpipe piezometer
GNPS-02	317564	6410201	76.82	9.2	Bowmans Creek Alluvium	Standpipe piezometer
GNPS-03	316946	6411686	84.94	2.8	Bowmans Creek Alluvium	Standpipe piezometer
GNPS-05	317865	6409311	82.23	10.5	Bowmans Creek Alluvium	Standpipe piezometer
GNPS-06	317605	6411062	79.55	9.9	Bowmans Creek Alluvium	Standpipe piezometer
GNPS-07	316530	6412448	90.00	3.3	Bowmans Creek Alluvium	Standpipe piezometer
2013 - 2014						
NPZ101	324046	6410343	83	13	Main Creek Alluvium	Standpipe piezometer
NPZ102	324489	6412637	121	9	Main Creek Alluvium	Standpipe piezometer
NPZ103	321177	6410370	92.03	6	Bettys Creek Alluvium	Standpipe piezometer
NPZ104	321028	6408055	80	6	Bettys Creek Alluvium	Standpipe piezometer
NPZ105	323022	6408934	84	9	Main Creek Alluvium	Standpipe piezometer
NPZ106	321091	6408918	93	7	Bettys Creek Alluvium	Standpipe piezometer

Continuous groundwater pressure data are available since 2005 for the existing monitoring network for Mount Owen Complex. Hydrographs are displayed in **Figure 2-11** and **Figure 2-12** for single and dual (nested) piezometers targeting the alluvium (triangles), shallow (circles) and deep (crosses) hard rock aquifers, along with the cumulative rainfall deviation from the mean (taking a segment of the long-term record, hence the imbalanced curves) for the local area represented by the rainfall record at BoM Station 61270 (Bowmans Creek (Grenell)). Groundwater level data for the shallow and deep hard rock aquifers do not appear to be influenced by rainfall, with groundwater pressures generally remaining constant or decreasing despite wetter than average rainfall conditions since 2008. Unconsolidated alluvial deposits would typically be expected to exhibit a correlation between groundwater levels and rainfall as a consequence of their fast recharge rates.

Figure 2-11 and **Figure 2-12** show groundwater level data for nested piezometers (the NPZ-series bores) generally illustrate higher groundwater pressures in the deeper bore relative to the shallow bore. Such upward pressure gradients have been observed in other environmental assessments for the region (Ashton, 2009a) and suggest that under natural (e.g. pre-mining) conditions groundwater likely discharges from the deeper hard rock aquifer upward towards the overlying alluvial aquifers and associated surface streams.

Those bores closest to mining operations (*see* **Figure 2-9**) clearly show drawdown effects with time. This is particularly for the deeper bores, while many shallow bores show no impacts (*e.g.* East, North, NPZ8, NPZ10, NPZ11). As discussed in **Section 2.1**, extensive coal mining activities have been undertaken in the region for many years, resulting in significant depressurisation of the regional hard rock aquifer and corresponding effects on the local hydrogeological regime. Hydrographs for piezometer South and nested piezometers NPZ1, NPZ3, NPZ6, NPZ7, NPZ8, and NPZ11 through NPZ16 all show decreasing groundwater pressures during the monitoring period. Given the extensive mining activities at Mount Owen Complex and adjacent operations (*e.g.* Integra Underground; Ashton), such depressurisations are likely a result of dewatering and other activities required to accommodate such operations.

To date groundwater level measurements collected for the shallow standpipe piezometers installed in the alluvial aquifers of Yorks Creek, Swamp Creek and Bowmans Creek since 2012 and Main Creek, Bettys Creek and Glennies Creek since 2013 (refer **Figure 2-10**) indicate varying water levels in the alluvium ranging from two to twelve metres below ground surface (**Figure 2-13**), with standpipes installed within the higher alluvial terrace deposits remaining dry throughout the monitoring period.

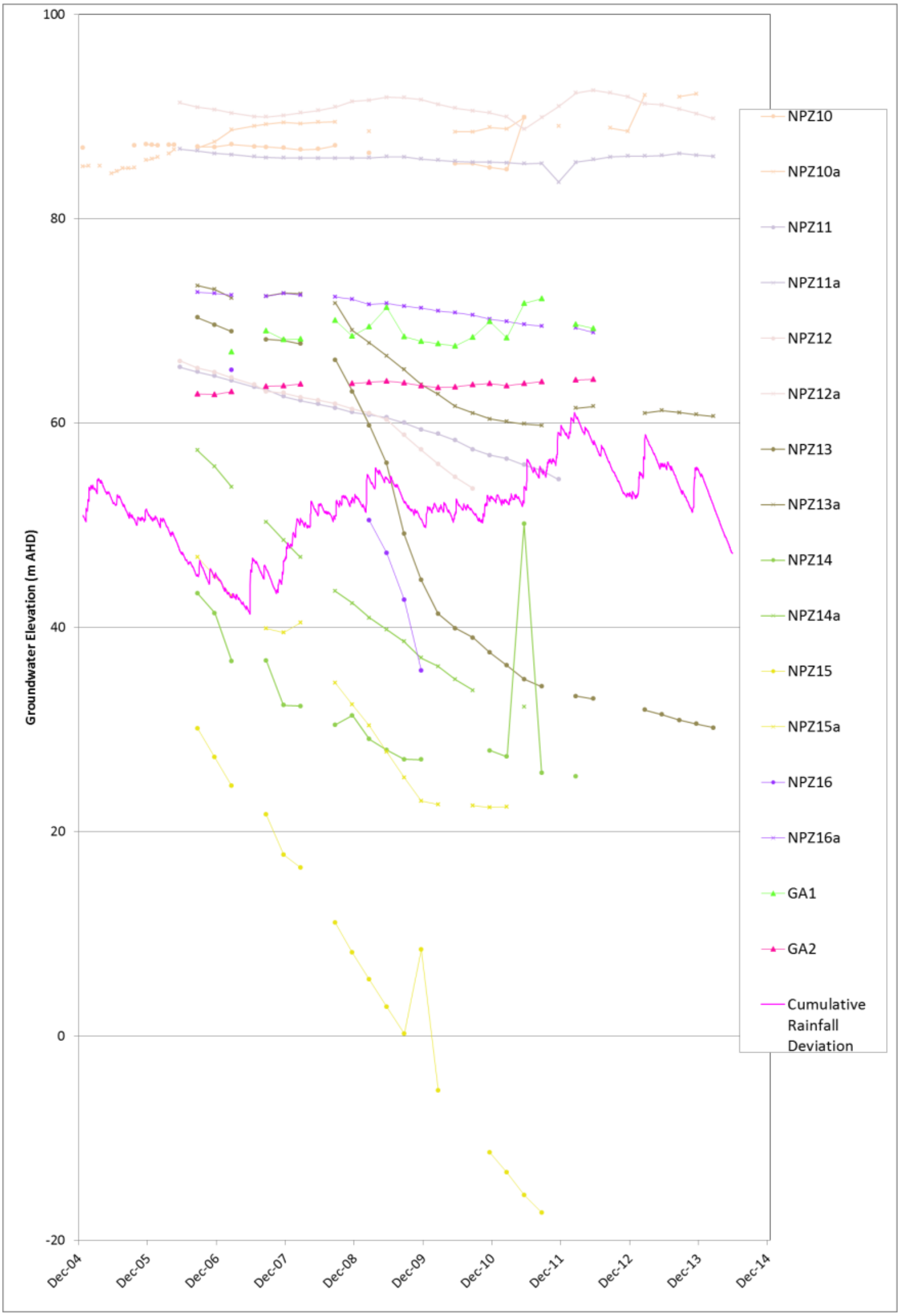
Groundwater pressure data collected to date by the VWPs installed in 2012 are provided in **Appendix A**. Significantly, piezometer MOP812, in the northeast of the Project area and located on the northern side of the Hunter Thrust, shows groundwater pressures more than 100 m higher than pressures observed in other VWPs around the mining area. This strongly indicates that the Hunter Thrust is a significant barrier to groundwater flow.

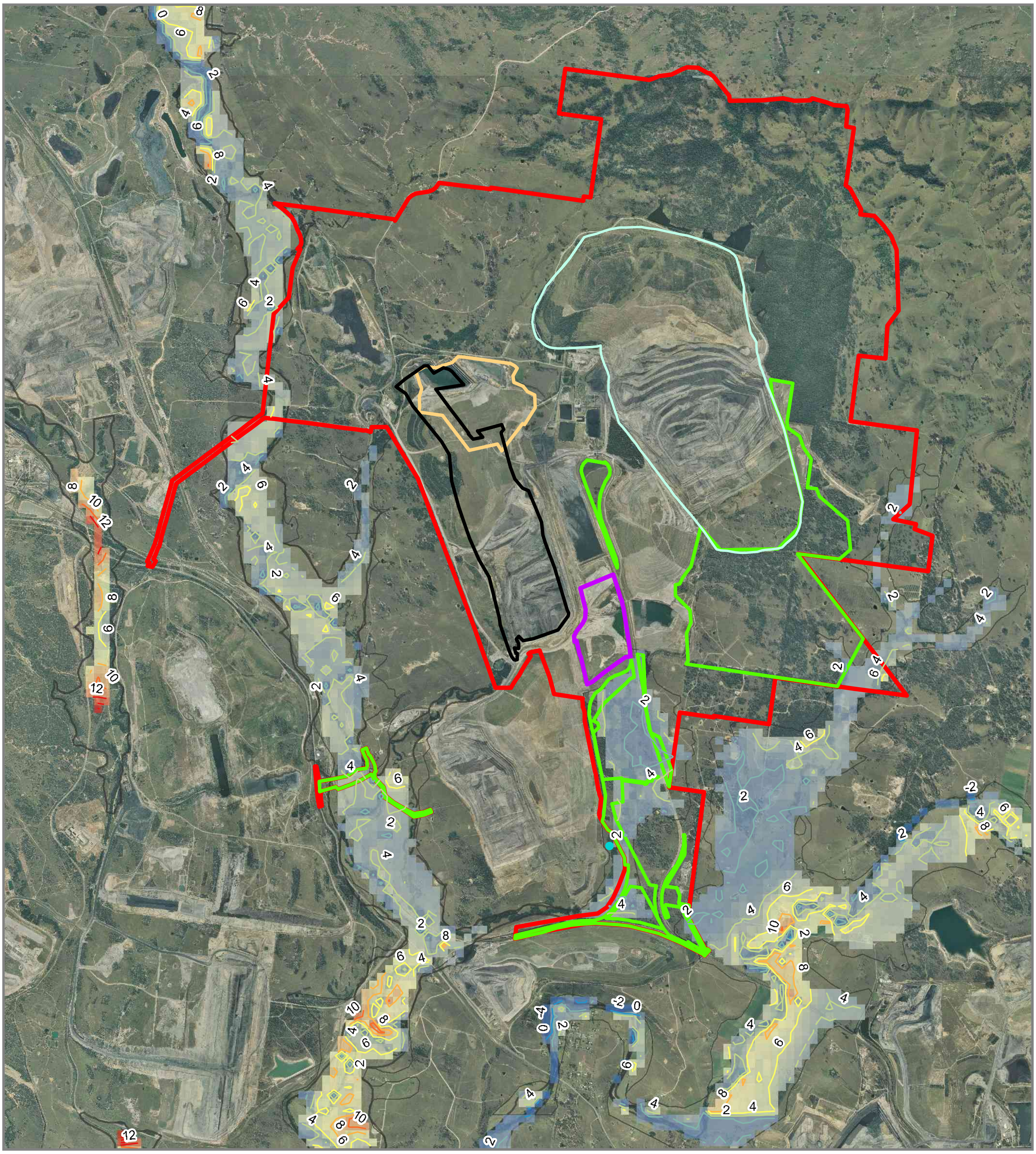
The complexity of the region with respect to mining operations results in water tables that reflect shallow groundwater movement dominated by flow towards major drawdown areas, namely the open cut pits. Further, outside the alluvium aquifers, shallow water tables occur as perched, discrete lenses in the regolith and there is not a contiguous water table across the region. For modelling purposes, however, a contiguous surface is estimated, and the modelled, end of calibration, water table surface is illustrated in **Figure 2-14** for contextual only.

Figure 2-15 shows the current (as modelled) potentiometric surface for the coal measures aquifers for the targeted (Bayswater) seams. This can be compared to the drawdown impact maps in **Section 3.5.1.2**.

Figure 2-11 – Hydrographs for Monitoring Network Piezometers (eastern bores)

Figure 2-12 – Hydrographs for Monitoring Network Piezometers (western bores)





Legend

Depth to Water Table 2015 (metres below ground level)

- 0
- 2
- 4
- 6
- 8
- 10
- >10
- Mount Owen Project Area
- West Pit
- Bayswater North Pit
- Mount Owen Disturbance Area
- Approved North Pit Shell
- RERR Mining Area
- Alluvium Extent

0 0.5 1 2 Kilometers

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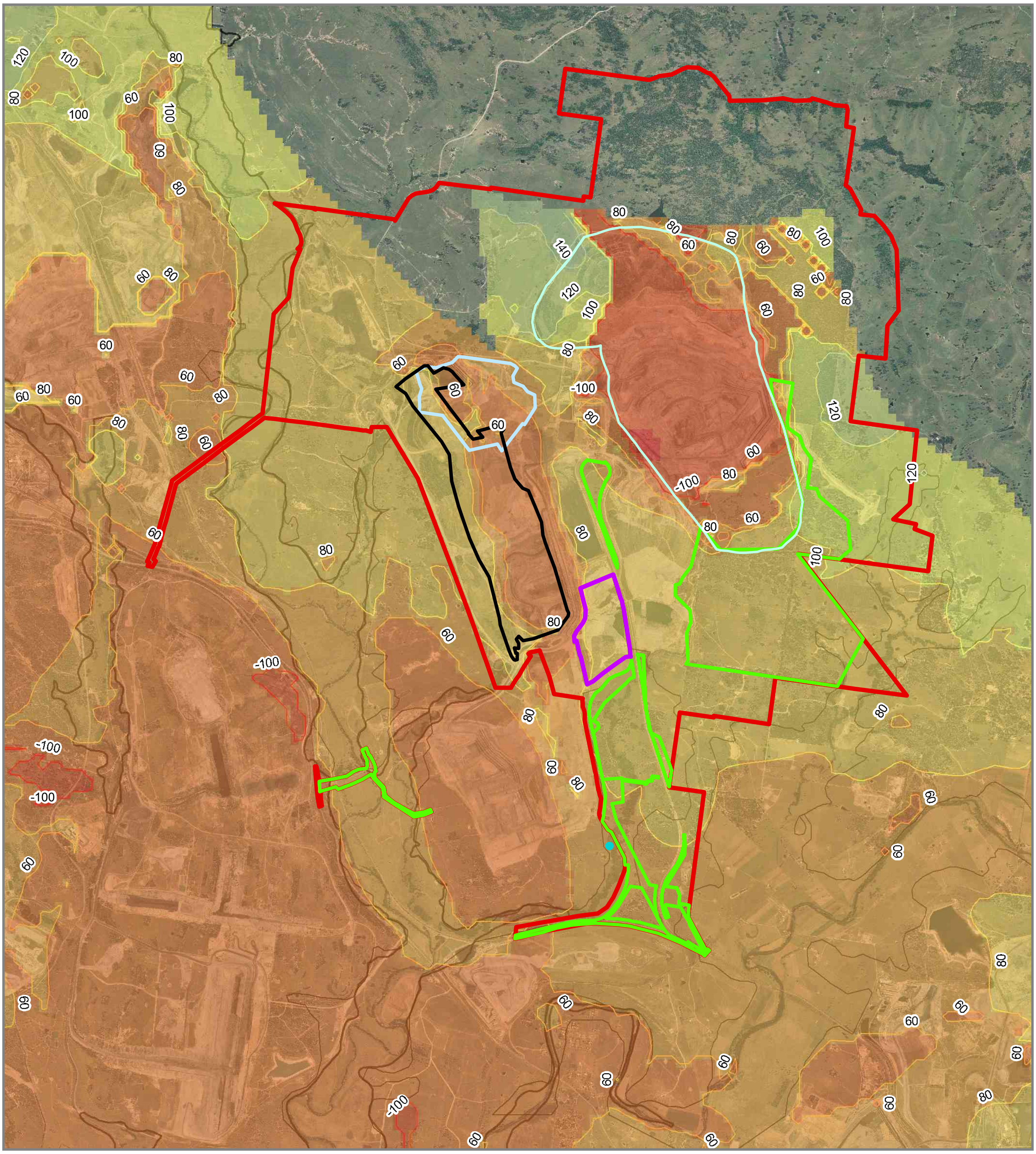
File Name: Figure 2-13 MOCO GIA_Modelled depth to water table for 2014_v2
Prepared by: LS
Checked by: RC

Figure 2-13 Modelled depth to water table for 2014 (Base Case Scenario)

JACOBS



Legend

Water table elevation (mAHD)

- -100
- 60
- 80
- 100
- 120
- 140
- 160
- 180
- 200

- Mount Owen Project Area
- Mount Owen Disturbance Area
- West Pit
- Bayswater North Pit
- RERR Mining Area
- Approved North Pit Shell
- Alluvium Extent

0 0.5 1 2 Kilometers

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File Name: Figure 2-14 MOCO GIA_Modelled water table for 2014_v2
Prepared by: LS
Checked by: RC

Figure 2-14 Modelled water table for 2014 (Base Case Scenario)

JACOBS

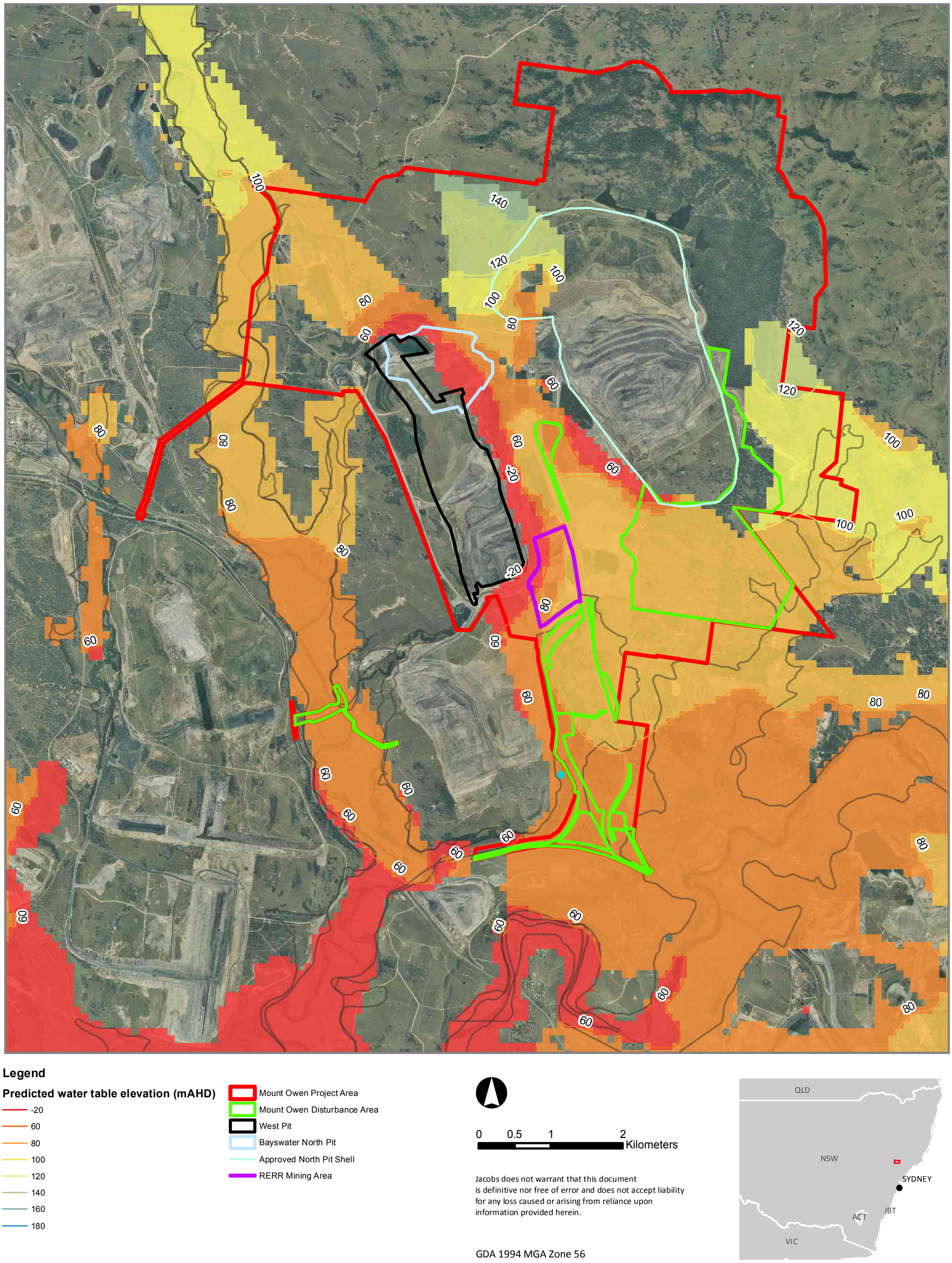

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Figure 2-15 Modelled potentiometric surface for the Bayswater Seam (Layer 4) at the end of calibration (2014 - Base Case Scenario)

JACOBS

File Name: Figure 2-15 MOCO GIA_Modelled potentiometric surface for the Bayswater Seam (Layer 4) at the end of calibration (2014)_v2
Prepared by: LS
Checked by: RC

2.6.5 Groundwater Quality

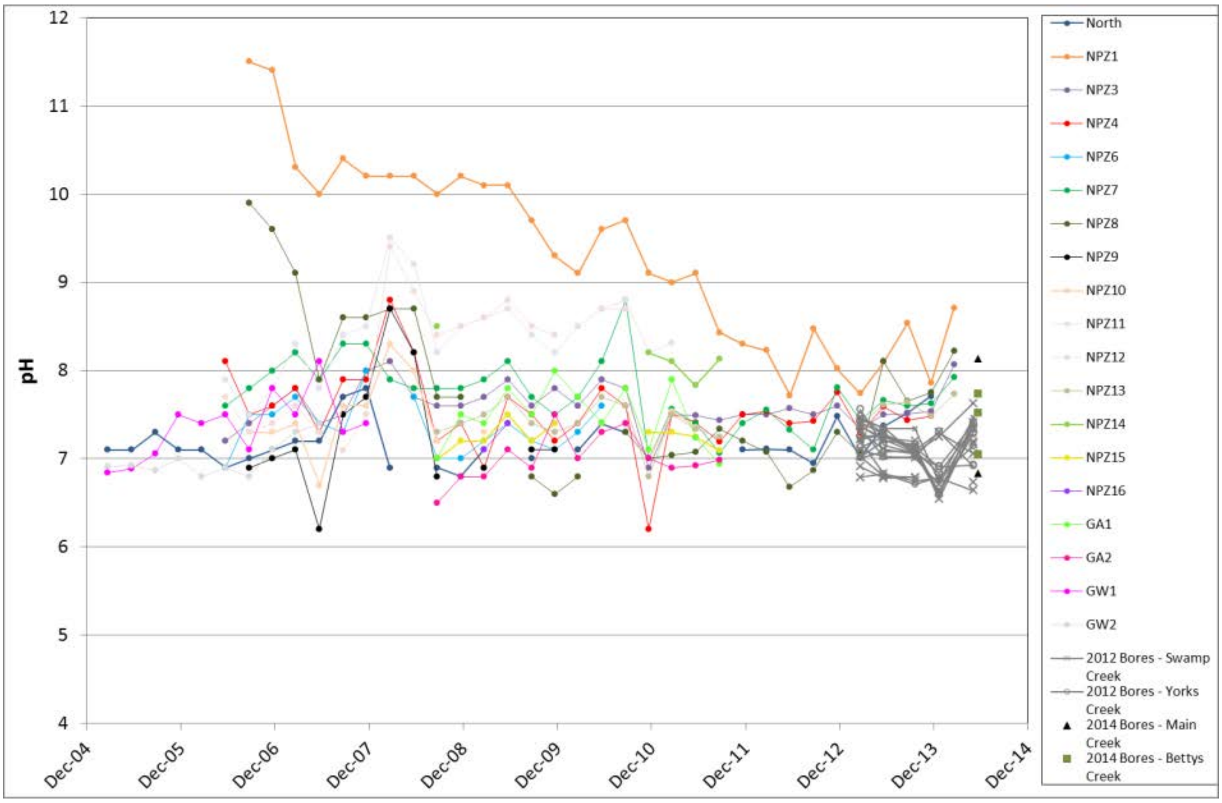
Groundwater quality in the alluvial and hard rock aquifers in the region varies, with water quality in the alluvium generally slightly less saline than in the coal measures. Alluvial groundwater in the region is generally classified as fresh to brackish, while the coal seam aquifers are generally brackish.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

At Mount Owen, the groundwater monitoring program comprises quarterly pH and electrical conductivity (EC) measurements and six monthly analysis of samples for a suite of inorganic substances. **Figure 2-16** shows pH data for piezometers targeting the shallow and deep hard rock aquifer, and **Figure 2-17** and **Figure 2-18** show EC data for the same piezometers.

pH generally varied between 6.5 and 9, values typically found in natural waters, though the range and fluctuations in pH observed over the monitoring period appear to be higher than expected. Piezometers NPZ1 and NPZ8 recorded decreasing pH over the monitoring period. The most recent pH readings at these bores are within the range of values generally found in natural waters (between pH 7 and 8.5), however pH values recorded prior to 2009 were significantly higher (above pH 9) and may reflect incomplete bore development (i.e. the presence of residual drilling muds).

EC readings generally indicate fresh to slightly saline (less than 15,000 µS/cm) waters, though NPZ4 has consistently recorded EC values exceeding 20,000 µS/cm in both shallow and deep piezometers. EC data have generally remained consistent throughout the monitoring period. Exceptions include the alluvial bore GW1 (increasing), shallow bedrock piezometers NPZ3 and NPZ9 (decreasing), and deeper hard rock bores NPZ1a and NPZ8a. The latter two bores both record significant increases in salinity during the monitoring period, though EC levels now reflect salinities observed in other local bores, suggesting that these bores held remnant drilling fluids that have gradually been flushed with more dilute natural groundwaters.

Figure 2-16 – pH Data for Piezometers Targeting the Shallow (top) and Deep (bottom) Hard Rock Aquifer



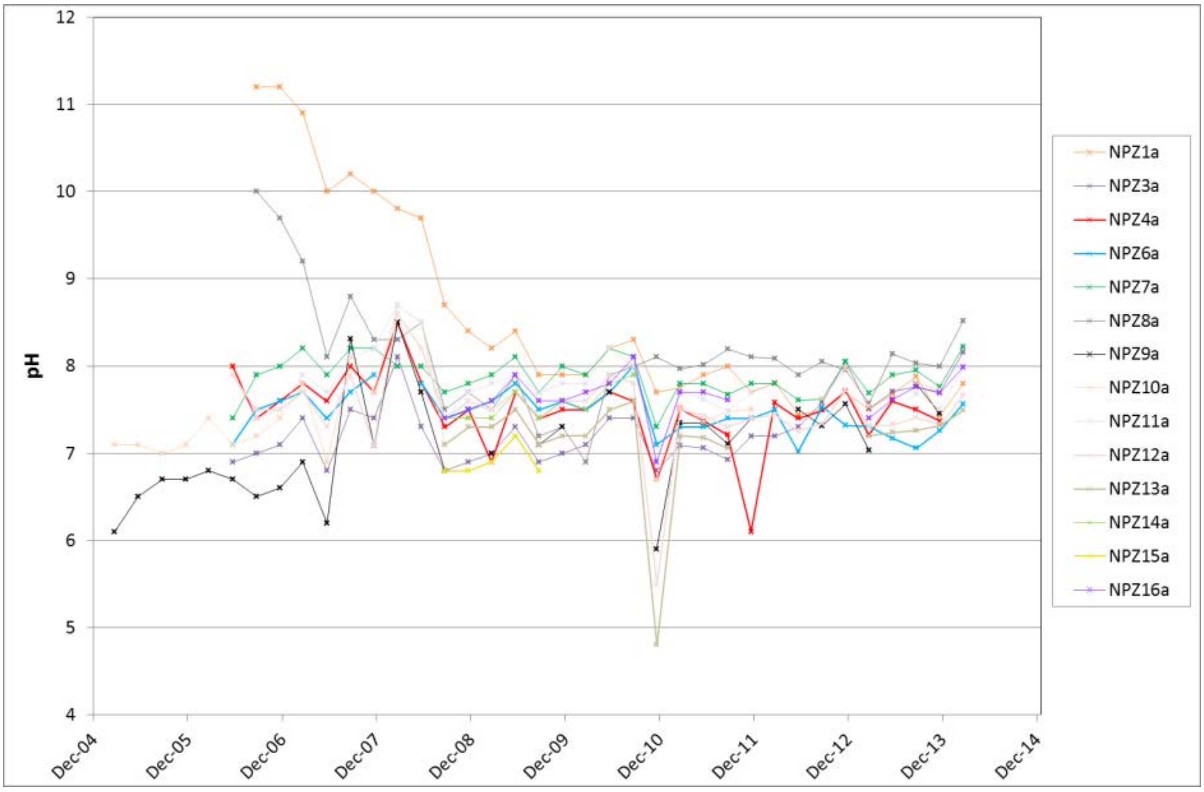


Figure 2-17 – EC Data for Piezometers Targeting the Shallow Hard Rock Aquifer and local alluvial bores

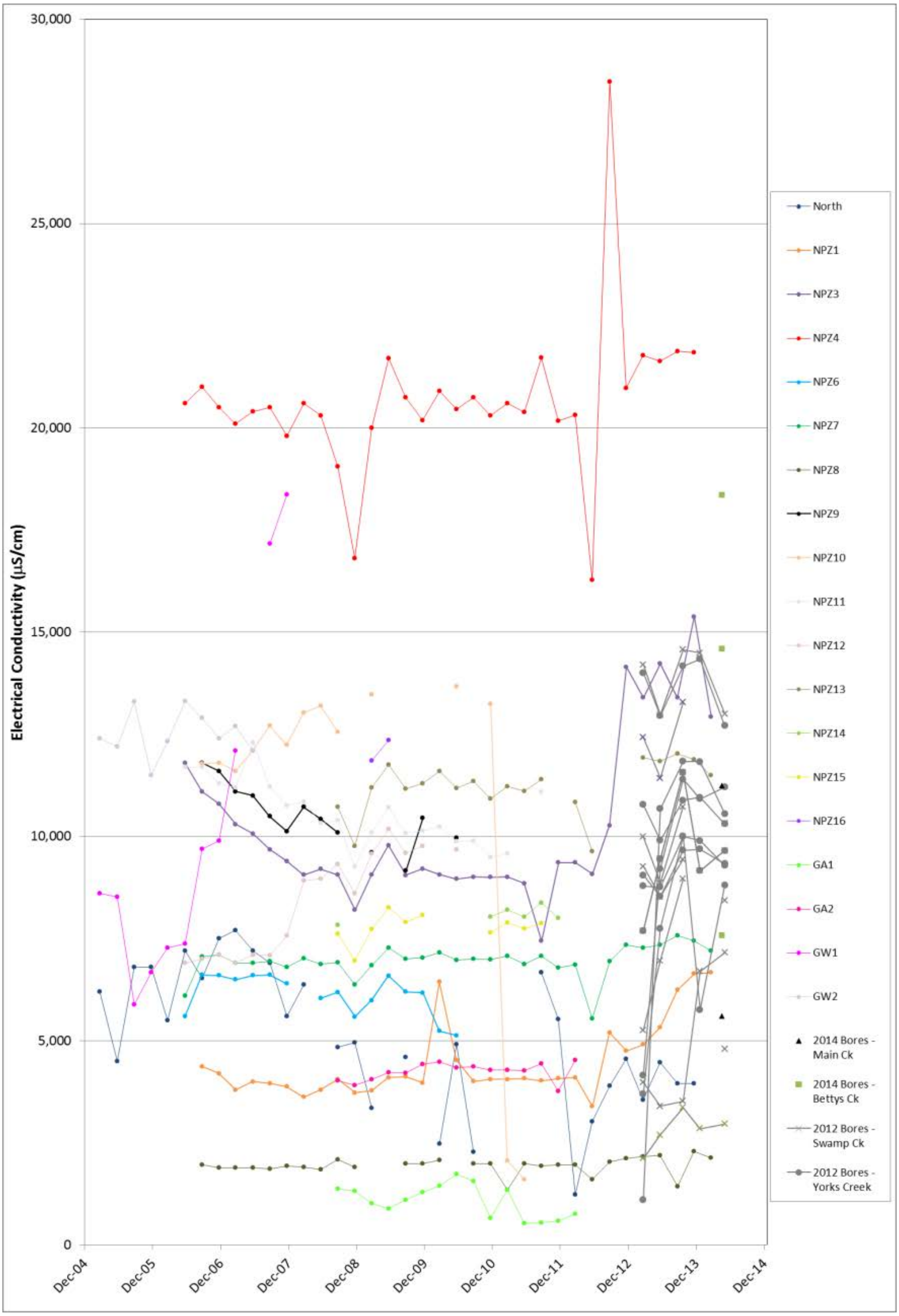
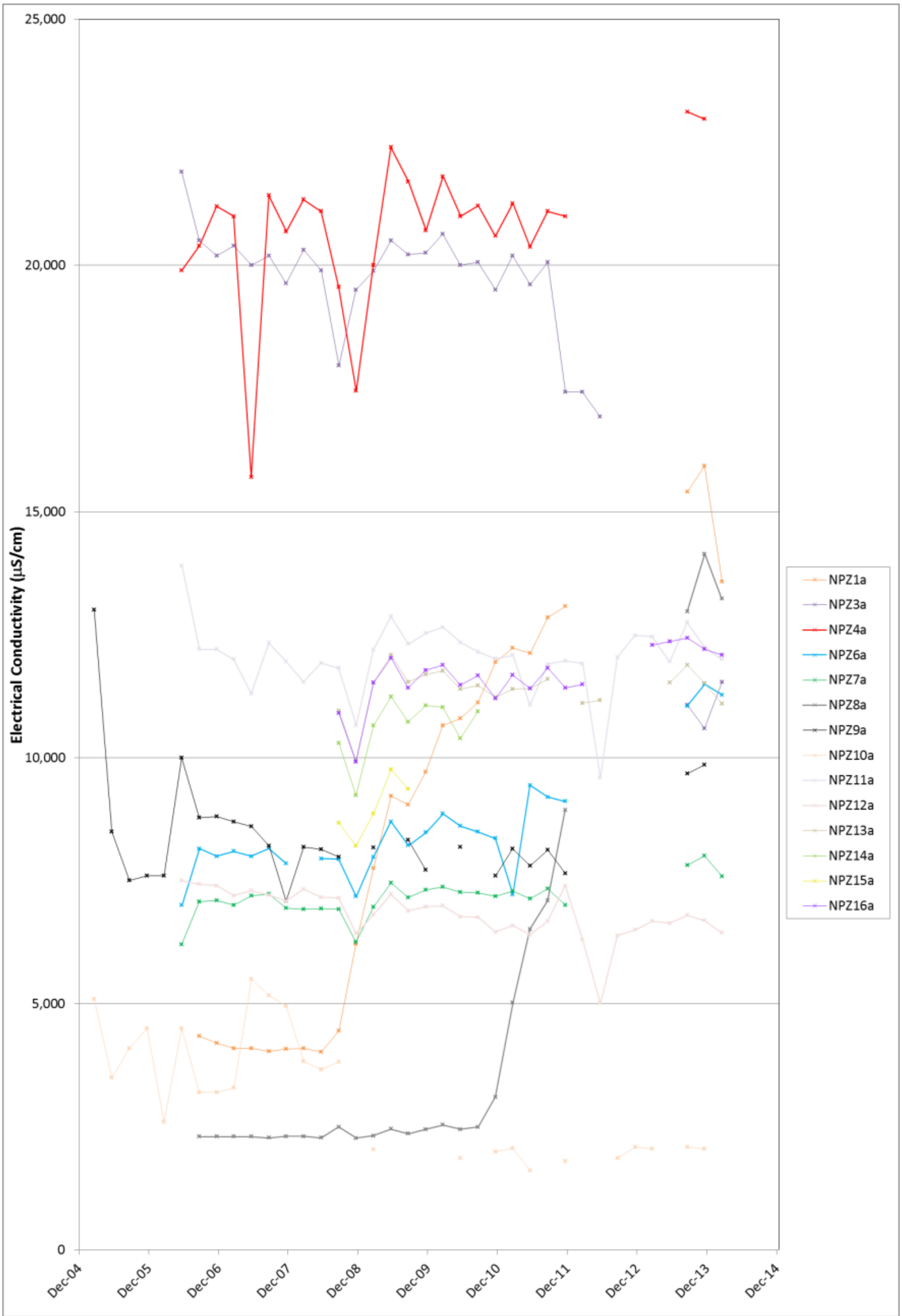


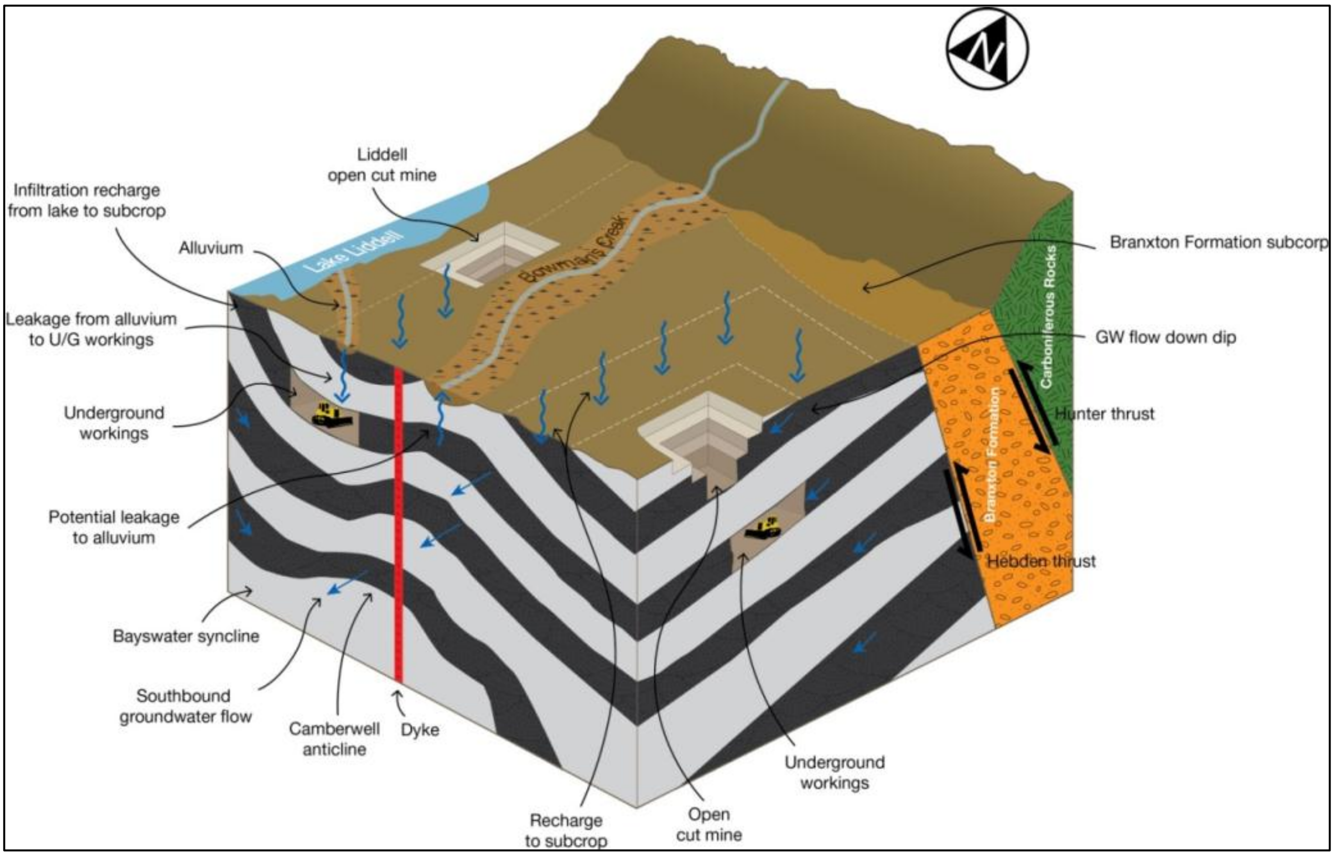
Figure 2-18 – EC Data for Piezometers Targeting the Deep Hard Rock Aquifer



2.6.6 Conceptual Model

Based on the geology and aquifer systems described above, a conceptual model describing the general hydrogeological regime and groundwater relationships present across the Bowmans Creek area was developed (**Figure 2-19**) and has been used to guide the development of the numerical groundwater flow model for the Greater Ravensworth region.

Figure 2-19 – Conceptual Hydrogeological Relationships for the Mount Owen and Liddell Coal Operations *(not to scale)*



The presence of underground workings in the region adds a particular complication to groundwater modelling as hard rock is removed leaving a void, which then collapses to become in-filled with more porous backfill (goaf), resulting in extensive fracturing to some height above the underground workings. These fractured zones have been extensively investigated throughout the Sydney Basin and particularly locally and were cited in the 1980s as responsible for shallow groundwater loss from the alluvial aquifer of Bowmans Creek. This loss was ascribed to fracturing penetrating to the surface as a result of multiple underground workings of LCO which encroached beneath the overlying alluvium. This component of temporal variability in the groundwater model was investigated during the modelling process and is reported below.

Note that water movement (shown by blue arrows in **Figure 2-19**) is indicative only. Actual flow paths for groundwater will be determined by hydraulic gradients. Flux may be positive or negative, that is, up or down, or into or out of a formation, depending on pressure gradients. All arrows should therefore be considered as indicative of the likely dominant flow direction and actual groundwater flow will be influenced by local conditions. In particular, shallow bedrock interactions with the alluvium may change direction of flux in a temporal as well as spatial manner, with variably losing and gaining reaches and seasonal reversals of flow between the two aquifers. During floods, for example, dominant flow will be initially from the alluvium to the bedrock until the bedrock aquifer fills to a point where it discharges back to the alluvium. These processes are incorporated into the numerical modelling described below.

The conceptualisation shown in **Figure 2-19** does not include all mining operations present in the region or all relevant structural features (such as dykes and coal barriers) that have been included in the development of the regional scale numerical groundwater model. However the conceptual model shown identifies the key hydrogeological processes present across the region, including accounting for the effect of current and former open cut and underground mining operations on groundwater flow regimes and the presence of the Hunter Thrust as a barrier to regional groundwater flow.

Hydraulic parameters have been initially incorporated from the earlier RUM model developed by Mackie Environmental Research (MER, 2011b). The layering developed considers the complexity of the region's geology and combines relevant units into single layers as will be described below. Structural features are deduced from existing geological mapping, mine constructions and available hydrogeological data.

Plate 2 – Glennies Creek south of the Mount Owen Complex

3. Groundwater Modelling

3.1 Overview

Jacobs has developed a regional numerical groundwater flow model for the Bowmans Creek and Glennies Creek (or Greater Ravensworth) area in order to provide Glencore with a tool for evaluating potential groundwater impacts that may accompany further development and expansion of mining operations in the area. The model incorporates, to the extent possible, mining operations north of the Hunter River to Lake Liddell, 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 Glennies and Jerrys water sources as defined in the Hunter Regulated and Unregulated and Alluvial WSPs respectively.

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 WSPs under the *Water Management Act 2000* and the AIP (NSW 2012)*,* have supported the development of a regional scale model to assess the potential cumulative impacts of mining operations in the area.

3.1.1 Model 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 Glencore mine operations in the region;
- Provide estimates of 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.

3.1.2 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.

The regional scale model is intended to be updated and refined as Glencore operations and future mining plans within the model domain are developed and/or expanded. Jacobs 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. The model version reflects the progression and updates of the model to its current state, with the version utilised for the groundwater impact assessment for the Project being Model Version 8.1. A summary of the model update log up to and including the version used for this assessment is provided in **Table 3-1**. Other assessments to date that have made use of previous model versions include:

- Groundwater Impact Assessment for the Ravensworth East Resource Recovery (RERR) Environmental Assessment (Version 2.1) – submitted December 2012; and
- Groundwater Impact Assessment for Liddell Coal Operations (LCO) Development Consent Modification 5 Environmental Assessment (Version 6.1 and Version 7.2) – submitted July 2013.

Table 3-1 – Model Update Log

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

Model Version	Model Build	Project	Description of Modification(s)	Model Version Number
7	0	Mount Owen	Representation of Glennies Creek and Main Creek alluvium based upon LIDAR data Refinement of Glendell and Mount Owen approved mine sequences and plans Incorporation of Integra Underground mine Modification of hydrogeological parameters to account for enhanced conductivity above former underground workings and according to depth of overburden Modification of model size and stress periods to accommodate updated mine sequencing Recalibration (steady state and transient) to extended calibration dataset Updated stochastic predictive simulations of proposed operations	7.0
7	1	Mount Owen	Recalibration to refine specific yields	7.1 Mount Owen
	2	Liddell	Incorporation of Liddell base case into Version 7	7.2 Liddell
8	0	Mount Owen	Recalibration of the model to account for: • Changes in ET values: Non-mining areas use Actual Areal Evapotranspiration values for maximum ET rates; • Inclusion of Liddell total dewatering rates for 2012 and 2013 • Inclusion of additional alluvial monitoring data	8.0
8	1	Mount Owen	Predictive simulations for Mount Owen Continued Operations EIS	8.1 Mount Owen

3.1.3 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 are primarily limited to Glencore operations within the region (e.g. Liddell, Mount Owen Complex (including Ravensworth East and Bayswater Pit North), Glendell and Ravensworth underground and surface operations) due to the confidential nature of data from non-Glencore sources, though where possible, summary information is sourced from publicly available reports for such operations. A summary of the data sources used in this report can be found in **Appendix B**.

3.2 Model Design

3.2.1 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 Project Area) available for the study and hence the conceptualisation should be reasonably well founded.
- Calibration has been 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 Project Area, and there are multiple measured inflow rates to mines during historic mining operations. As a consequence, calibration has provided some constraint 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 achieved a Class 2 (medium confidence) level. 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 mines in the region and further river gauging and baseflow estimates to help quantify the groundwater contribution to the major rivers and streams included in the model.

3.2.2 Model Description

The model constructed was based on the RUM model (MER, 2011b) and extended to the north and east to include LCO and Mount Owen operations. 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 model cells 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:

- Pumping from private bores;
- Flooding events or high river stage recharge; or
- Calibration to baseflow, although a comparison for reasonableness has been provided.

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.

3.2.3 Model Domain

The model domain measures 20.5 km in the north-south direction and 22.1 km in the east-west direction. Grid cells are 100 m by 100 m, resulting in a model grid of 205 rows and 221 columns. The model contains 675,660 active cells in total. The extent of the model domain is shown in **Figure 3-1**. Model cells were designated inactive in areas where coal seams belonging to the Vane Subgroup are not present, such as in the northwest and southeast corners of the model domain and north of the Hunter Thrust.

Plate 3 – Looking north at the Hunter Thrust, north of the Mount Owen Complex

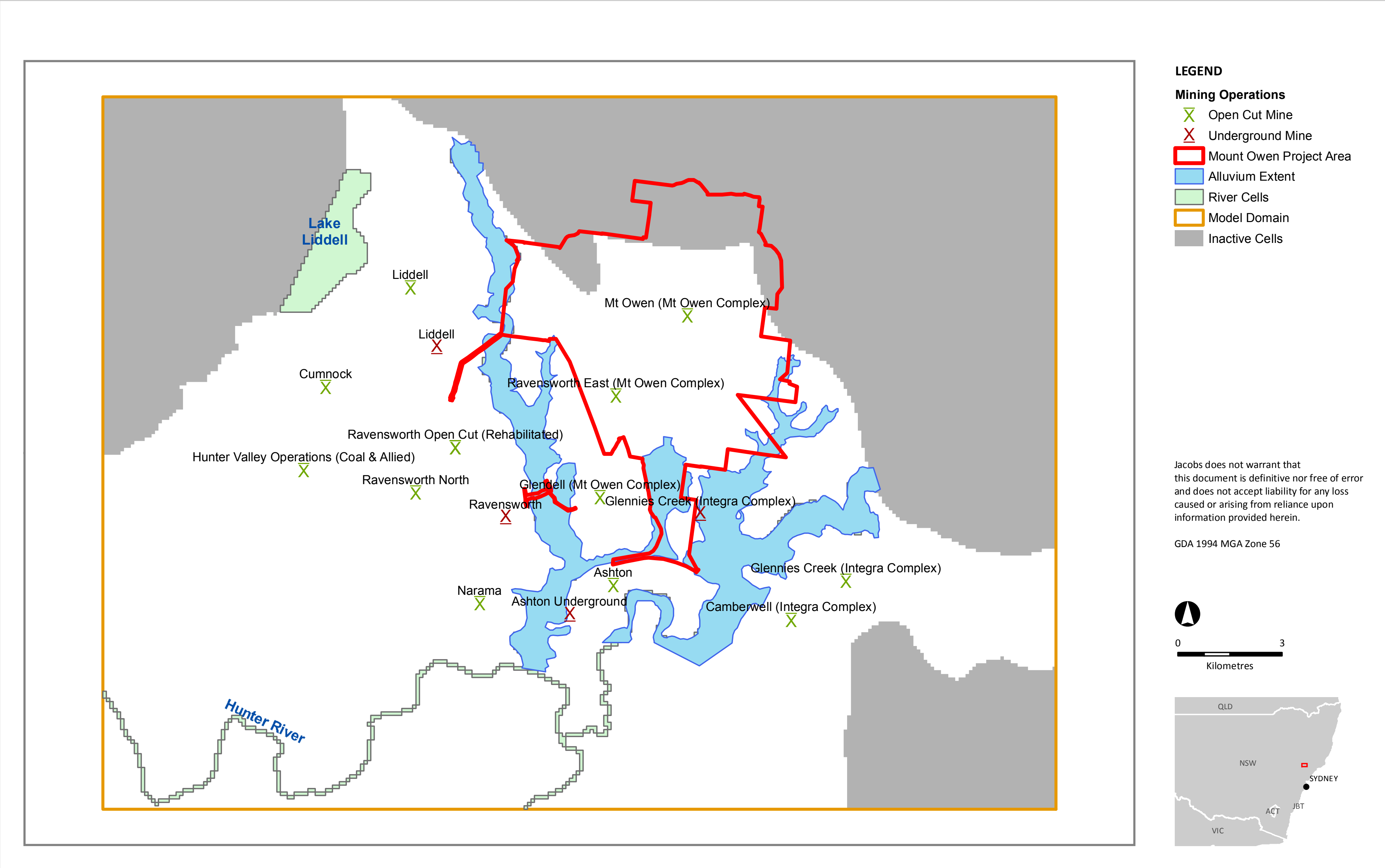


Figure 3-1 - Model Domain

JACOBS

File Name: Figure 3-1 MOCO GIA_Model Domain
Prepared by: CD
Checked by: RC

3.2.4 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 3-2**.

Table 3-2 – 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 Barrett B, middle Barrett B, lower Barrett B, Barrett C1, Barrett 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.

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 Mount Owen), 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. For those areas included within the area of the LiDAR data set, the top of layer 1 is defined by ground surface as delineated in the LiDAR data.

- Alluvial deposits are included in the uppermost layer of the model (layer 1). 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 were initially 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 extent and depth of the model layer representing the alluvial aquifers was further refined based on the LiDAR data and 41 borehole logs that constrain the thickness of the alluvium (**Table 3-3**). This resulted in the alluvium layer shown in **Figure 3-1**. The alluvium thickness was set to 1 m along the boundaries of the alluvium extent. Outside the areas where alluvium is present the top model layer is uniformly 1 m thick.

Table 3-3 – Boreholes used to determine alluvium thickness in the model

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

- Layer 2 of the model represents some areas of alluvial sediments within river valleys and regolith elsewhere.

- The top and bottom of 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 Mount Owen geological model. Beyond these mine extents, layer elevations from the original RUM model (MER, 2011b) were used where correspondence exists between the RUM and regional scale model layering.

- The sub-crop locations for the individual seams are not known with accuracy outside the Liddell and Mount Owen geological models. The Bayswater Seam was assumed to sub-crop where the Jerrys Plain Subgroup does, while the Pikes Gully, Arties, Liddell, Barrett and Hebden Seams were assumed to sub-crop where the Vane Subgroup sub-crops. The sub-crop 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 LCO 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.

3.2.5 Boundary Conditions

Boundary conditions used in the model include general head boundaries, river, stream and drain cells to represent surface water features, and recharge and evapotranspiration packages.

3.2.5.1 General Head Boundaries

General head boundaries (MODFLOW GHB package) were assigned to 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 such general head boundary cells during initial calibration and sensitivity assessments to produce a reasonable piezometric surface.

3.2.5.2 Faults, dykes and barriers

In general, faults and dykes are treated as barriers to flow, unless evidence suggests otherwise. This assumption is supported by observations of distinct groundwater pressure differences either side of the Davis Fault structure and the Hunter Thrust.

3.2.5.3 Surface Water Features

River boundary conditions (MODFLOW RIV package) were assigned to replicate surface water – groundwater interactions for the Hunter River and Glennies Creek and their associated alluvial aquifers as well as Lake Liddell (**Figure 3-2**). River bed elevations in river cells were set to 1 m below the ground surface elevation and a uniform 0.1 m stage was assumed for all rivers.

The MODFLOW Stream Routing Package (STR) is used for replicating the surface water - groundwater interactions of Bowmans Creek. The advantage of using the STR 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.Drain cells (MODFLOW DRN package) were assigned to non-perennial streams (e.g. Swamp, Yorks, Bettys and Main 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.

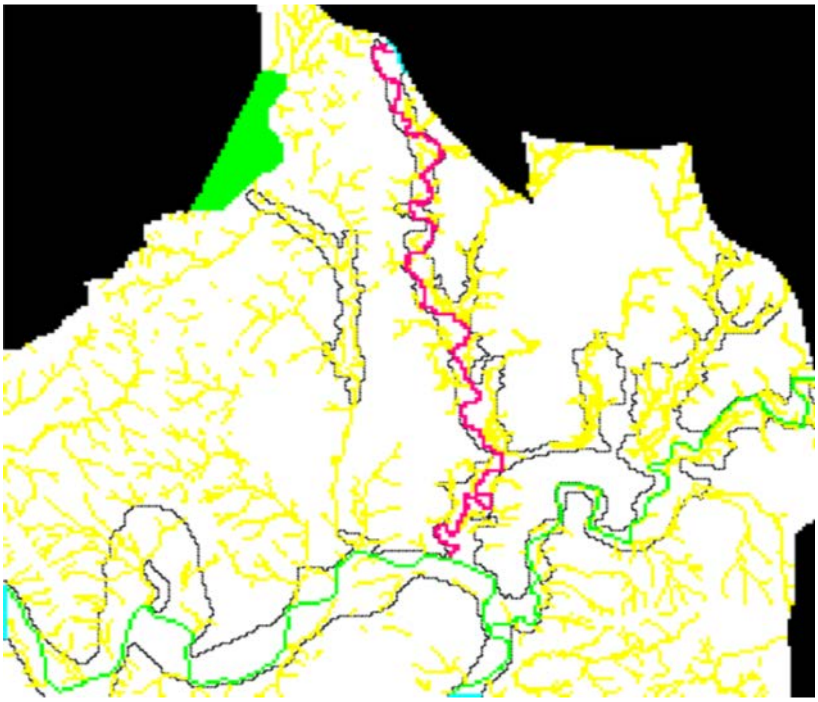
3.2.5.4 Recharge

Recharge (MODFLOW RCH package) was applied to the upper most active model layer at a rate consistent with the surface geology characterisation. Areas of alluvium were calibrated using recharge rates ranging between 3% and 9% average annual rainfall, and other areas were calibrated with recharge rates between 0.0005% and 0.8% average annual rainfall, except for backfilled areas where a range between 1.5% and 9% was used. The recharge rates determined through the calibration process are presented in **Section 3.3**.

3.2.5.5 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 (approximately 1,460 mm/year) with an extinction depth of 2 m for areas where ponded water is likely to occur, such as open voids and pits. For undisturbed or backfilled areas, where groundwater levels are expected to be below ground surface, the maximum evapotranspiration rate is set to actual areal evapotranspiration (www.bom.com.au) (650 mm/year).

Figure 3-2 – Assignment of River (green), Stream (pink) and Drain (yellow) cells to simulate surface water features within the model domain



3.2.6 Regional Mining Operations

The model incorporates historical and currently 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) associated with voids as well as increased storage properties (specific yield), and increased hydraulic conductivity due to cracking above current and former underground. Post-1990 model 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.

In total, the transient model incorporates 38 distinct mining operations with an additional five historic underground operations included in the pre-calibration, steady-state framework. Beyond the Glencore operations (including open cut, underground and dewatering activities), where historic knowledge is directly from the mine, most other operations have been determined from published information held in environmental impact statements, annual operational and monitoring reports and published mine development plans.

Each mining operation is assigned to those of the layers that it impacts and determination is made of the timing of that impact. Drain cells in the model can be turned on and off and hydrogeological parameters varied as necessary to represent each operation at the appropriate time. The relationship (timing and spatial interactions) between layers, operations and timing is described in **Appendix B**.

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 became available. Updates to the model are tracked through the model version protocol described in **Section 3.1.2.**

It should be noted that little accurate de-watering information has been collected prior to this assessment (meters were installed on primary pumping bores at Liddell in 2011 and at Mount Owen in 2013), with de-watering governed by the requirement to maintain specific water levels in underground voids at Liddell and to maintain a dry pit at Mount Owen. Thus, the model uses water-levels in the underground workings to determine the necessary water extraction rates at the respective de-watering bores and makes comparison to pit water dewatering estimates at Mount Owen.

3.2.6.1 Drain Cells

Representation of open cut mining operations in the model comprised the assignment of drain cells to the target seam layer and all model layers above it. For underground operations, drains were 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 was set to the bottom elevation of the target seam layer and layer bottom for layers above the target seam, where appropriate.

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.

Drain cells assignment for each layer are indicated in **Appendix B**.

3.2.6.2 Hydrogeological Parameters

An important feature of the regional scale model was 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 areal and vertical migration and growth of pits and subsequent backfilling sequences. The changes to parameters used to replicate groundwater recovery post-mining are set to take effect in the stress period when each active drain cell first becomes inactive. The multiplier for each HSU was calculated by dividing the new parameter(s) by the starting (i.e. calibrated) parameter(s).

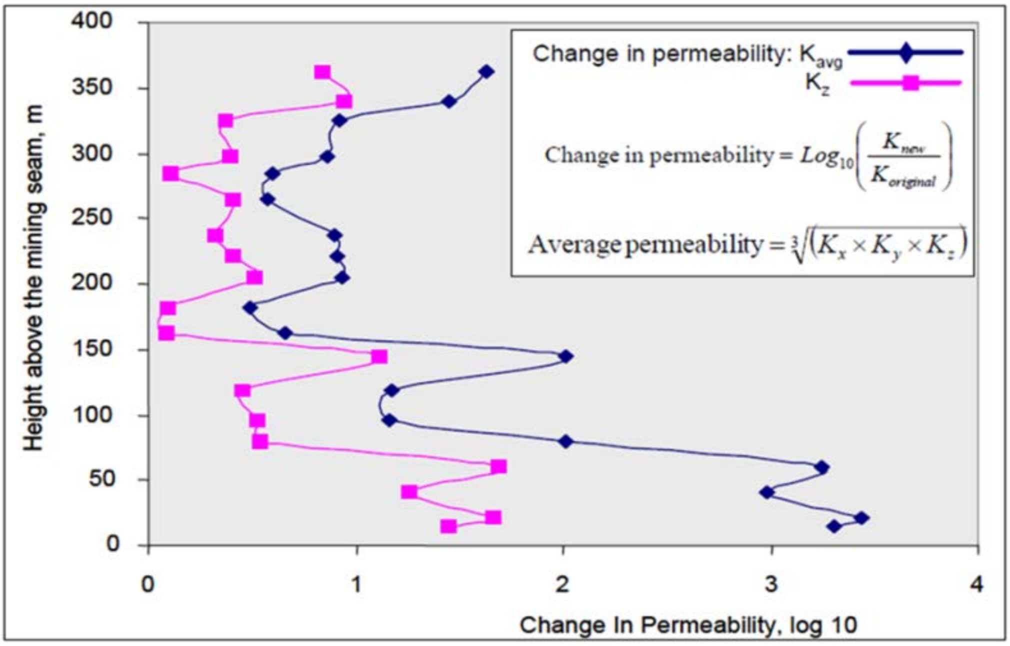
Backfill was assumed to have a hydraulic conductivity of 1 m/day and a specific yield of 0.2 (Mackie, 2009). Multipliers for voids (air) were based on a hydraulic conductivity of 1,000 m/day and a specific yield of one.

3.2.6.3 Fracture zones

Fracture zones were included to replicate the historic cracking that has occurred above all underground workings. Vertical propagation of the fracture zones assumed in the model were obtained from observations of the relationship between the extent of fracturing and the seam and longwall height at the Integra Underground Operations to the south-east (Aurecon, 2012 - **Figure 3-3**). Fracture zones in the model are assumed to extend over a thickness of 200 m above the base of the respective underground workings. To facilitate the change in hydraulic parameters, multipliers were applied to the inherent hydraulic conductivities in units above and across the entire extents of the cells above the underground workings accordingly to the scheme developed by Guo, et al. (2007)(**Figure 3-3**) and is scaled to represent the workings, goaf and enhanced fracturing as these change through time. Thus, three zones of hydraulic conductivity (K_h and K_z) are assigned to time steps as mining progressed through the workings to goaf to enhanced fracturing phases of development.

Specific yields are only changed in the workings after the initial de-watering has taken place.

Figure 3-3 – Estimated changes in average vertical permeability with height above underground workings to the east of Bowmans Creek (Aurecon, 2012). (*Inset*: Multiplier equations from Guo, et al., 2007)



Localised zones of cracking that penetrated to the surface were identified above the Liddell Underground Operations to the west of Mount Owen (Umwelt, 2006) and are associated to these workings. While there is reason to believe these zones have self-sealed, there is a possibility cracking may have led to a new equilibrium of enhanced vertical leakage of groundwater through higher permeability zones associated with the cracking (MER, 2001). Adopting a precautionary approach, these suspected cracking features have been implemented in the model using increased vertical conductivity values (1 x 10^{-4} m/day to 5 x 10^{-4} m/day) 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 and surface waters.

3.2.6.4 Recharge and Evapotranspiration

At times when 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 were held constant throughout the model simulation. However the surface from which the maximum depth of influence – 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 were 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 and rehabilitated. Evapotranspiration extinction depths for final voids are kept at 0.2 m after mining activities cease.

3.3 Model Calibration

3.3.1 Methodology

Calibration of the regional scale model was undertaken using a stochastic calibration methodology designed 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.

The stochastic approach was adopted in preference to a deterministic calibration methodology as it is capable of meeting the agreed objectives while offering the additional benefits of providing appropriate predictive uncertainty analysis. This concept is highlighted specifically in the *Australian Groundwater Modelling Guidelines* (Barnett et al., 2012):

The approach taken to model calibration must be linked to the questions that all groups of stakeholders (project proponents, regulators and modellers) are trying to answer. It is important at the start of model calibration to understand the purpose of the model, that is, what the model is intended to predict. It is the desire for accuracy in future predictions that must drive the choices that are made during model calibration.

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 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 in the *Australian Groundwater Modelling Guidelines* (Barnett et al., 2012).

The stochastic calibration methodology comprised the following tasks:

- Generation of initial datasets using Monte Carlo analysis within parameter bounds and constraints determined from the conceptual hydrogeological model and relevant data sources;
- Model simulations using each dataset;
- Comparison of model results to calibration targets, including historical groundwater levels, inflows to North Pit, and dewatering rates at Liddell operations.;
- Establish the set of calibrated datasets; and
- Run predictive simulations using the calibrated datasets.

The number of stochastic datasets required for recalibration of Model Version 8.0 (adopted for this Project) was significantly lower than required for previous model versions. Revisions and outputs from previous model versions and calibration procedures (manual, PEST and stochastic) have allowed for the continued constraint of parameter ranges allowed within the datasets generated using Monte Carlo analysis. As the model continues to be updated and refined, the parameter ranges are expected to be further constrained, reducing the corresponding uncertainty ranges.

3.3.2 Monte Carlo Simulations

The initial datasets were generated automatically using a Monte Carlo simulation program developed by Jacobs. The program allows for the range of values for each parameter to be:

- Distributed as normal, log normal, random, or log random; and
- Selected randomly from their own distribution; 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 they do not 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).

The model parameters used as inputs for the Monte Carlo analysis included hydrogeological parameters (horizontal and vertical hydraulic conductivity, specific yield); conductance terms for river, stream, and general head boundary cells, and recharge rates.

Table 3-4 summarises the range of values within which the model parameters were permitted to vary. The range in values used is based upon the continued refinement and understanding of likely ranges based upon the level of constraint for the parameter bounds from previous model calibrations, which in turn was directly related to field-based and reference information available for the parameters. Therefore, the ranges in values are a reflection of the cumulative knowledge (field based and model calibration revisions) gained to date.

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.

3.3.3 Stress Periods

The transient calibration model simulated the period from 1 January 1980 to 31 December 2012 in 17 stress periods, the first of which was steady state. The steady state stress period was aimed at providing stable initial conditions for the subsequent transient calibration runs. No drain cell boundary conditions representing mining operations are included in the steady-state model. Steady-state does, however, include artefacts of the historical underground workings at Liddell as enhanced conductivity zones representing the impacts of previous underground mining of the Pikes Gully and Liddell Seams.

Early (first four) transient stress periods are represented by blocks of 5 years (1,826 days), followed by a single stress period covering 2000-2002 (731 days). All stress periods from 2002 through to 2030 are represented by annual time-steps (365 days). The sequencing is illustrated in **Appendix B.3.**

Table 3-4 – Parameter Bounds Assigned for Monte Carlo Analysis

		Parameter Bounds			
Model Parameter	**Geologic unit**	**Distribution Type**	**Mean**	**Std Dev[3] (Log(x))**	**Constraints**
Sy	Alluvium	Log Random	1.0E-01	0.25	
Sy	Regolith	Log Random	8.8E-03	0.25	
Sy	Interburden	Log Random	7.4E-03	0.25	
Sy	Bayswater Seams (0-100m)[1]	Log Random	1.3E-02	0.25	
Sy	Bayswater Seams (100-200m)[1]	Log Random	1.3E-02	0.25	
Sy	Bayswater Seams (> 200m)[1]	Log Random	1.4E-02	0.25	
Sy	Archerfield Sandstone	Log Random	8.6E-04	0.25	
Sy	Interburden \ Lemington Seam	Log Random	1.1E-04	0.58	
Sy	Pikes Gully & Liddell Seams (0-100m)[1]	Log Random	5.5E-03	0.25	
Sy	Pikes Gully & Liddell Seams (100-200m)[1]	Log Random	4.6E-04	0.25	
Sy	Pikes Gully & Liddell Seams (> 200m)[1]	Log Random	7.9E-03	0.41	
Sy	Arties Seams (0-100m)[1]	Log Random	8.3E-03	0.25	
Sy	Arties Seams (100-200m)[1]	Log Random	9.8E-03	0.28	
Sy	Arties Seams (> 200m)[1]	Log Random	9.4E-03	0.25	
Sy	Barrett Seams (0-100m)[1]	Log Random	4.9E-03	0.25	
Sy	Barrett Seams (100-200m)[1]	Log Random	1.2E-02	0.37	
Sy	Barrett Seams (>200m)[1]	Log Random	1.2E-03	0.25	
Sy	Underground workings	Log Random	3.3E-01	0.25	
Sy	Hebden Seams (0-100m)[1]	Log Random	1.9E-03	0.25	
Sy	Hebden Seams (100-200m)[1]	Log Random	2.0E-04	0.90	
Sy	Hebden Seams (> 200m)[1]	Log Random	1.2E-03	0.25	
Sy	Interburden	Log Random	2.9E-04	0.25	
Sy	Saltwater Creek Formation	Log Random	2.1E-04	0.25	
Sy	Upper Cumnock Workings	Log Random	5.9E-03	0.25	
Sy	Lower Cumnock Workings	Log Random	6.2E-03	0.25	
Ss (1/m)	All confined units	Fixed	5.0E-06	5.0E-06	
Kx (m/d)	Alluvium	Log Random	7.0E-01	0.29	
Kx (m/d)	Regolith	Log Random	1.2E-02	0.26	
Kx (m/d)	Interburden	Log Normal	6.8E-05	0.38	
Kx (m/d)	Bayswater Seams (0-100m)[1]	Log Normal	5.2E-04	0.25	
Kx (m/d)	Bayswater Seams (100-200m)[1]	Log Normal	2.2E-04	0.25	
Kx (m/d)	Bayswater Seams (> 200m)[1]	Log Normal	3.9E-05	0.25	
Kx (m/d)	Archerfield Sandstone	Log Normal	1.5E-05	0.64	
Kx (m/d)	Interburden \ Lemington Seam	Log Normal	2.5E-05	0.71	
Kx (m/d)	Pikes Gully & Liddell Seams (0-100m)[1]	Log Normal	1.9E-02	0.25	

		Parameter Bounds			
Model Parameter	Geologic unit	Distribution Type	Mean	Std Dev[3] (Log(x))	Constraints
Kx (m/d)	Pikes Gully & Liddell Seams (100-200m)[1]	Log Normal	1.2E-02	0.25	
Kx (m/d)	Pikes Gully & Liddell Seams (> 200m)[1]	Log Normal	1.0E-03	0.25	
Kx (m/d)	Arties Seams (0-100m)[1]	Log Normal	8.3E-02	0.25	
Kx (m/d)	Arties Seams (100-200m)[1]	Log Normal	6.4E-03	0.25	
Kx (m/d)	Arties Seams (> 200m)[1]	Log Normal	1.8E-03	0.25	
Kx (m/d)	Barrett Seams (0-100m)[1]	Log Normal	6.3E-03	0.25	
Kx (m/d)	Barrett Seams (100-200m)[1]	Log Normal	5.7E-03	0.25	
Kx (m/d)	Barrett Seams (>200m)[1]	Log Normal	2.6E-03	0.25	
Kx (m/d)	Underground workings	Log Random	4.6E+01	0.67	
Kx (m/d)	Hebden Seams (0-100m)[1]	Log Normal	3.8E-02	0.38	
Kx (m/d)	Hebden Seams (100-200m)[1]	Log Normal	6.6E-03	0.42	
Kx (m/d)	Hebden Seams (> 200m)[1]	Log Normal	7.2E-04	0.72	
Kx (m/d)	Interburden	Log Normal	1.3E-06	0.25	
Kx (m/d)	Saltwater Creek Formation	Log Normal	4.3E-06	0.68	
Kz (m/d)	Alluvium	Log Random	1.2E-01	0.36	Could not exceed Kx
Kz (m/d)	Regolith	Log Random	3.7E-04	0.30	Could not exceed Kx
Kz (m/d)	Interburden	Log Normal	5.1E-05	0.36	Could not exceed Kx
Kz (m/d)	Bayswater Seams (0-100m)[1]	Log Normal	5.2E-05	0.25	Could not exceed Kx
Kz (m/d)	Bayswater Seams (100-200m)[1]	Log Normal	1.8E-06	0.32	Could not exceed Kx
Kz (m/d)	Bayswater Seams (> 200m)[1]	Log Normal	6.7E-06	0.25	Could not exceed Kx
Kz (m/d)	Archerfield Sandstone	Log Normal	3.9E-07	0.64	Could not exceed Kx
Kz (m/d)	Interburden \ Lemington Seam	Log Normal	2.6E-07	0.80	Could not exceed Kx
Kz (m/d)	Pikes Gully & Liddell Seams (0-100m)[1]	Log Normal	9.4E-05	0.75	Could not exceed Kx
Kz (m/d)	Pikes Gully & Liddell Seams (100-200m)[1]	Log Normal	1.4E-06	0.68	Could not exceed Kx
Kz (m/d)	Pikes Gully & Liddell Seams (> 200m)[1]	Log Normal	1.9E-04	0.52	Could not exceed Kx
Kz (m/d)	Arties Seams (0-100m)[1]	Log Normal	1.7E-03	0.55	Could not exceed Kx
Kz (m/d)	Arties Seams (100-200m)[1]	Log Normal	4.0E-04	0.91	Could not exceed Kx
Kz (m/d)	Arties Seams (> 200m)[1]	Log Normal	9.1E-06	0.50	Could not exceed Kx
Kz (m/d)	Barrett Seams (0-100m)[1]	Log Normal	3.1E-06	1.03	Could not exceed Kx
Kz (m/d)	Barrett Seams (100-200m)[1]	Log Normal	6.7E-05	0.58	Could not exceed Kx
Kz (m/d)	Barrett Seams (>200m)[1]	Log Normal	3.5E-04	0.59	Could not exceed Kx
Kz (m/d)	Underground workings	Log Normal	8.5E+00	0.67	
Kz (m/d)	Hebden Seams (0-100m)[1]	Log Normal	5.8E-04	0.75	Could not exceed Kx
Kz (m/d)	Hebden Seams (100-200m)[1]	Log Normal	1.0E-04	0.71	Could not exceed Kx
Kz (m/d)	Hebden Seams (> 200m)[1]	Log Normal	3.1E-07	1.04	Could not exceed Kx
Kz (m/d)	Interburden	Log Normal	7.2E-08	0.36	Could not exceed Kx
Kz (m/d)	Saltwater Creek Formation	Log Normal	5.1E-06	0.89	Could not exceed Kx

Model Parameter	Geologic unit	Parameter Bounds Distribution Type	Mean	Std Dev[3] (Log(x))	Constraints
Conductance (m^2/d)	Hunter River (River cells)	Log Normal	9.9E+05	1.36	
Conductance (m^2/d)	Glennies Creek (River cells)	Log Normal	8.6E-02	1.77	
Conductance (m^2/d)	Bowmans Creek (Stream cells)	Log Normal	2.5E+01	0.82	
Conductance (m^2/d)	General Head Boundary cells	Log Normal	1.1E+03	1.11	
Recharge[2]	Alluvium	Log Normal	3.6%	0.25	
Recharge[2]	All other coal seam and interburden zones	Log Normal	0.02% - 1.5%	0.25 – 0.91	
Recharge[2]	Backfill	Log Normal	2.0%	1.0	

[1] Following the schema of Mackie, 2009

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

[3] Probability distributions are calculated in log form and then converted to actual values (except S_s = fixed)

3.3.4 Calibration Targets

Five distinct datasets were identified as appropriate calibration targets to determine which sets of model parameters represented calibrated datasets:

- The first calibration target was the matching of historical water levels recorded in alluvial bores associated with Bowmans Creek (including bores ALV1L through ALV8L adjacent to LCO and the BC_SP series bores adjacent Mount Owen) and Glennies Creek (GCP series bores). These bores are shown in **Figure 3-4** and were chosen as initial calibration targets as potential impacts on these alluvial aquifers were specifically identified as a key concern in the DGRs and by NSW Office of Water (refer **Section 1.2**). A target calibration statistic of a 5% scaled root mean squared (SRMS) error was used for the alluvial bores.

- The second calibration target was the matching of historic water levels in shallow hard rock bores located in the vicinity of the Project area, shown in **Figure 3-4**. A target calibration statistic of a <5% SRMS was also used for the project hard rock bores.

- The third calibration target was the matching of historic water levels in all hard rock bores (including those some distance from the Project) with a SRMS <10%.

- An estimated pit inflow to the North Pit of no more than 1.4 ML/day was assigned the fourth calibration target, based on estimated pumping rates and mine-site mass balance modelling (Umwelt, 2014a).

- The fifth calibration target dataset comprised the observed dewatering rates at LCO for 2012 (between13,600 ML/year and 17,000 ML/year) and 2013 (between 2,600 ML/year and 4,700 ML/year).

3.3.5 Calibration Results

The calibration simulations resulted in 748 realisations, or sets of model parameters, that were able to achieve a stable solution (i.e. converged). 648 of these realisations simulated groundwater levels at the alluvial calibration bores within the target calibration criteria of 5% SRMS (the first calibration target), and 536 of these realisations achieved the target calibration criteria of 5% SRMS for the hard rock calibration bores (the second calibration target). All but one of the realisations (535) that met the first two criteria met the third calibration target of less than 10% SRMS for all bedrock bores. 534 of the realisations that met the first three criteria also met the calibration criterion for inflows to the North Pit (fourth criterion). 53 realisations matched the criteria for dewatering rates at the Liddell operations for 2013, although none could match the 2012 dewatering rates. Most realisations predict significantly greater dewatering rates for 2012 than 2013 and, in a qualitative sense the model does replicate the relative magnitude of changes in flows. It should also be noted that some model setup parameters, such as the mined area for each year, are not calibrated and could also be a factor limiting dewatering rates.

The calibration procedure resulted in a total of 53 parameter sets that are considered the calibrated datasets available for predictive simulations. **Table** 3-5 summarises the range of values for model parameters within the calibrated datasets, and **Appendix C** compares the simulated hydrographs from the calibrated realisations with observed data from the calibration bores.

Table 3-6 provides a summary of statistical measures used to compare results from model simulations using the calibrated datasets with observed data used as calibration targets (measured groundwater levels at alluvial and hard rock bores). Plots of observed and predicted groundwater levels for all calibrated realisations for the alluvial and hard rock calibration bores (*for locations see* **Figure 3-4**) are presented in **Figure 3-5** and **Figure 3-6**, respectively.

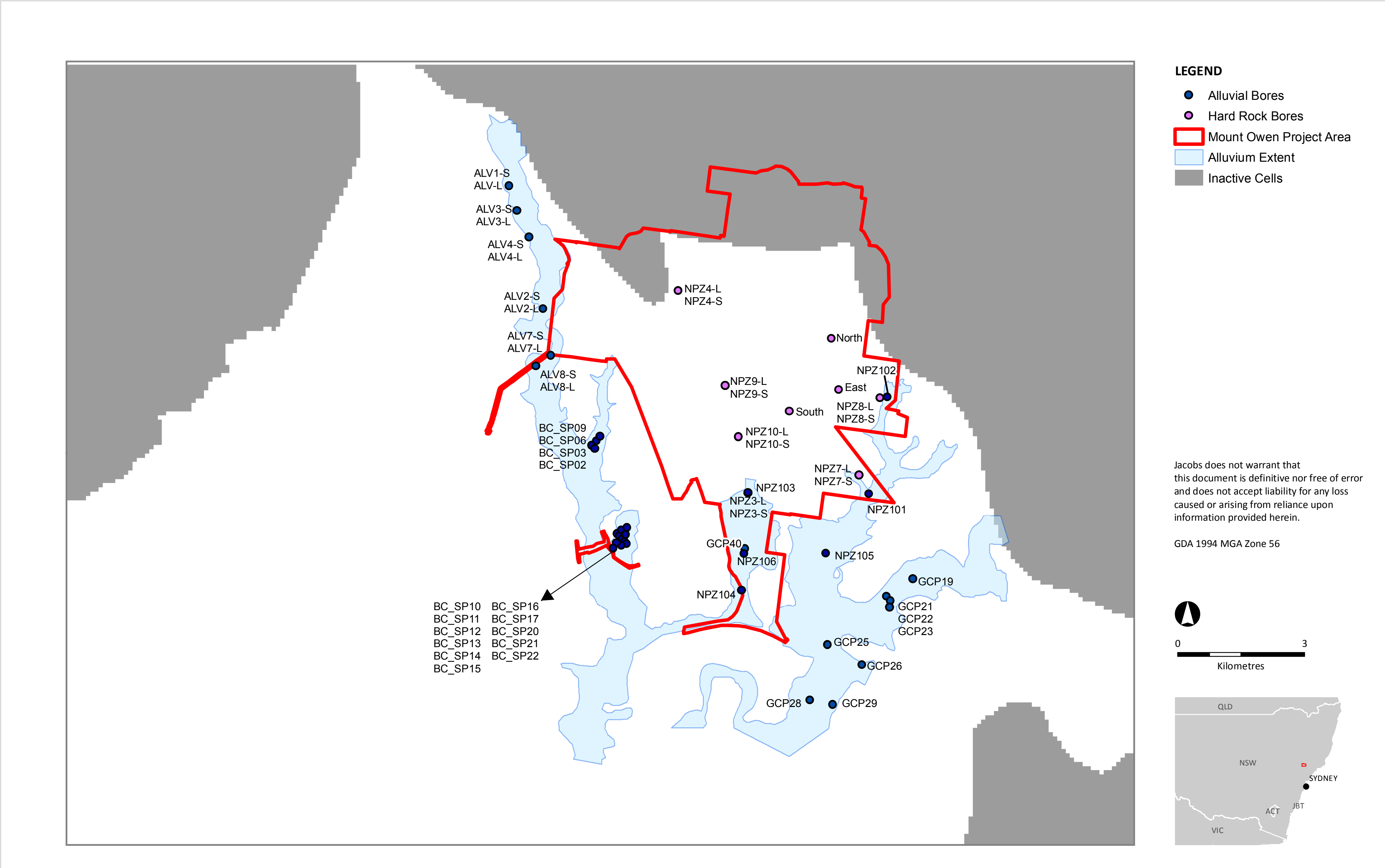


Figure 3-4 - Model Calibration Bores

JACOBS

File Name: Figure 3-4 MOCO Alluvial and bedrock bores_model calibration
Prepared by: LS
Checked by: RC

Table 3-5 – Range of Model Parameter Values for Calibrated Datasets

Model Parameter	Geologic unit	Minimum	Maximum
Sy	Alluvium	1.2E-02	6.5E-02
Sy	Regolith	4.2E-03	2.6E-02
Sy	Interburden	3.8E-03	2.7E-02
Sy	Bayswater Seams (0-100m)[1]	8.1E-03	4.3E-02
Sy	Bayswater Seams (100-200m)[1]	3.1E-03	1.5E-02
Sy	Bayswater Seams (> 200m)[1]	3.5E-03	2.0E-02
Sy	Archerfield Sandstone	2.9E-04	1.2E-03
Sy	Interburden \ Lemington Seam	4.2E-05	1.3E-02
Sy	Pikes Gully & Liddell Seams (0-100m)[1]	1.2E-03	4.8E-03
Sy	Pikes Gully & Liddell Seams (100-200m)[1]	4.2E-04	3.2E-03
Sy	Pikes Gully & Liddell Seams (> 200m)[1]	7.8E-04	4.3E-02
Sy	Arties Seams (0-100m)[1]	2.6E-03	1.2E-02
Sy	Arties Seams (100-200m)[1]	9.0E-03	1.4E-01
Sy	Arties Seams (> 200m)[1]	1.6E-03	1.3E-02
Sy	Barrett Seams (0-100m)[1]	1.7E-03	7.6E-03
Sy	Barrett Seams (100-200m)[1]	6.6E-04	1.6E-02
Sy	Barrett Seams (>200m)[1]	1.9E-04	1.3E-03
Sy	Underground workings	3.2E-01	1.0E+00
Sy	Hebden Seams (0-100m)[1]	4.3E-04	1.8E-03
Sy	Hebden Seams (100-200m)[1]	4.6E-05	9.1E-04
Sy	Hebden Seams (> 200m)[1]	4.7E-04	1.9E-03
Sy	Interburden	4.5E-04	2.2E-03
Sy	Saltwater Creek Formation	1.7E-04	9.9E-04
Sy	Upper Cumnock Workings	3.9E-03	1.8E-02
Sy	Lower Cumnock Workings	2.4E-03	2.4E-02
Ss (1/m)	All confined units	5.0E-6	5.0E-6
Kx (m/d)	Alluvium	9.8E-02	2.5E+00
Kx (m/d)	Regolith	2.9E-03	3.1E-02
Kx (m/d)	Interburden	5.5E-05	5.6E-04
Kx (m/d)	Bayswater Seams (0-100m)[1]	4.0E-04	1.7E-03
Kx (m/d)	Bayswater Seams (100-200m)[1]	5.9E-05	6.9E-04
Kx (m/d)	Bayswater Seams (> 200m)[1]	4.7E-05	2.2E-04
Kx (m/d)	Archerfield Sandstone	3.4E-06	2.2E-04
Kx (m/d)	Interburden \ Lemington Seam	4.6E-06	2.6E-04
Kx (m/d)	Pikes Gully & Liddell Seams (0-100m)[1]	1.1E-02	6.1E-02
Kx (m/d)	Pikes Gully & Liddell Seams (100-200m)[1]	3.4E-03	2.1E-02
Kx (m/d)	Pikes Gully & Liddell Seams (> 200m)[1]	1.2E-03	6.3E-03
Kx (m/d)	Arties Seams (0-100m)[1]	1.8E-02	6.6E-02
Kx (m/d)	Arties Seams (100-200m)[1]	5.0E-03	2.7E-02
Kx (m/d)	Arties Seams (> 200m)[1]	2.5E-03	8.0E-03

Model Parameter	Geologic unit	Minimum	Maximum
Kx (m/d)	Barrett Seams (0-100m)[1]	4.3E-03	4.0E-02
Kx (m/d)	Barrett Seams (100-200m)[1]	4.9E-04	5.1E-03
Kx (m/d)	Barrett Seams (>200m)[1]	7.6E-04	1.5E-02
Kx (m/d)	Underground workings	5.8E+01	1.1E+03
Kx (m/d)	Hebden Seams (0-100m)[1]	4.0E-02	4.4E-01
Kx (m/d)	Hebden Seams (100-200m)[1]	4.2E-03	5.8E-02
Kx (m/d)	Hebden Seams (> 200m)[1]	2.1E-04	4.4E-02
Kx (m/d)	Interburden	2.8E-06	1.7E-05
Kx (m/d)	Saltwater Creek Formation	7.2E-07	1.3E-04
Kz (m/d)	Alluvium	1.7E-02	1.6E-01
Kz (m/d)	Regolith	2.2E-04	4.6E-04
Kz (m/d)	Interburden	2.0E-06	3.7E-05
Kz (m/d)	Bayswater Seams (0-100m)[1]	1.6E-05	1.4E-04
Kz (m/d)	Bayswater Seams (100-200m)[1]	1.3E-06	2.5E-05
Kz (m/d)	Bayswater Seams (> 200m)[1]	1.4E-06	9.1E-06
Kz (m/d)	Archerfield Sandstone	3.1E-07	1.4E-05
Kz (m/d)	Interburden \ Lemington Seam	4.2E-08	3.5E-06
Kz (m/d)	Pikes Gully & Liddell Seams (0-100m)[1]	9.7E-06	4.2E-03
Kz (m/d)	Pikes Gully & Liddell Seams (100-200m)[1]	3.0E-07	1.4E-04
Kz (m/d)	Pikes Gully & Liddell Seams (> 200m)[1]	1.5E-05	9.2E-04
Kz (m/d)	Arties Seams (0-100m)[1]	2.3E-04	1.6E-02
Kz (m/d)	Arties Seams (100-200m)[1]	1.2E-08	2.1E-04
Kz (m/d)	Arties Seams (> 200m)[1]	1.4E-05	3.7E-04
Kz (m/d)	Barrett Seams (0-100m)[1]	5.6E-08	5.7E-03
Kz (m/d)	Barrett Seams (100-200m)[1]	2.7E-05	2.0E-03
Kz (m/d)	Barrett Seams (>200m)[1]	5.9E-05	3.3E-04
Kz (m/d)	Underground workings	4.4E+00	1.9E+02
Kz (m/d)	Hebden Seams (0-100m)[1]	9.9E-05	2.5E-02
Kz (m/d)	Hebden Seams (100-200m)[1]	6.3E-06	8.6E-03
Kz (m/d)	Hebden Seams (> 200m)[1]	2.8E-06	4.9E-04
Kz (m/d)	Interburden	3.9E-08	7.3E-07
Kz (m/d)	Saltwater Creek Formation	1.2E-08	5.9E-06
Conductance (m^2/d)	Hunter River (River cells)	3.7E+00	1.8E+05
Conductance (m^2/d)	Glennies Creek (River cells)	7.6E-01	2.7E+05
Conductance (m^2/d)	Bowmans Creek (Stream cells)	1.1E+00	9.3E+03
Conductance (m^2/d)	General Head Boundary cells	1.8E+02	4.7E+05
Recharge[2]	Alluvium	3%	9%
Recharge[2]	All other coal seam and interburden zones	0.0005%	0.8%
Recharge[2]	Backfill	1.5%	9%

[1] Following the convention of Mackie, 2009

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

Table 3-6 – Summary of Calibration Statistics

	Statistical Range		
Statistical Measure	**All Alluvial Bores (unweighted)**	**Project Bedrock Observations (unweighted)**	**All Bedrock Bore Observations (weighted*)**
Mean Residual (m)	-0.6 – 2.2	-4.7 – 7.8	-3.6 – 2.9
Absolute Residual Mean (m)	0.8 – 2.2	4.1 – 8.5	8.5 – 12.6
Standard Deviation (m)	1.1 – 2.5	5.7 – 9.9	12.1 – 16.5
Sum of Squares (m)	922 – 3,883	6,712 – 19,415	889,061 – 1,707,146
RMS[1] Error (m)	1.2 – 2.6	6.1 – 10.4	12.1 – 16.8
Minimum Residual (m)	-33.7 – -0.6	-27.2 – -7.7	-73.4 – -51.1
Maximum Residual (m)	3 – 6.2	18.9 – 32.6	41.9 – 46.7
Number of Observations	593	180	6,049
Range in Observations (m)	48.5	184.1	184.1
Scaled Standard Deviation	2% – 5%	3% – 5%	7% – 9%
Scaled Absolute Mean	2% – 5%	2% – 5%	5% – 7%
Scaled RMS	3% – 5%	3% – 5%	7% – 9%

[1] RMS = root mean square

* All alluvial and Project Bores are given a weight of 1 to calculate residuals. For all other bores a weight of 0.4 was applied.

Figure 3-5 – Observed vs. Simulated Levels for all Alluvial Bores

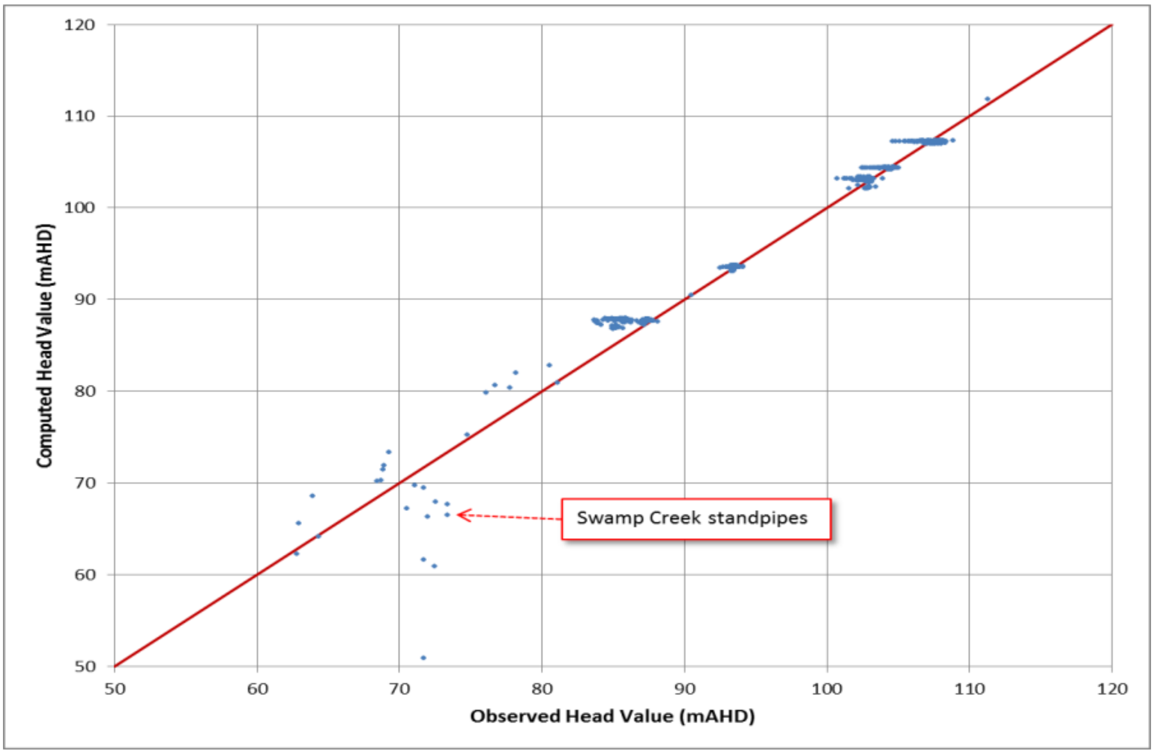
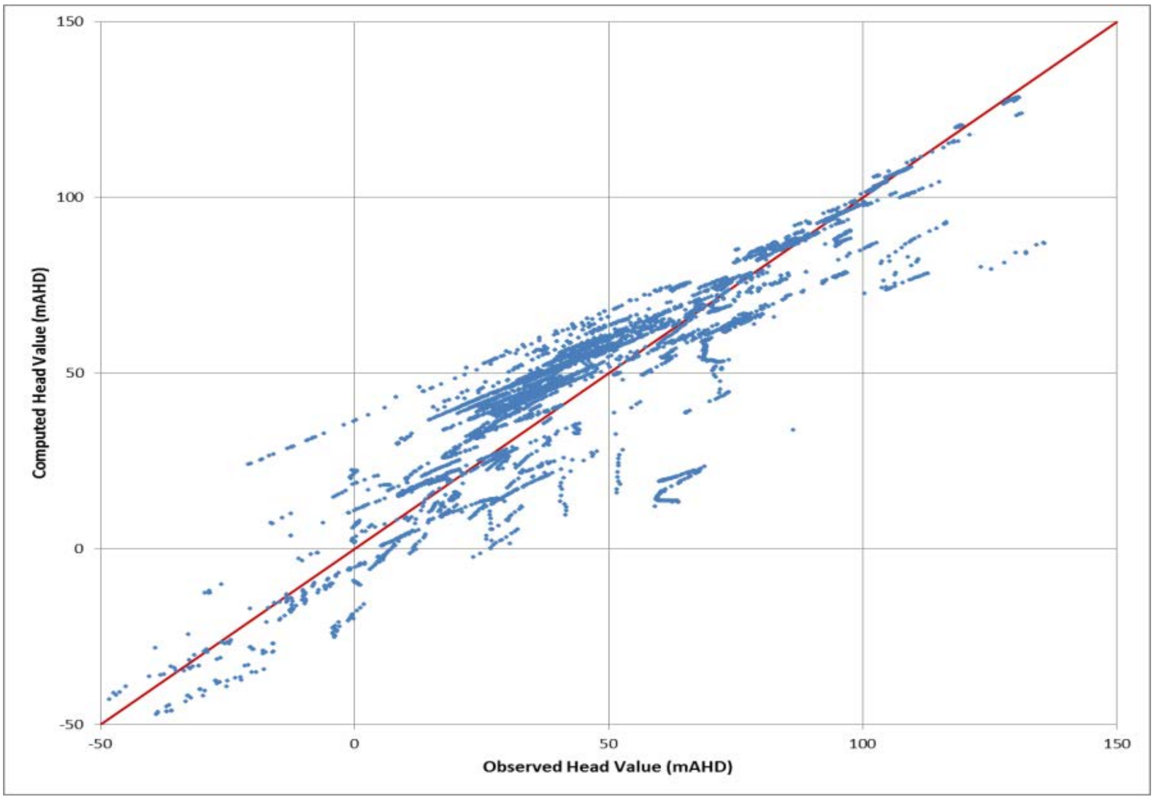


Figure 3-6 – Observed vs. Simulated Groundwater Levels for Hard Rock Calibration Bores



In the area along Swamp Creek, the regional model is underestimating alluvial water levels (**Figure 3-5**) which could indicate that the model is overestimating impacts from the Glendell Mine. Simulated levels with greater than 3 m difference from observed levels account for less than 10% of comparisons (588 observations).

Trends in **Figure 3-6** generally represent sub-stress period changes in observed pressures most likely reflecting inter-annual changes in mining operations affecting these bores. Simulated levels with greater than 10 m difference from observed levels account for less than 8% of comparisons (724 observations).

The observed and modelled trends provide an indication of system recovery times and the consistency of these trends suggests similar recovery rate for all impacted formations. This validates the use of a single storativity value in the model for all hard rock aquifers. Thus, from the observed trends, an average water pressure recovery of about 0.01m/day is determined, whilst modelled rates are slightly lower at 0.008 m/day.

Hydrographs of observed and simulated groundwater levels for all bores are presented in **Appendix C**.

The calibration statistics and hydrographs indicate the numerical model accurately replicates the observed data.

3.3.6 Bowmans Creek baseflow estimations

The scale of model cells (100m x 100m) and temporal resolution (annual steps) of the numerical model precludes detailed and temporal quantitative comparison of potential baseflow changes to the tributaries of the Hunter River. Further, the regulated flow of Glennies Creek precludes meaningful comparisons of observed and modelled estimates of the baseflow component of stream flow for that system. Flow for the unregulated Bowmans Creek, however, has been assessed (during modelling for the recent Liddell Groundwater Impact Assessment (JacobsSKM, 2014) using model version 7.2) to determine whether the model is predicting comparable values.

Loss of streamflow flow to Bowmans Creek due to reduced groundwater input was estimated from reduction in flow to stream cells along Bowmans Creek. These results were compared to baseflow estimations from baseflow analysis of streamflow data at the gauges along this creek (**Table 3-7**) which suggest average baseflow between 0.4 and 4 ML/day. Whilst the model provides output data only at an annual time step, there is good agreement between the model and long-term median values at the gauges (**Figure 3-7**), with the model generating between 0.9 and 1.5 ML/day.

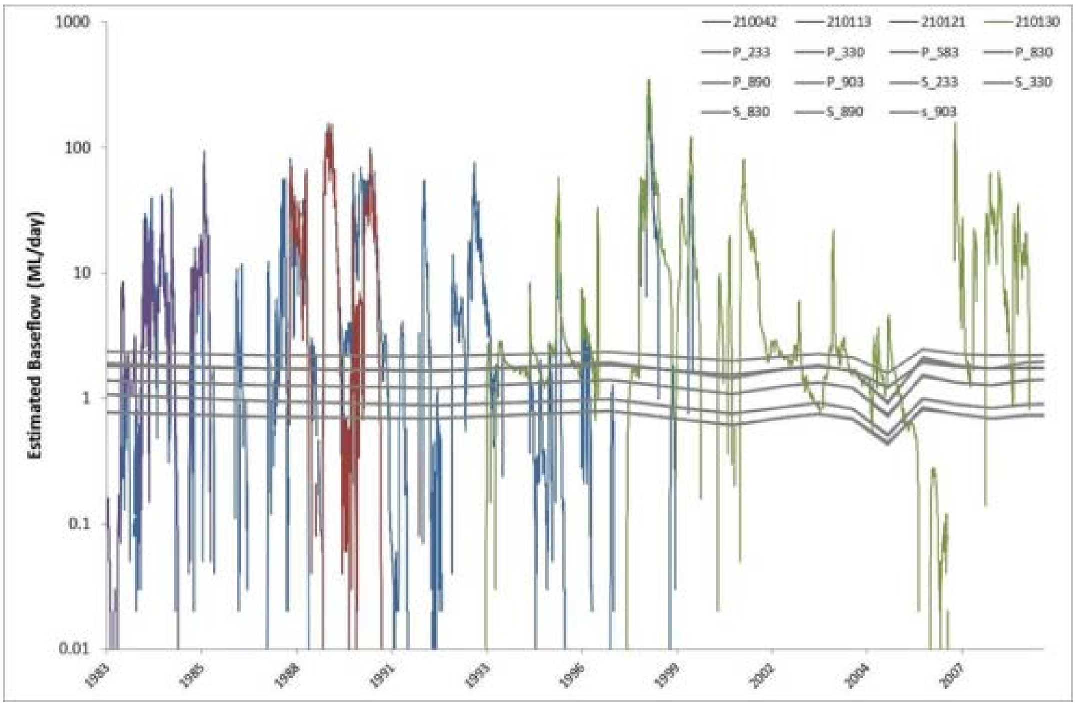
Table 3-7 – Calculated baseflow assessed at streamflow gauges along Bowmans Creek using model version 7.1

Stream gauge[1]	Median baseflow[2] (ML/day)	Period of assessment
210113	1.0	1980-1985
210115	3.9	1981-1985
210116	3.4	1982-1985
210042	0.4	1980-1999
210130	2.1	1993-2009

[1] Gauges run north to south

[2] Calculated using Basejumper® software

Figure 3-7 – Modelled baseflow from the eleven calibrated realisations from model version 7.1, compared to baseflow estimations from streamflow data from four gauges along Bowmans Creek



3.4 Sensitivity Analysis

Table 3-8 summarises the range of values of model parameters within the calibrated datasets along with the percentage of the input parameter range determined by the Monte Carlo simulations. The calibrated parameter ranges in relation to the input parameter ranges are presented graphically in **Figure 3-8** through **Figure 3-12**. In these figures, the boxes illustrate the range included within the calibrated model realisations, while the vertical lines (whiskers) represent the range used to select data for the Monte Carlo simulation. These figures and in particular the percentage of the box compared to the whisker 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 3-8 – Range of Model Parameter for Calibrated Datasets

Model Parameter	Geologic unit	Minimum	Maximum	Percent of Stochastic Range
Sy	Alluvium	1.2E-02	6.5E-02	31%
Sy	Regolith	4.2E-03	2.6E-02	40%
Sy	Interburden	3.8E-03	2.7E-02	41%
Sy	Bayswater Seams (0-100m)[1]	8.1E-03	4.3E-02	34%
Sy	Bayswater Seams (100-200m)[1]	3.1E-03	1.5E-02	27%
Sy	Bayswater Seams (> 200m)[1]	3.5E-03	2.0E-02	30%
Sy	Archerfield Sandstone	2.9E-04	1.2E-03	30%
Sy	Interburden \ Lemington Seam	4.2E-05	1.3E-02	65%
Sy	Pikes Gully & Liddell Seams (0-100m)[1]	1.2E-03	4.8E-03	25%
Sy	Pikes Gully & Liddell Seams (100-200m)[1]	4.2E-04	3.2E-03	29%
Sy	Pikes Gully & Liddell Seams (> 200m)[1]	7.8E-04	4.3E-02	30%
Sy	Arties Seams (0-100m)[1]	2.6E-03	1.2E-02	28%
Sy	Arties Seams (100-200m)[1]	9.0E-03	1.4E-01	96%
Sy	Arties Seams (> 200m)[1]	1.6E-03	1.3E-02	29%
Sy	Barrett Seams (0-100m)[1]	1.7E-03	7.6E-03	30%
Sy	Barrett Seams (100-200m)[1]	6.6E-04	1.6E-02	22%
Sy	Barrett Seams (>200m)[1]	1.9E-04	1.3E-03	33%
Sy	Underground workings	3.2E-01	1.0E+00	27%
Sy	Hebden Seams (0-100m)[1]	4.3E-04	1.8E-03	30%
Sy	Hebden Seams (100-200m)[1]	4.6E-05	9.1E-04	0.3%
Sy	Hebden Seams (> 200m)[1]	4.7E-04	1.9E-03	30%
Sy	Interburden	4.5E-04	2.2E-03	44%
Sy	Saltwater Creek Formation	1.7E-04	9.9E-04	37%
Sy	Upper Cumnock Workings	3.9E-03	1.8E-02	39%
Sy	Lower Cumnock Workings	2.4E-03	2.4E-02	35%
Ss (1/m)	All confined units	5.0E-6	5.0E-6	100%
Kx (m/d)	Alluvium	9.8E-02	2.5E+00	50%
Kx (m/d)	Regolith	2.9E-03	3.1E-02	76%
Kx (m/d)	Interburden	5.5E-05	5.6E-04	45%

Model Parameter	Geologic unit	Minimum	Maximum	Percent of Stochastic Range
Kx (m/d)	Bayswater Seams (0-100m)[1]	4.0E-04	1.7E-03	30%
Kx (m/d)	Bayswater Seams (100-200m)[1]	5.9E-05	6.9E-04	34%
Kx (m/d)	Bayswater Seams (> 200m)[1]	4.7E-05	2.2E-04	32%
Kx (m/d)	Archerfield Sandstone	3.4E-06	2.2E-04	14%
Kx (m/d)	Interburden \ Lemington Seam	4.6E-06	2.6E-04	6%
Kx (m/d)	Pikes Gully & Liddell Seams (0-100m)[1]	1.1E-02	6.1E-02	43%
Kx (m/d)	Pikes Gully & Liddell Seams (100-200m)[1]	3.4E-03	2.1E-02	34%
Kx (m/d)	Pikes Gully & Liddell Seams (> 200m)[1]	1.2E-03	6.3E-03	28%
Kx (m/d)	Arties Seams (0-100m)[1]	1.8E-02	6.6E-02	25%
Kx (m/d)	Arties Seams (100-200m)[1]	5.0E-03	2.7E-02	35%
Kx (m/d)	Arties Seams (> 200m)[1]	2.5E-03	8.0E-03	26%
Kx (m/d)	Barrett Seams (0-100m)[1]	4.3E-03	4.0E-02	42%
Kx (m/d)	Barrett Seams (100-200m)[1]	4.9E-04	5.1E-03	26%
Kx (m/d)	Barrett Seams (>200m)[1]	7.6E-04	1.5E-02	73%
Kx (m/d)	Underground workings	5.8E+01	1.1E+03	9%
Kx (m/d)	Hebden Seams (0-100m)[1]	4.0E-02	4.4E-01	24%
Kx (m/d)	Hebden Seams (100-200m)[1]	4.2E-03	5.8E-02	11%
Kx (m/d)	Hebden Seams (> 200m)[1]	2.1E-04	4.4E-02	1%
Kx (m/d)	Interburden	2.8E-06	1.7E-05	41%
Kx (m/d)	Saltwater Creek Formation	7.2E-07	1.3E-04	6%
Kz (m/d)	Alluvium	1.7E-02	1.6E-01	16%
Kz (m/d)	Regolith	2.2E-04	4.6E-04	8%
Kz (m/d)	Interburden	2.0E-06	3.7E-05	46%
Kz (m/d)	Bayswater Seams (0-100m)[1]	1.6E-05	1.4E-04	60%
Kz (m/d)	Bayswater Seams (100-200m)[1]	1.3E-06	2.5E-05	34%
Kz (m/d)	Bayswater Seams (> 200m)[1]	1.4E-06	9.1E-06	21%
Kz (m/d)	Archerfield Sandstone	3.1E-07	1.4E-05	16%
Kz (m/d)	Interburden \ Lemington Seam	4.2E-08	3.5E-06	1%
Kz (m/d)	Pikes Gully & Liddell Seams (0-100m)[1]	9.7E-06	4.2E-03	24%
Kz (m/d)	Pikes Gully & Liddell Seams (100-200m)[1]	3.0E-07	1.4E-04	11%
Kz (m/d)	Pikes Gully & Liddell Seams (> 200m)[1]	1.5E-05	9.2E-04	19%
Kz (m/d)	Arties Seams (0-100m)[1]	2.3E-04	1.6E-02	44%
Kz (m/d)	Arties Seams (100-200m)[1]	1.2E-08	2.1E-04	4%
Kz (m/d)	Arties Seams (> 200m)[1]	1.4E-05	3.7E-04	46%
Kz (m/d)	Barrett Seams (0-100m)[1]	5.6E-08	5.7E-03	42%
Kz (m/d)	Barrett Seams (100-200m)[1]	2.7E-05	2.0E-03	37%
Kz (m/d)	Barrett Seams (>200m)[1]	5.9E-05	3.3E-04	6%
Kz (m/d)	Underground workings	4.4E+00	1.9E+02	22%
Kz (m/d)	Hebden Seams (0-100m)[1]	9.9E-05	2.5E-02	19%
Kz (m/d)	Hebden Seams (100-200m)[1]	6.3E-06	8.6E-03	46%
Kz (m/d)	Hebden Seams (> 200m)[1]	2.8E-06	4.9E-04	1%
Kz (m/d)	Interburden	3.9E-08	7.3E-07	21%

Model Parameter	Geologic unit	Minimum	Maximum	Percent of Stochastic Range
Kz (m/d)	Saltwater Creek Formation	1.2E-08	5.9E-06	27%
Conductance (m^2/d)	Hunter River (River cells)	3.7E+00	1.8E+05	2%
Conductance (m^2/d)	Glennies Creek (River cells)	7.6E-01	2.7E+05	1%
Conductance (m^2/d)	Bowmans Creek (Stream cells)	1.1E+00	9.3E+03	54%
Conductance (m^2/d)	General Head Boundary cells	1.8E+02	4.7E+05	0.4%
Recharge[2]	Alluvium	3%	9%	20%
Recharge[2]	All other coal seam and interburden zones	0.0005%	0.8%	1%-22%
Recharge[2]	Backfill	1.5%	9%	41%

[1] Following the convention of Mackie, 2009

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

Figure 3-8 – Model Parameter Sensitivity: Horizontal Hydraulic Conductivity

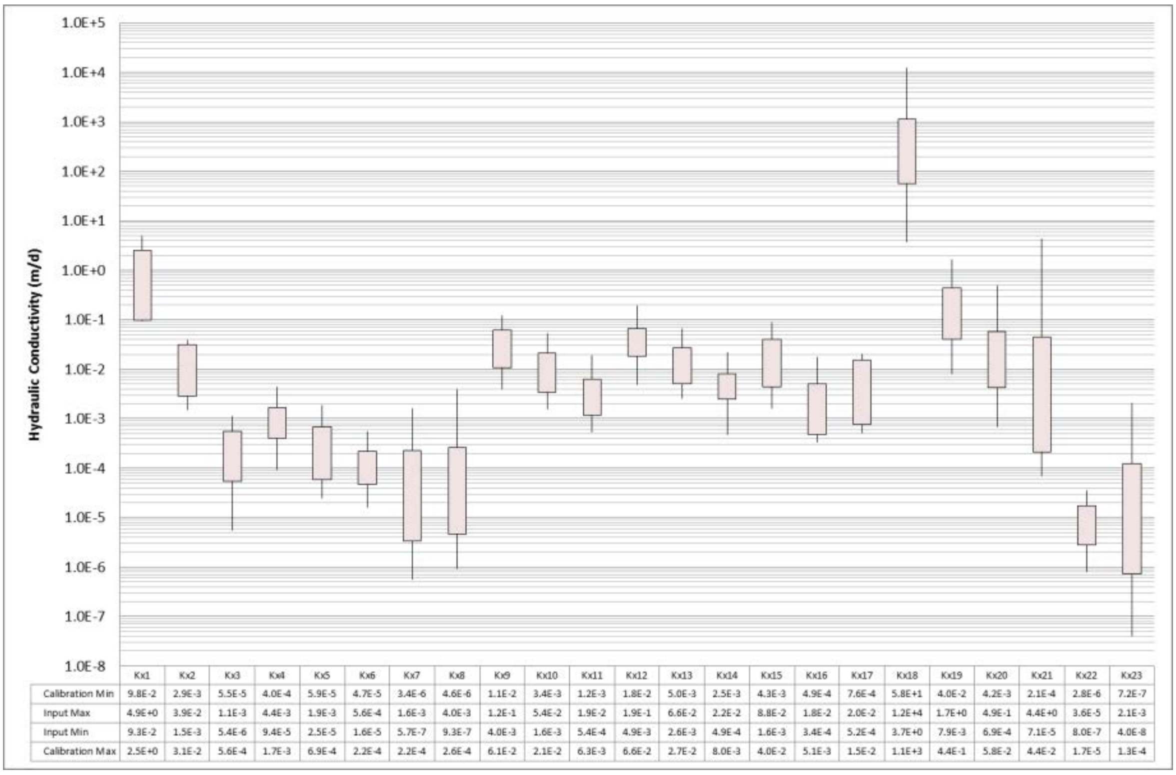
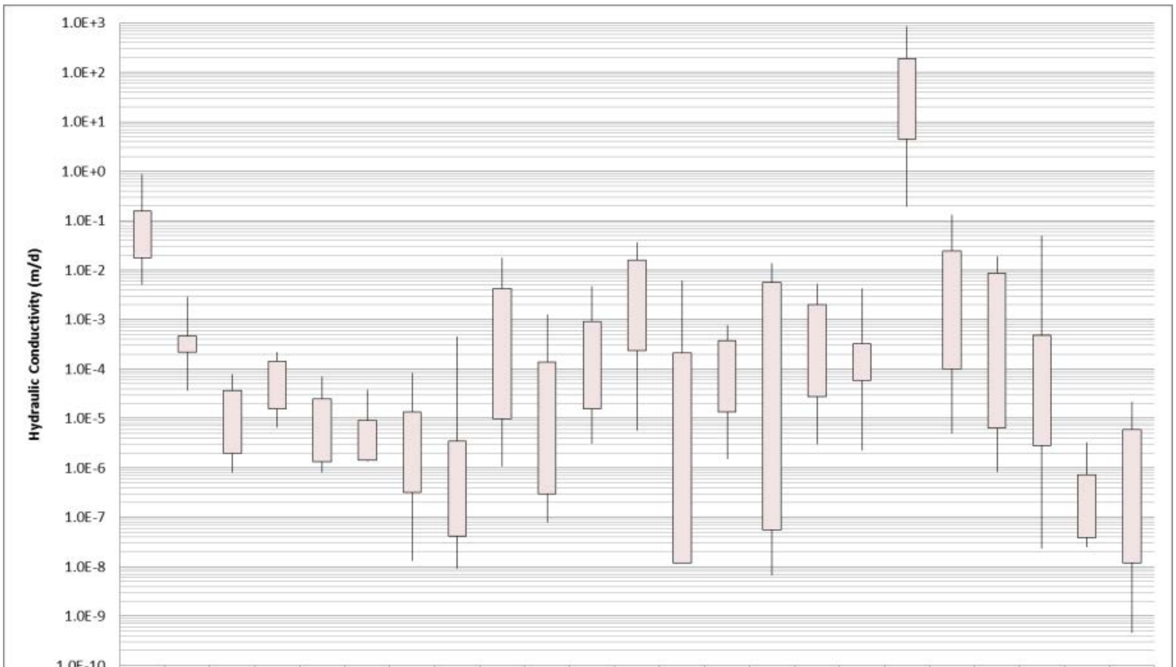
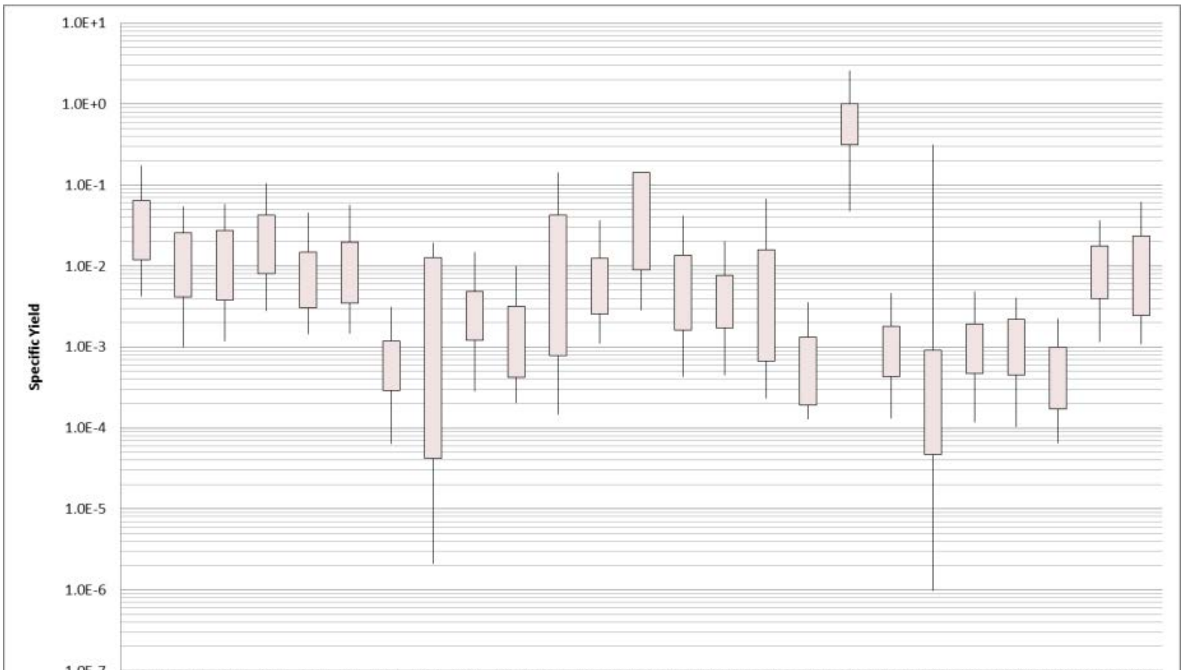


Figure 3-9 – Model Parameter Sensitivity: Vertical Hydraulic Conductivity



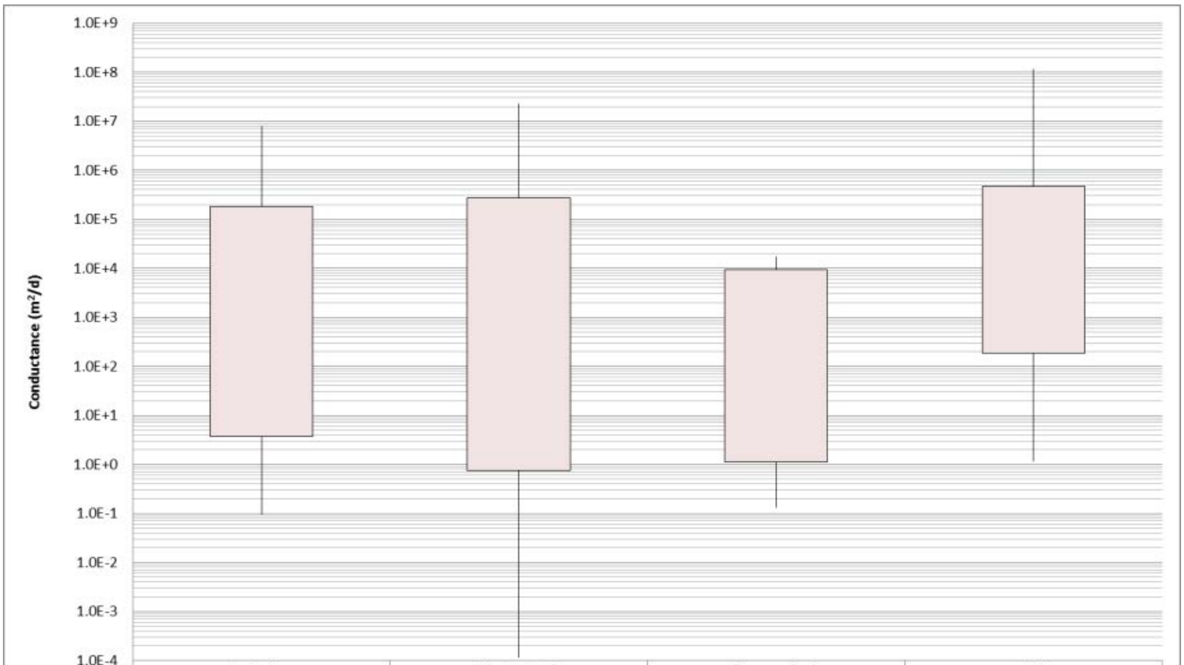
	Kz1	Kz2	Kz3	Kz4	Kz5	Kz6	Kz7	Kz8	Kz9	Kz10	Kz11	Kz12	Kz13	Kz14	Kz15	Kz16	Kz17	Kz18	Kz19	Kz20	Kz21	Kz22	Kz23
Calibration Min	1.7E-2	2.2E-4	2.0E-6	1.6E-5	1.3E-6	1.4E-6	3.1E-7	4.2E-8	9.7E-6	3.0E-7	1.5E-5	2.3E-4	1.2E-8	1.4E-5	5.6E-8	2.7E-5	5.9E-5	4.4E+0	9.9E-5	6.3E-6	2.8E-6	3.9E-8	1.2E-8
Input Max	8.7E-1	2.9E-3	7.7E-5	2.2E-4	6.9E-5	3.8E-5	8.4E-5	4.6E-4	1.7E-2	1.3E-3	4.7E-3	3.6E-2	6.0E-3	7.8E-4	1.4E-2	5.2E-3	4.2E-3	8.4E+2	1.3E-1	1.9E-2	5.0E-2	3.3E-6	2.2E-5
Input Min	5.1E-3	3.7E-5	8.1E-7	6.5E-6	8.1E-7	1.4E-6	1.3E-8	9.4E-9	1.1E-6	7.9E-8	3.1E-6	5.7E-6	1.2E-8	1.5E-6	6.7E-9	3.0E-6	2.2E-6	1.9E-1	5.1E-6	8.3E-7	2.3E-8	2.5E-8	4.6E-10
Calibration Max	1.6E-1	4.6E-4	3.7E-5	1.4E-4	2.5E-5	9.1E-6	1.4E-5	3.5E-6	4.2E-3	1.4E-4	9.2E-4	1.6E-2	2.1E-4	3.7E-4	5.7E-3	2.0E-3	3.3E-4	1.9E+2	2.5E-2	8.6E-3	4.9E-4	7.3E-7	5.9E-6

Figure 3-10 – Model Parameter Sensitivity: Specific Yield



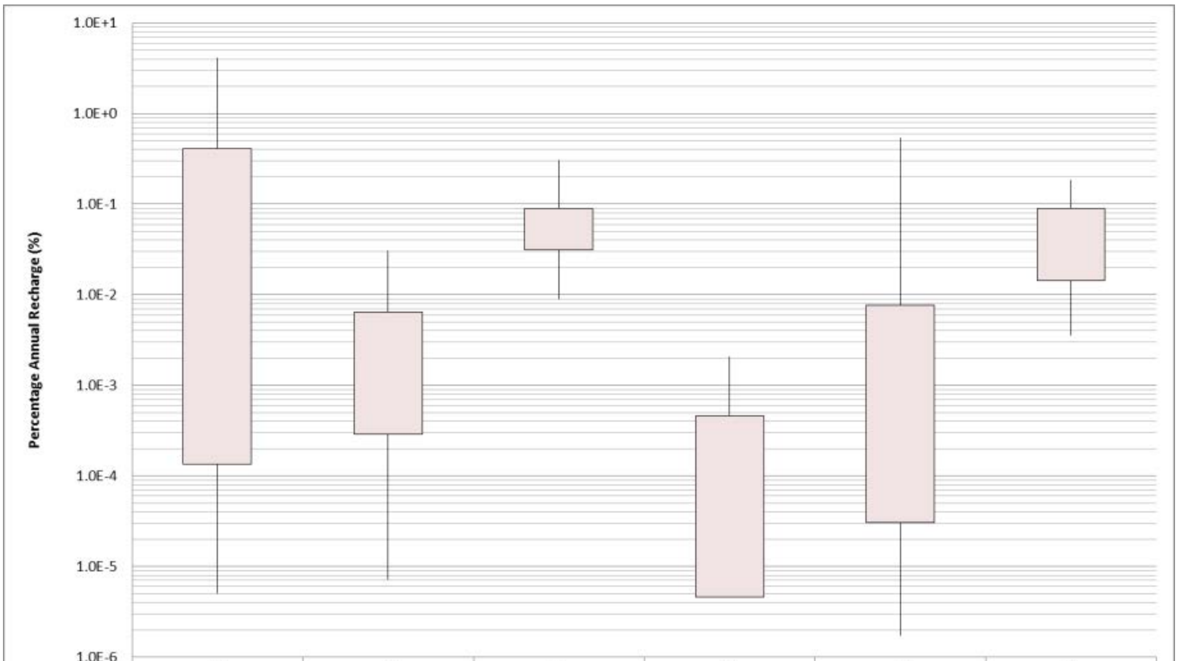
	Sy1	Sy2	Sy3	Sy4	Sy5	Sy6	Sy7	Sy8	Sy9	Sy10	Sy11	Sy12	Sy13	Sy14	Sy15	Sy16	Sy17	Sy18	Sy19	Sy20	Sy21	Sy22	Sy23	Sy24	Sy25
Calibration Min	1.2E-2	4.2E-3	3.8E-3	8.1E-3	3.1E-3	3.5E-3	2.9E-4	4.2E-5	1.2E-3	4.2E-4	7.8E-4	2.6E-3	9.0E-3	1.6E-3	1.7E-3	6.6E-4	1.9E-4	3.2E-1	4.3E-4	4.6E-5	4.7E-4	4.5E-4	1.7E-4	3.9E-3	2.4E-3
Input Max	1.7E-1	5.4E-2	5.8E-2	1.0E-1	4.5E-2	5.7E-2	3.1E-3	1.9E-2	1.5E-2	9.9E-3	1.4E-1	3.6E-2	1.4E-1	4.2E-2	2.0E-2	6.8E-2	3.5E-3	2.6E+0	4.6E-3	3.2E-1	4.9E-3	4.0E-3	2.3E-3	3.6E-2	6.2E-2
Input Min	4.2E-3	9.9E-4	1.2E-3	2.8E-3	1.4E-3	1.5E-3	6.4E-5	2.1E-6	2.9E-4	2.0E-4	1.5E-4	1.1E-3	2.9E-3	4.3E-4	4.5E-4	2.3E-4	1.3E-4	4.7E-2	1.3E-4	9.8E-7	1.2E-4	1.0E-4	6.5E-5	1.2E-3	1.1E-3
Calibration Max	6.5E-2	2.6E-2	2.7E-2	4.3E-2	1.5E-2	2.0E-2	1.2E-3	1.3E-2	4.8E-3	3.2E-3	4.3E-2	1.2E-2	1.4E-1	1.3E-2	7.6E-3	1.6E-2	1.3E-3	1.0E+0	1.8E-3	9.1E-4	1.9E-3	2.2E-3	9.9E-4	1.8E-2	2.4E-2

Figure 3-11 – Model Parameter Sensitivity: Boundary Conductance



	Hunter River	Glennies Creek	Bowmans Creek	GHB
Calibration Min	3.7E+0	7.6E-1	1.1E+0	1.8E+2
Input Max	7.9E+6	2.2E+7	1.7E+4	1.2E+8
Input Min	9.5E-2	1.1E-4	1.3E-1	1.2E+0
Calibration Max	1.8E+5	2.7E+5	9.3E+3	4.7E+5

Figure 3-12 – Model Parameter Sensitivity: Recharge



	r2	r3	r1	r5	r6	r8
Calibration Min	1.3E-4	2.9E-4	3.1E-2	4.6E-6	3.0E-5	1.4E-2
Input Max	4.1E+0	3.0E-2	3.1E-1	2.1E-3	5.5E-1	1.9E-1
Input Min	5.1E-6	7.2E-6	9.0E-3	4.6E-6	1.7E-6	3.6E-3
Calibration Max	4.1E-1	6.4E-3	9.0E-2	4.6E-4	7.7E-3	8.9E-2

3.5 Predictive Simulations and Model Results

The calibrated 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 Glennies Creek and its alluvial aquifer as a result of the Project;
- Drawdown in the alluvial and hard rock aquifers as a result of the Project;
- The cumulative impacts of the Project within the context of regional mining operations;
- Pit inflows and dewatering requirements; and
- Post mining equilibrium.

Predictive simulations were undertaken using two different scenarios in order to better quantify the potential impacts of the Project on regional groundwater resources:

1) Base case: simulates all historical, current and approved mining operations at Mount Owen and other mines included in the regional model as shown in **Figure 3-1** (includes Liddell Coal Operations modifications currently under assessment); and
2) Proposed case: includes all mining operations as in the Base case simulation and incorporates the mine progression and sequencing proposed for the Project, comprising of the continuation of the North Pit, BNP and the RERR mining area.

The Base case simulations provide an indication of current hydrogeological conditions and changes to such conditions resulting from historical and currently approved mining operations at Mount Owen and the surrounding area. Comparison of results for the Proposed and Base case simulations provide estimates of the additional incremental impacts (if any) that can be attributed to the Project.

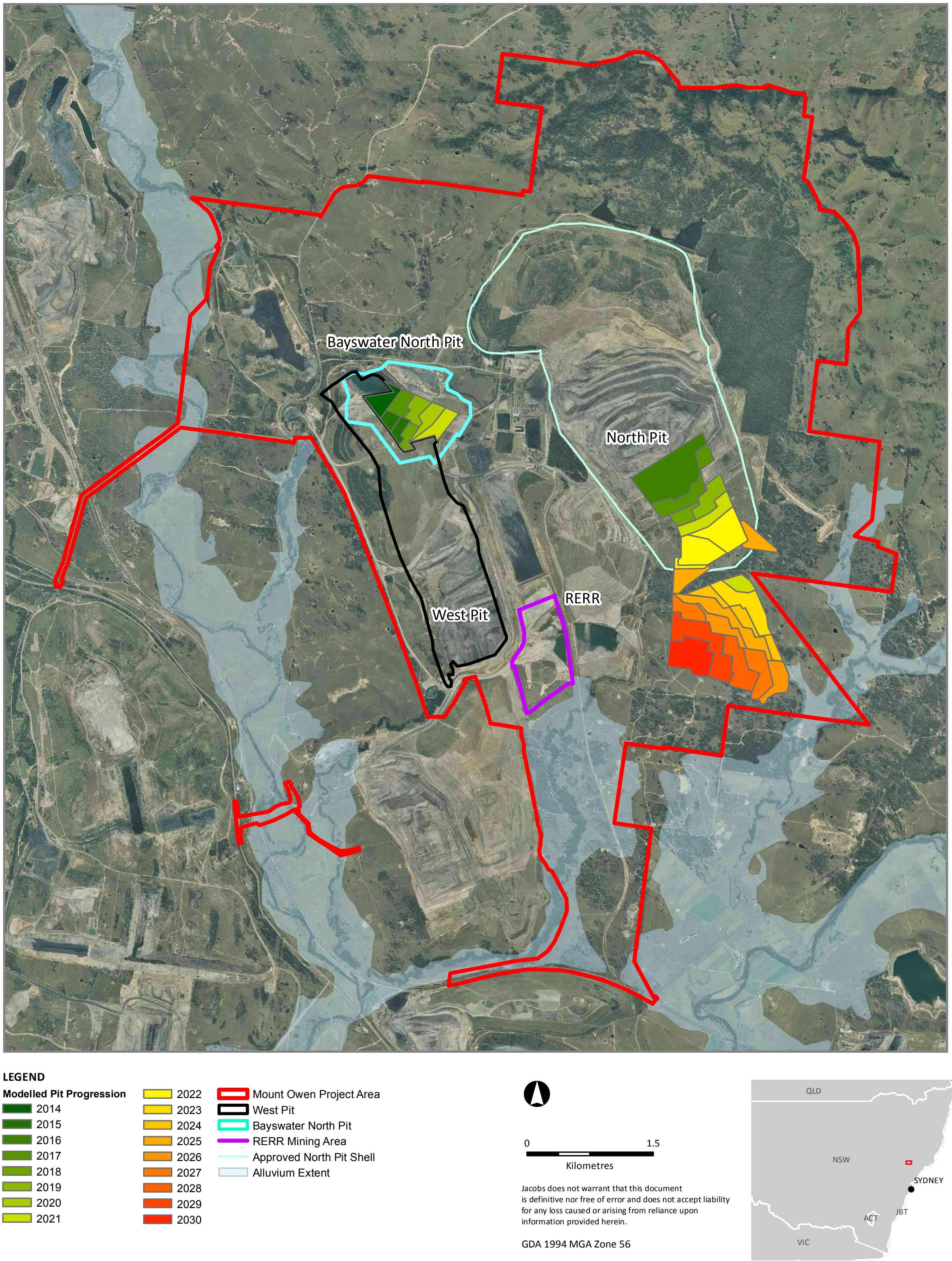
The annual progression for the continuation of the North Pit, as simulated for the Proposed case scenario, is shown in **Figure 3-13** along with the BNP and RERR mining area. Mining within the RERR area will comprise deepening a former shallow open cut pit to mine deeper coal seams within the previous disturbance area. Mining operations within the BNP and RERR Mining Areas will involve the excavation of overburden previously emplaced within the BNP and RERR Mining Area as part of the existing approved mining operations followed by mining of coal targeting the Bayswater seam.

The mine progression within the RERR mining area is not shown in **Figure 3-13** as the mining sequence comprises deepening an existing disturbance area. For the continuation of the North Pit, drain cells within the boundary of the pit shell were progressively switched on for the years shown in **Figure 3-13** to simulate the extension and deepening of the pit.

Removal of the mine back-fill from the RERR mining area will de-water re-saturated overburden that was emplaced 10 years ago. Release of this water from this overburden re-handle in 2022, therefore, does not constitute additional inflow from the hard rock aquifer and has been subtracted from the RERR inflow volumes.

The continuation of the North Pit will result in mining above the currently approved Integra Underground mine, which holds development consent to mine the Middle Liddell Seam down to the Hebden Seam (Geoterra, 2009). Based on the geological model data, a minimum of 250 m vertical distance will separate the base of the North Pit and the approved Integra underground (Umwelt, 2013). Expected increased hydraulic conductivity associated with cracking in strata layers above the Integra Underground workings has been included in the Proposed case simulations in sequence with the approved mining progression.

Predictive model results for groundwater fluxes from the alluvial aquifers, drawdown in the alluvial and hard rock aquifers, estimates of pit inflows and dewatering requirements, and post mining equilibrium are presented in the following sections.



File Name: Figure 3-13 MOCO GIA_Modelled Progression
Prepared by: LS
Checked by: RC

Figure 3-13 - Modelled Mining Progression of the Project

3.5.1 Estimated Groundwater Flows and Drawdowns

Results from the predictive simulations were analysed to evaluate estimated reductions in groundwater flow and corresponding drawdown to alluvial aquifers as a result of the Project. The difference between the Base case and Proposed case scenarios provides a quantitative estimate of the changes in groundwater flux as a result of the Project.

3.5.1.1 Alluvial systems

Figure 3-14 shows the incremental estimated groundwater flows to the Main Creek and Glennies Creek alluvial aquifers, and **Figure 3-15** shows the incremental predicted fluxes for Bettys Creek and Bowmans Creek. These results were calculated by subtracting the groundwater fluxes estimated by the model for currently approved mining operations (the Base case scenario) from those predicted when including the Project (the Proposed case). The model predictions are provided from the beginning of 2009 to correlate with the introduction of the Hunter Regulated River WSP, and negative values correspond to groundwater flows out of the alluvium (i.e. leakage).

To provide context around the magnitude of predicted groundwater fluxes, estimated average baseflow contributions to Glennies Creek and Bowmans Creek estimated from stream flow analysis (refer **Section 2.4**) are also indicated in **Figure 3-14** and **Figure 3-15**, respectively. Note that there is no direct correlation to baseflow from the model results as the groundwater fluxes represent flux into or out of the alluvial aquifer and not the loss to stream cells along the creeks. The modelled values can be taken as the maximum potential impact to baseflow assuming the water table intersects the stream bed.

The model estimates shown in **Figure 3-14** and **Figure 3-15** indicate negligible impacts from the Project on the quantity of groundwater flows to the alluvial aquifers associated with Glennies Creek and Bowmans Creek and their tributaries, Main Creek and Bettys Creek, respectively.

The median predicted incremental leakage from the Main Creek alluvial aquifer as a result of the Project increases to 15 ML/year (+1 standard deviation (SD) gives about 22 ML/year) occurring in 2026. The model estimates negligible leakage from the Glennies Creek alluvium. For comparison, the estimated leakage rate for Main Creek is equivalent to less than 0.3 percent of the estimated baseflow contribution to Glennies Creek (refer **Section 2.4**).

Similarly, the median predicted incremental groundwater loss from the Bettys Creek alluvial aquifer is about 6 ML/year (+1 SD = 9 ML/year). Negligible impact (less than 1 ML/year) is predicted for the Bowmans Creek Alluvium. Baseflow loss to Bettys Creek is equivalent to less than 0.2 percent of the estimated baseflow contribution to Bowmans Creek (SKM, 2013).

For a model of this size and complexity, the inherent uncertainty in model predictions reflects modelling run precision on the order of 0.1 ML/day (or 36.5 ML/year). Changes of this order in flux represent noise in the results.

Figure 3-14 – Predicted Reduction in Groundwater Fluxes to Glennies Creek and Main Creek Alluvial Aquifers Compared to Baseflow Estimates[5] (*inset:* magnified view for Main Creek)

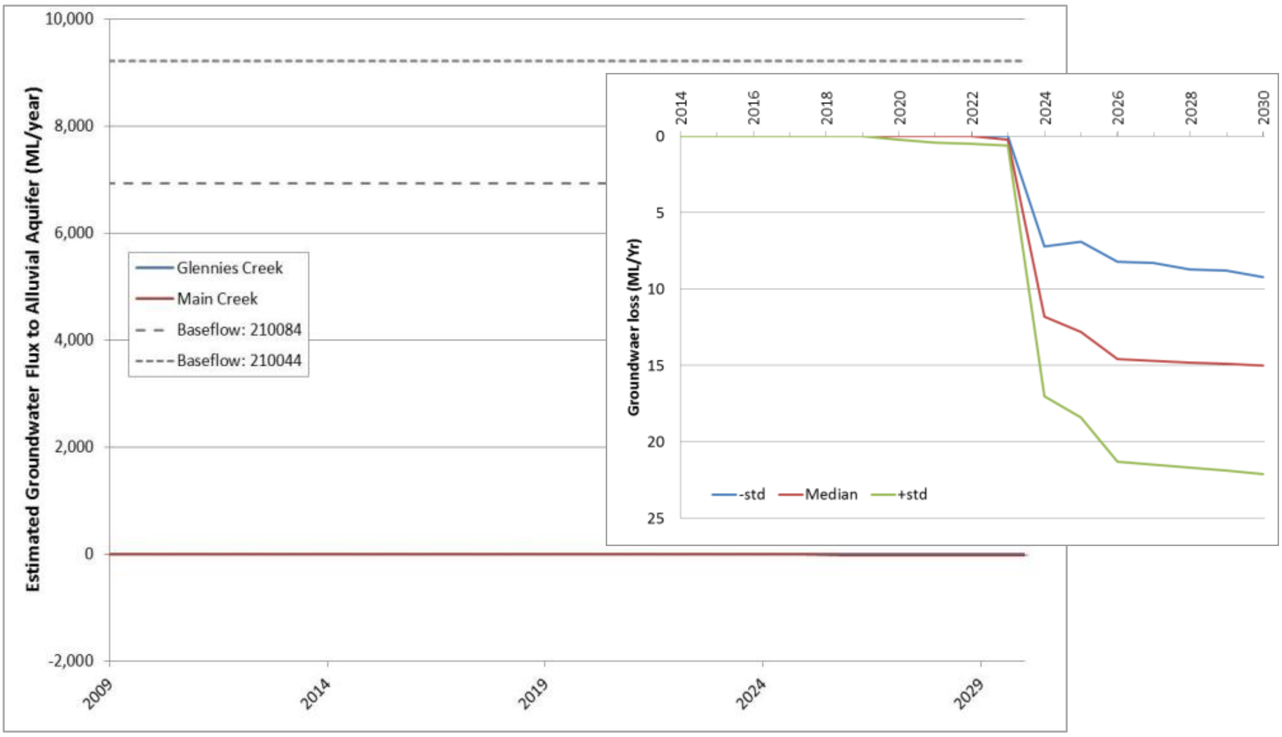
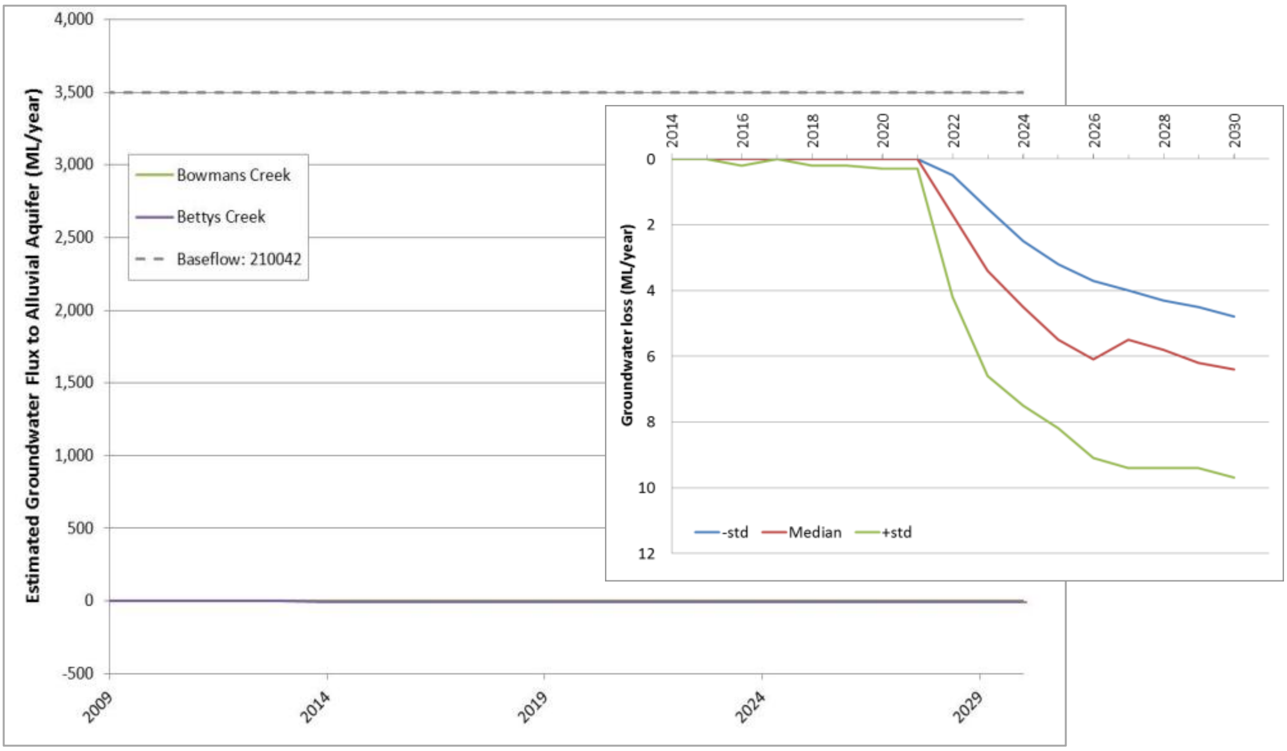


Figure 3-15 – Predicted Reduction in Groundwater Fluxes to Bowmans Creek and Bettys Creek Alluvial Aquifers Compared to Baseflow Estimates (*inset:* magnified view for Bettys Creek)



[5]Baseflow estimates determined using BaseJumper software program (Murphy et al., 2008)

Figure 3-16 through **Figure 3-27** present the estimated median incremental drawdown within the alluvial aquifers as a result of the Project (determined by the difference between Base case and Proposed case water levels for the alluvial model layers) and the corresponding extents for the one standard deviation (84^{th} percentile) of the 53 calibrated realisation results. Representations of water level drawdowns have been presented in this format to provide an indication of the predicted impact of the Project relative to currently approved mine plans.

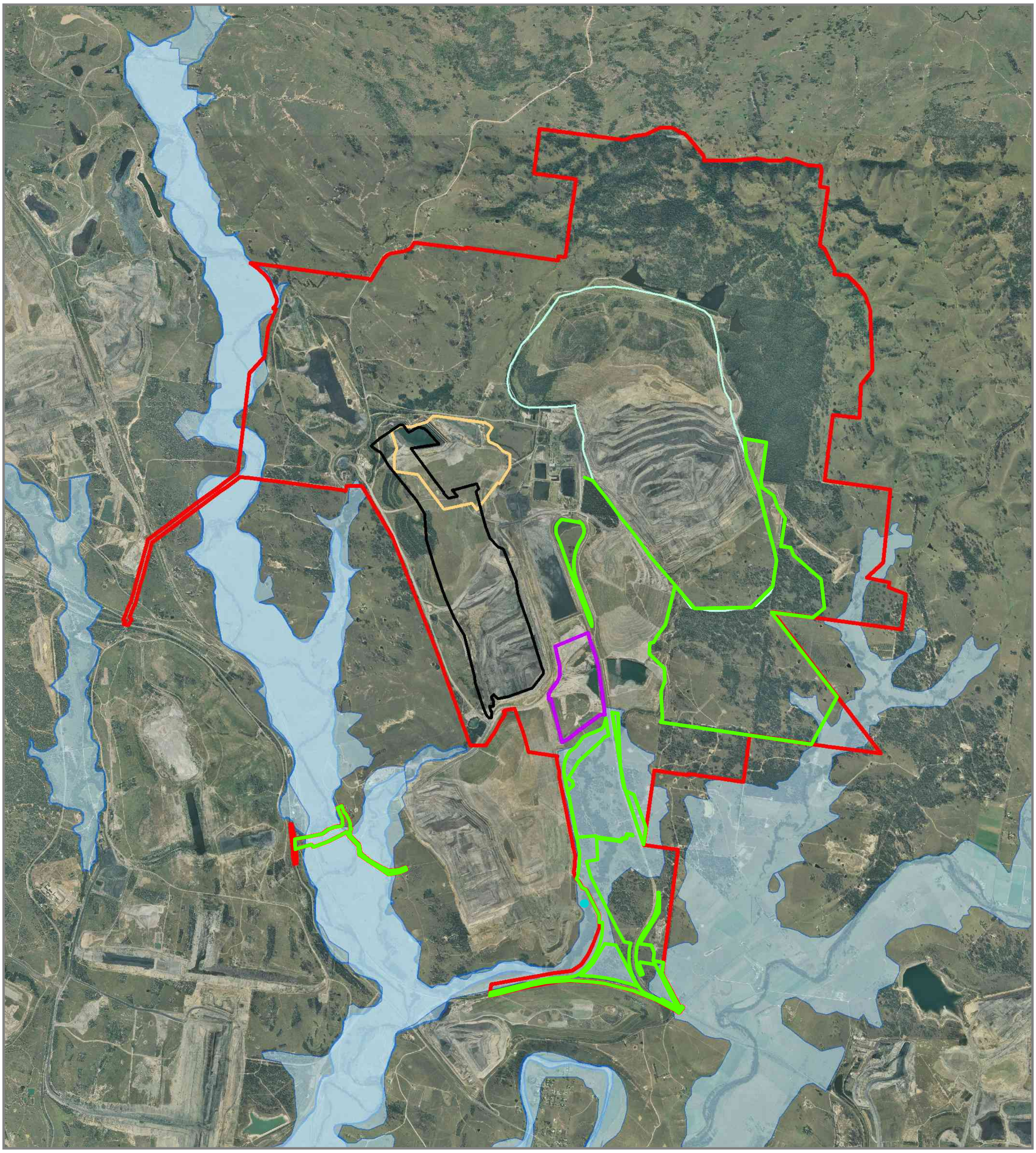
The predictive simulations indicate negligible drawdown will occur for most of the alluvial aquifers associated with Bowmans and Glennies Creeks, though local drawdowns are predicted to occur for reaches of limited extent within their tributaries: Bettys Creek and Main Creek, respectively. No drawdowns are predicted to impact on areas designated as BSAL(*see* **Figure 1-2**).

The alluvial extents shown in **Figure 3-1** and used in the numerical model are based on LiDAR data for the area and locally verified by field survey and observation data. For Bettys Creek, the depth of alluvium is less than 10 m in the area where drawdown is predicted to occur. Bettys Creek has also been the subject of three approved diversions, and thus does not represent natural conditions. Predicted drawdown in the Main Creek alluvium, meanwhile, occurs in an area where the alluvium is present in limited areal extent. Whilst the predicted drawdowns in both of these areas exceed the minimal impact criteria for aquifer interference activities as specified in the AIP, the significance of these alluvial aquifers is considered limited, with both creeks being ephemeral surface water features of similar, and poor, condition and with similar characteristics to Yorks Creek and Swamp Creek. Flow analysis for Yorks Creek and Swamp Creek, as shown in **Figure 2-4**, reflect ephemeral conditions and indicate these surface water features largely serve as local drainage courses and do not comprise reliable or utilised groundwater sources. No groundwater dependent ecosystems are related to these features.

3.5.1.2 Coal Measures

Predicted groundwater drawdowns within the Bayswater coal seam as a result of the Project are shown in **Figure 3-22** through **Figure 3-27**. Significant drawdown is shown for the coal seam due to the dewatering required to accommodate the Project. Impacts of these drawdowns are examined in **Section 4.1.1**.

Maximum impact on potentiometric heads is expected in 2025. This pressure surface is illustrated in **Figure 3-28**.



Legend

Predicted Drawdown (m)

- 0 - 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- > 6

- Mount Owen Project Area
- Mount Owen Disturbance Area
- West Pit
- Bayswater North Pit
- Approved North Pit Shell
- RERR Mining Area
- Alluvium Extent

0 0.5 1 2 Kilometers

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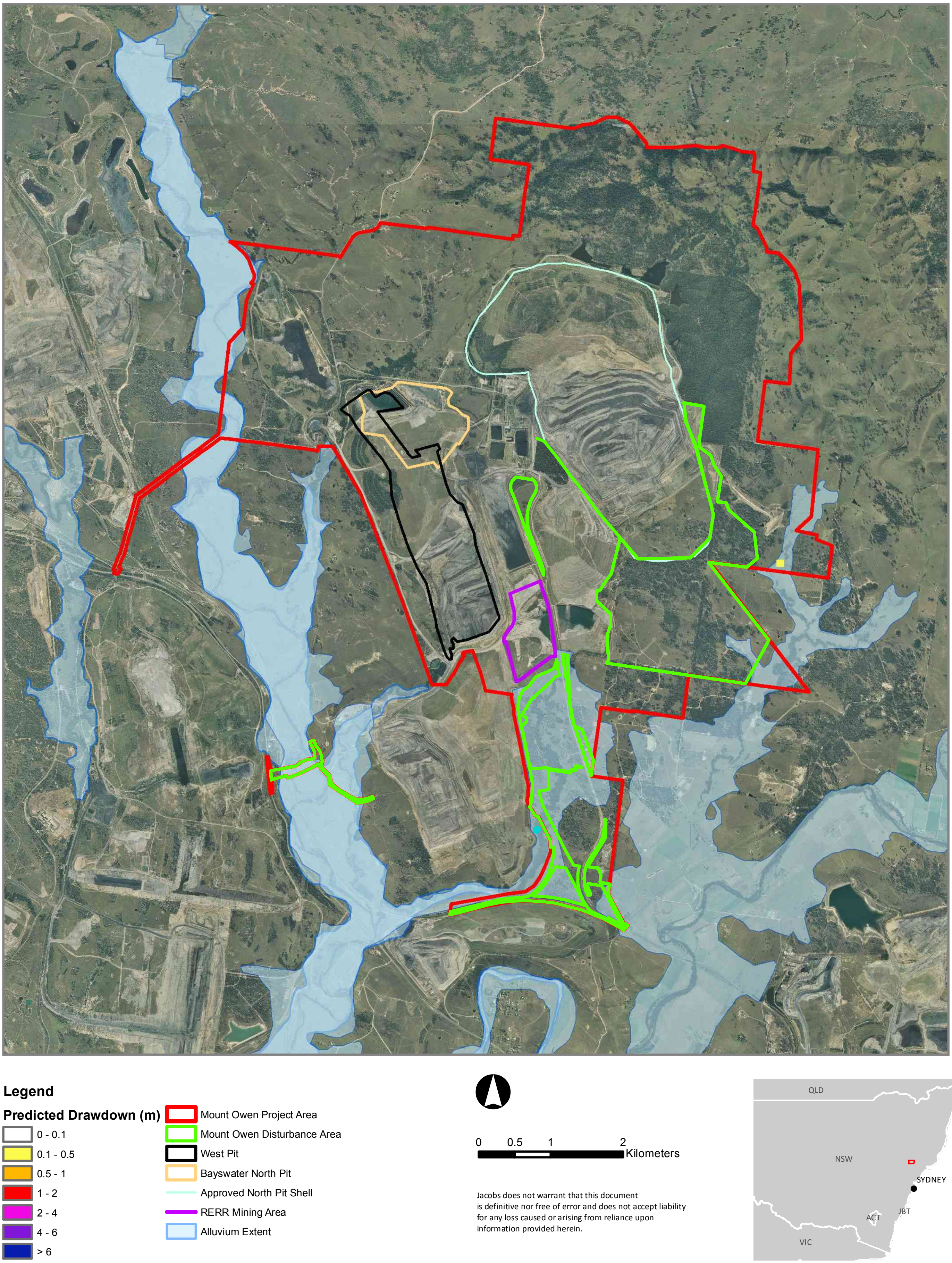
File Name: Figure 3-16 MOCO GIA_AlluviumDDs_50per_2020

Prepared by: LS
Checked by: RC

Figure 3-16 Predicted Median incremental Drawdown in Alluvial Aquifers in 2020

JACOBS

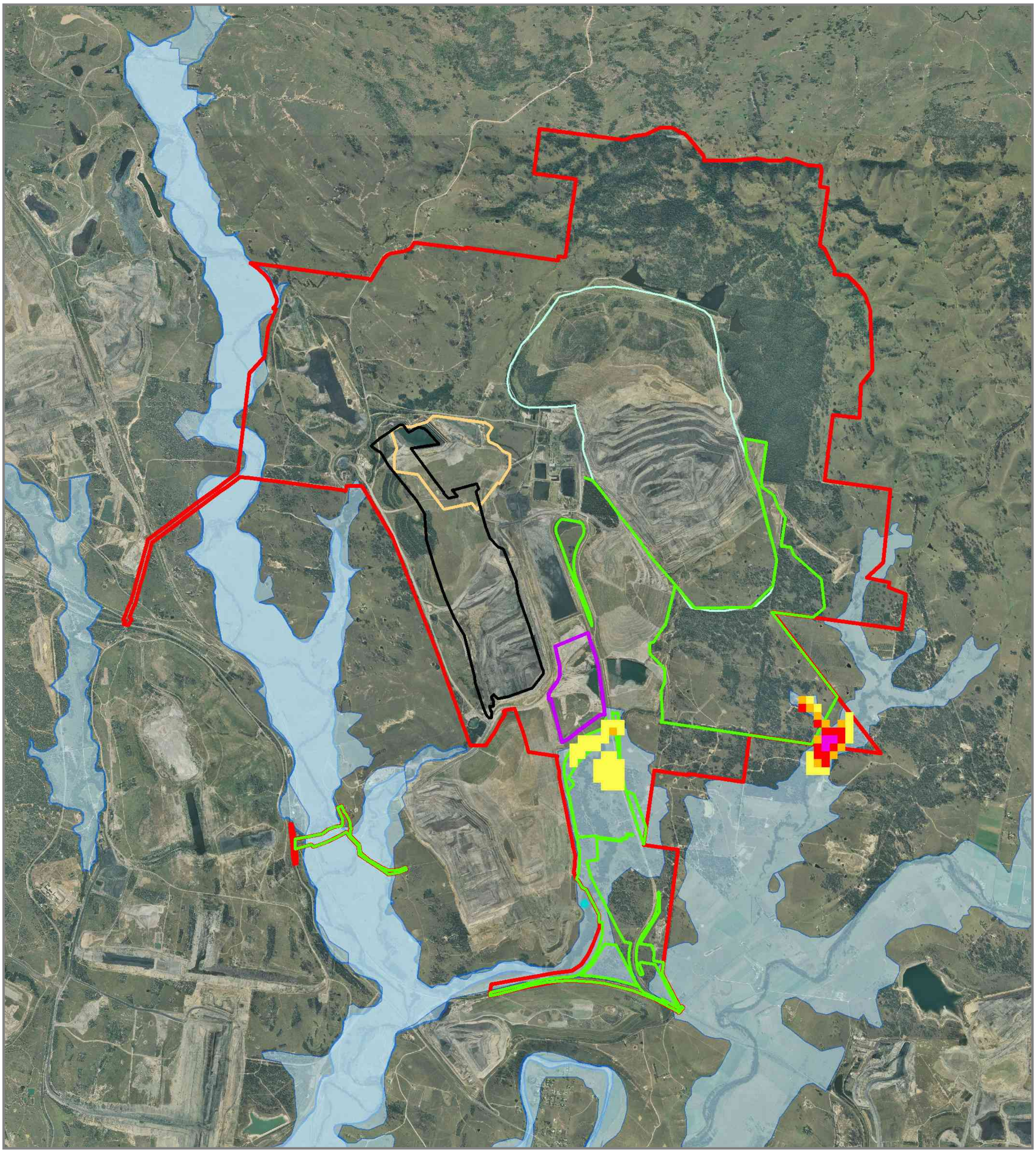


File Name: Figure 3-17 MOCO GIA_AlluviumDDs_84_2020

Prepared by: LS
Checked by: RC

Figure 3-17 Predicted Median + 1SD Incremental Drawdown in Alluvial Aquifers in 2020

JACOBS

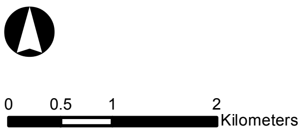


Legend

Predicted Drawdown (m)

- 0 - 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- > 6

- Mount Owen Project Area
- Mount Owen Disturbance Area
- West Pit
- Bayswater North Pit
- Approved North Pit Shell
- RERR Mining Area
- Alluvium Extent



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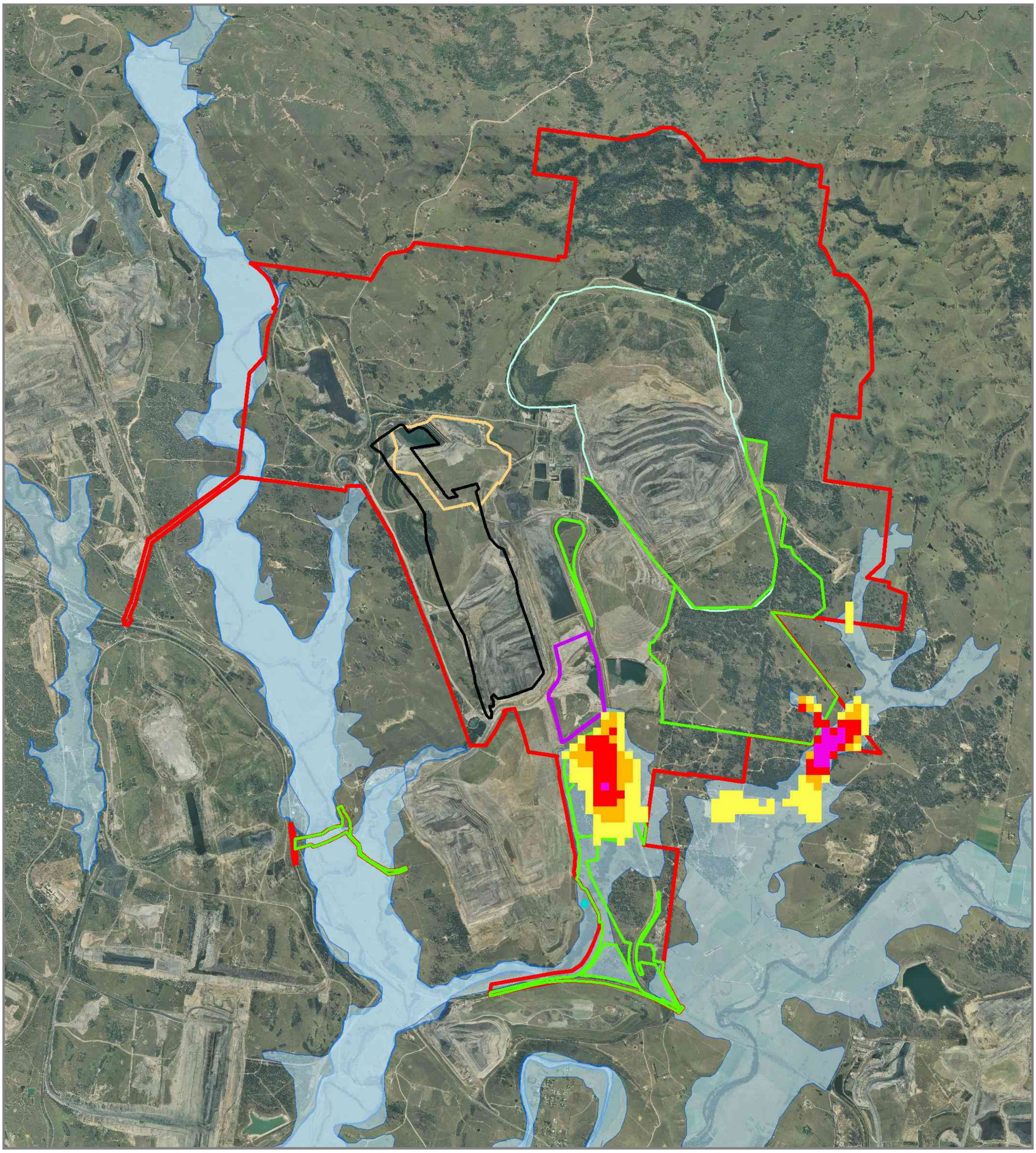
GDA 1994 MGA Zone 56

File Name: Figure 3-18 MOCO GIA_AlluviumDDs_50per_2025

Prepared by: LS
Checked by: RC

Figure 3-18 Predicted Median Incremental Drawdown in Alluvial Aquifers in 2025

JACOBS



Legend

Predicted Drawdown (m)

- 0 - 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- > 6

- Mount Owen Project Area
- Mount Owen Disturbance Area
- West Pit
- Bayswater North Pit
- Approved North Pit Shell
- RERR Mining Area
- Alluvium Extent

0 0.5 1 2 Kilometers

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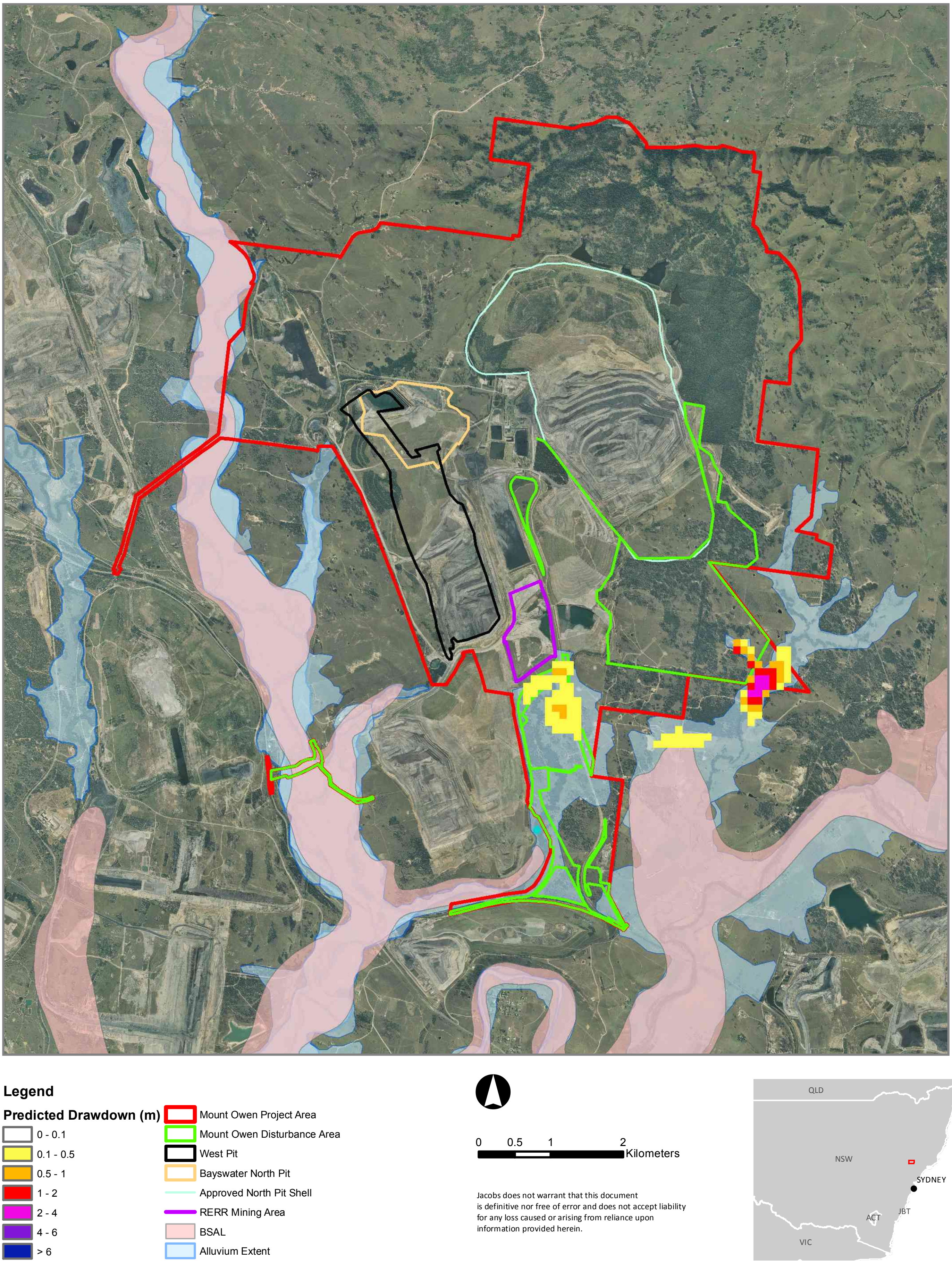
GDA 1994 MGA Zone 56

File Name: Figure 3-19 MOCO GIA_AlluviumDDs_84per_2025

Prepared by: LS
Checked by: RC

Figure 3-19 Predicted Median +1 SD Incremental Drawdown in Alluvial Aquifers in 2025

JACOBS



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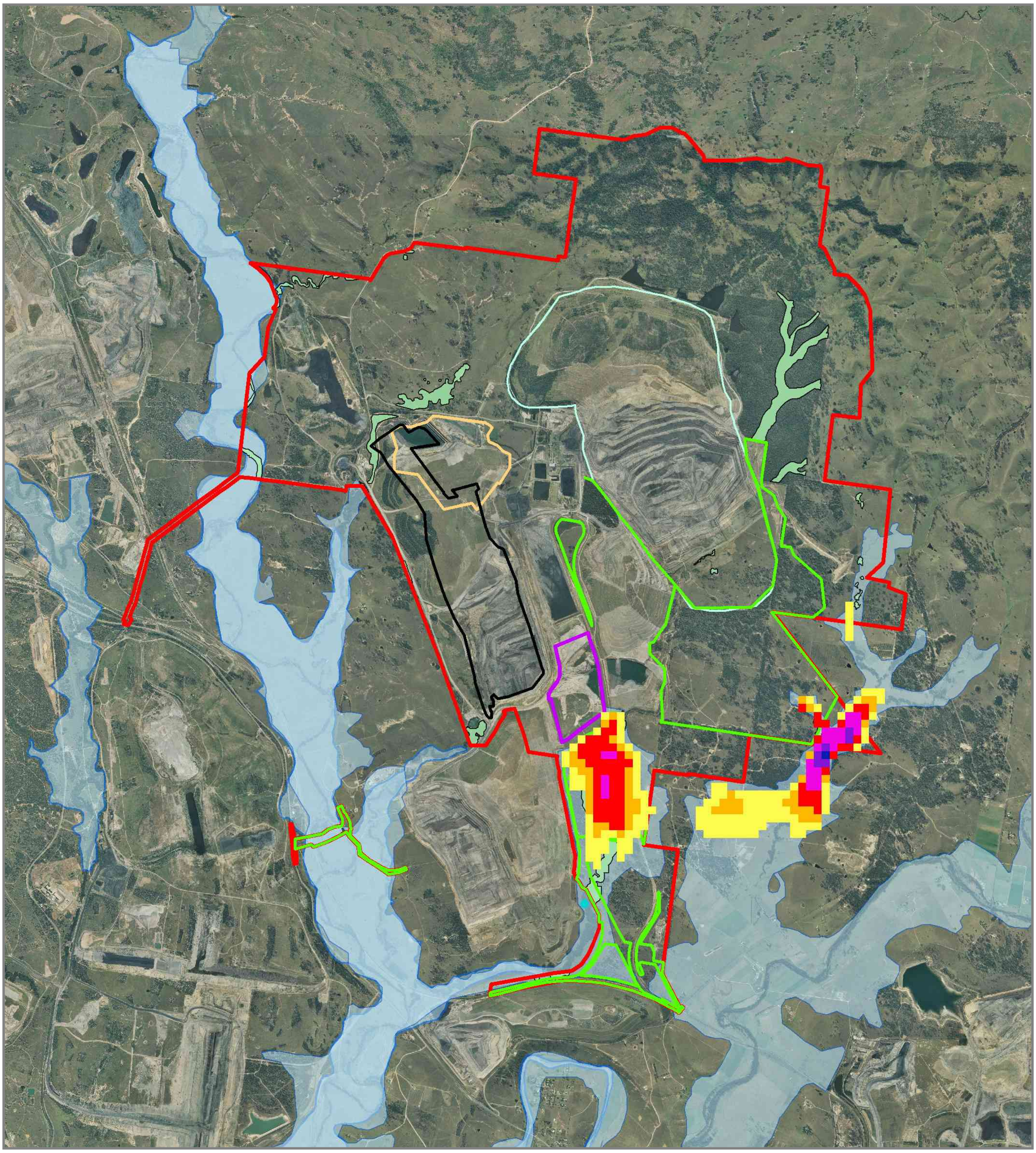
GDA 1994 MGA Zone 56

File Name: Figure 3-20 MOCO GIA_AlluviumDDs_50per_2030

Prepared by: LS
Checked by: RC

Figure 3-20 Predicted Median Incremental Drawdown in Alluvial Aquifers in 2030

JACOBS



Legend

Predicted Drawdown (m)

- 0 - 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- > 6

- Mount Owen Project Area
- Mount Owen Disturbance Area
- West Pit
- Bayswater North Pit
- Approved North Pit Shell
- RERR Mining Area
- Riparian Vegetation
- Alluvium Extent

0 0.5 1 2 Kilometers

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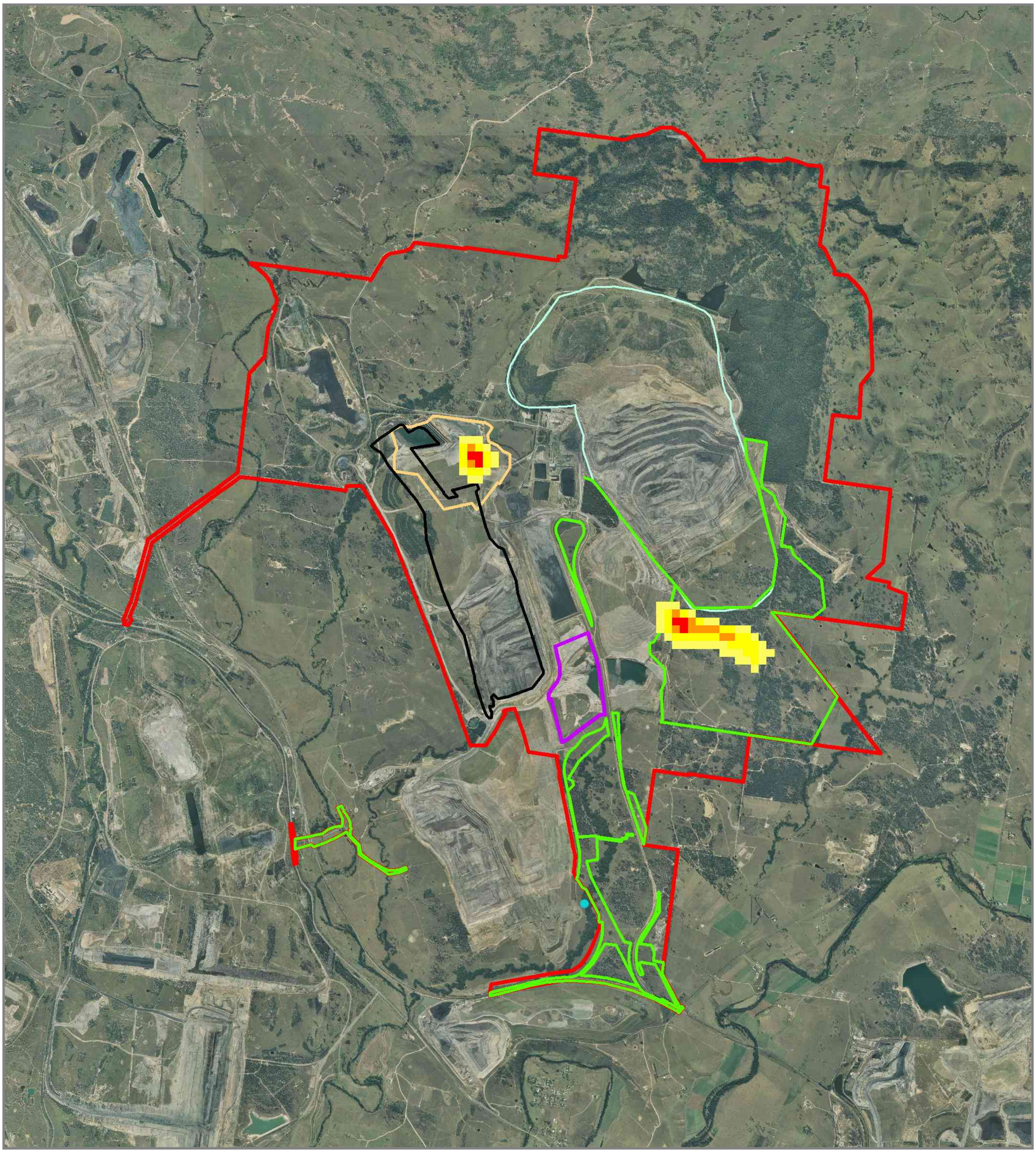
GDA 1994 MGA Zone 56

File Name: Figure 3-21 MOCO GIA_AlluviumDDs_84per_2030

Prepared by: LS
Checked by: RC

Figure 3-21 Predicted Median +1 SD Incremental Drawdown in Alluvial Aquifers in 2030

JACOBS



Legend

Predicted Drawdown (m)

- < 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 120
- 120 - 140
- 140 - 160
- > 160

- Mount Owen Project Area
- Mount Owen Disturbance Area
- West Pit
- Bayswater North Pit
- Approved North Pit Shell
- RERR Mining Area

0 0.5 1 2 Kilometers

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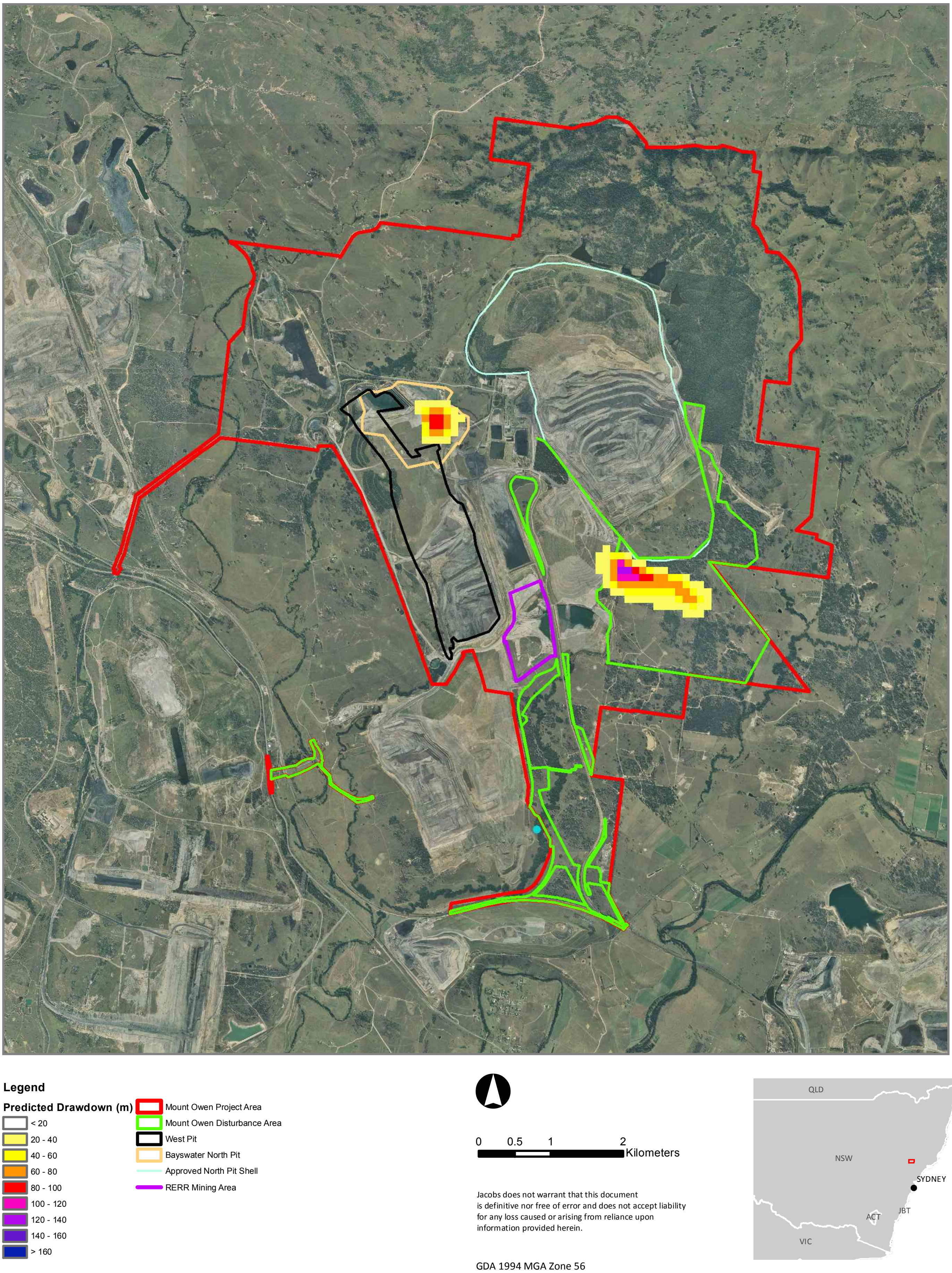
GDA 1994 MGA Zone 56

File Name: Figure 3-22 MOCO GIA_BayswaterDDs_50per_2020

Prepared by: LS
Checked by: RC

Figure 3-22 Predicted Median Incremental Drawdown in Bayswater Seam in 2020

JACOBS



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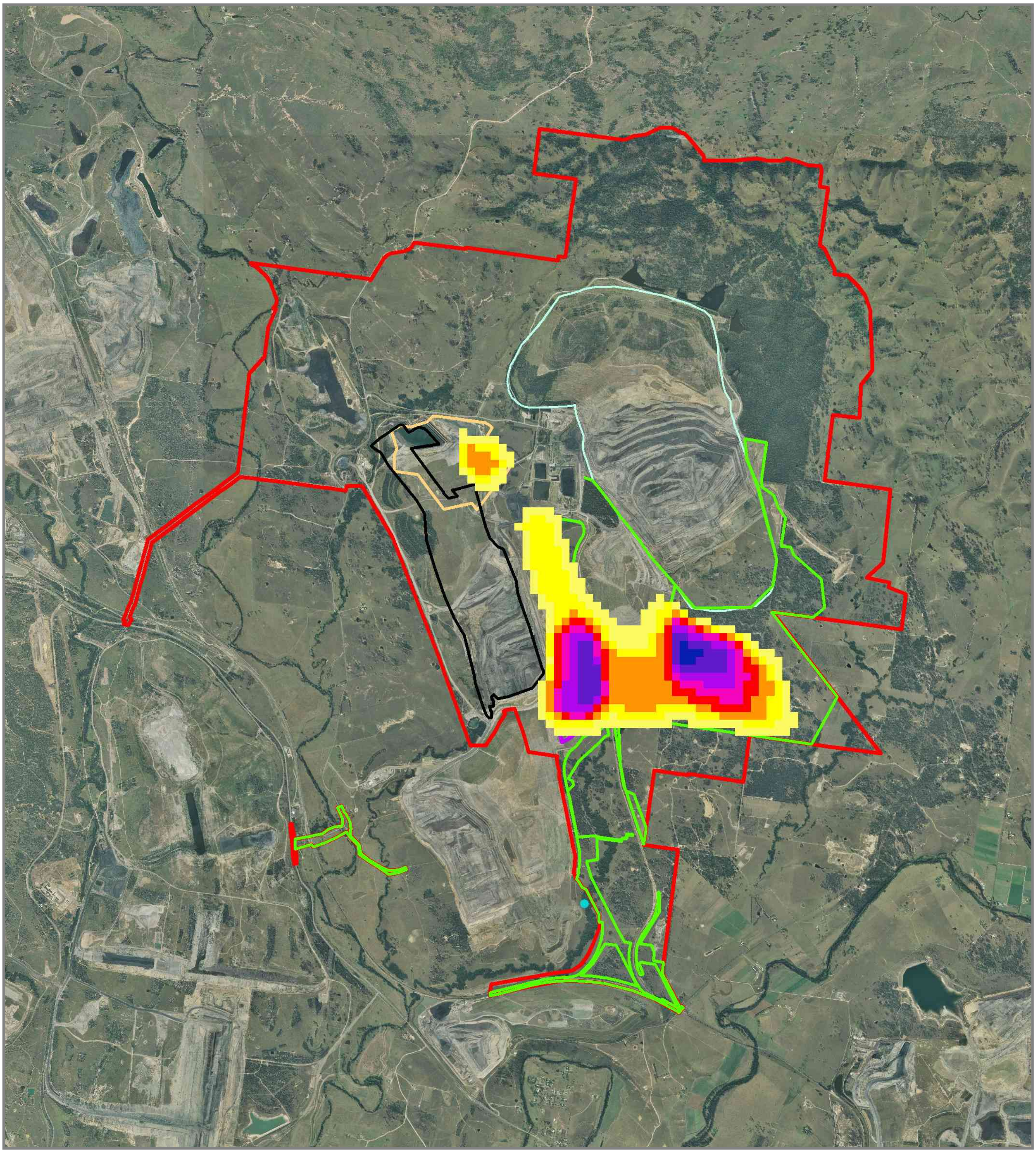
File Name: Figure 3-23 MOCO GIA_BayswaterDDs_84per_2020

Prepared by: LS
Checked by: RC

Figure 3-23 Predicted Median +1 SD Incremental Drawdown in Bayswater Seam in 2020

JACOBS



Legend

Predicted Drawdown (m)

- < 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 120
- 120 - 140
- 140 - 160
- > 160

- Mount Owen Project Area
- Mount Owen Disturbance Area
- West Pit
- Bayswater North Pit
- Approved North Pit Shell
- RERR Mining Area

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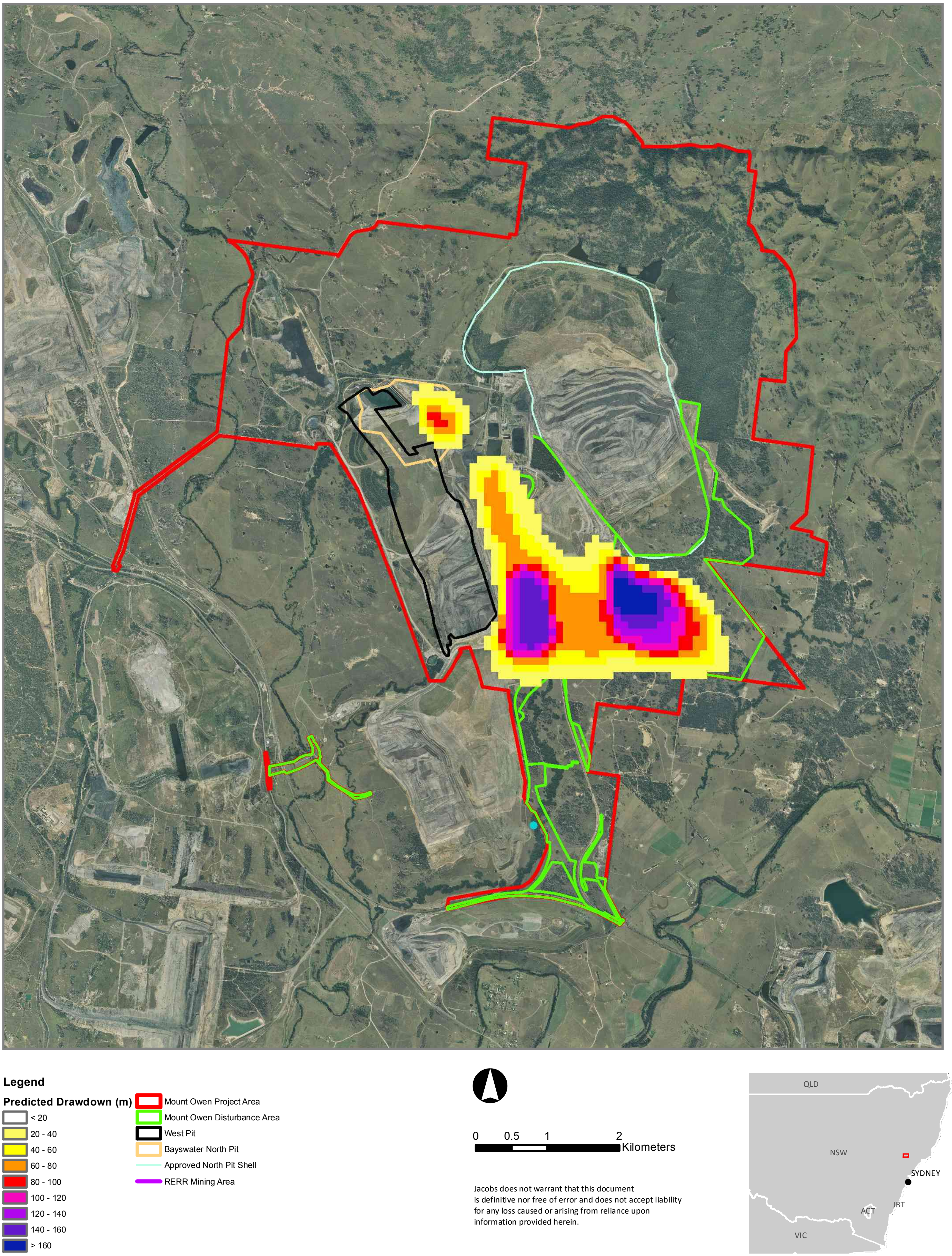
GDA 1994 MGA Zone 56

File Name: Figure 3-24 MOCO GIA_BayswaterDDs_50per_2025

Prepared by: LS
Checked by: RC

Figure 3-24 Predicted Median Incremental Drawdown in Bayswater Seam in 2025

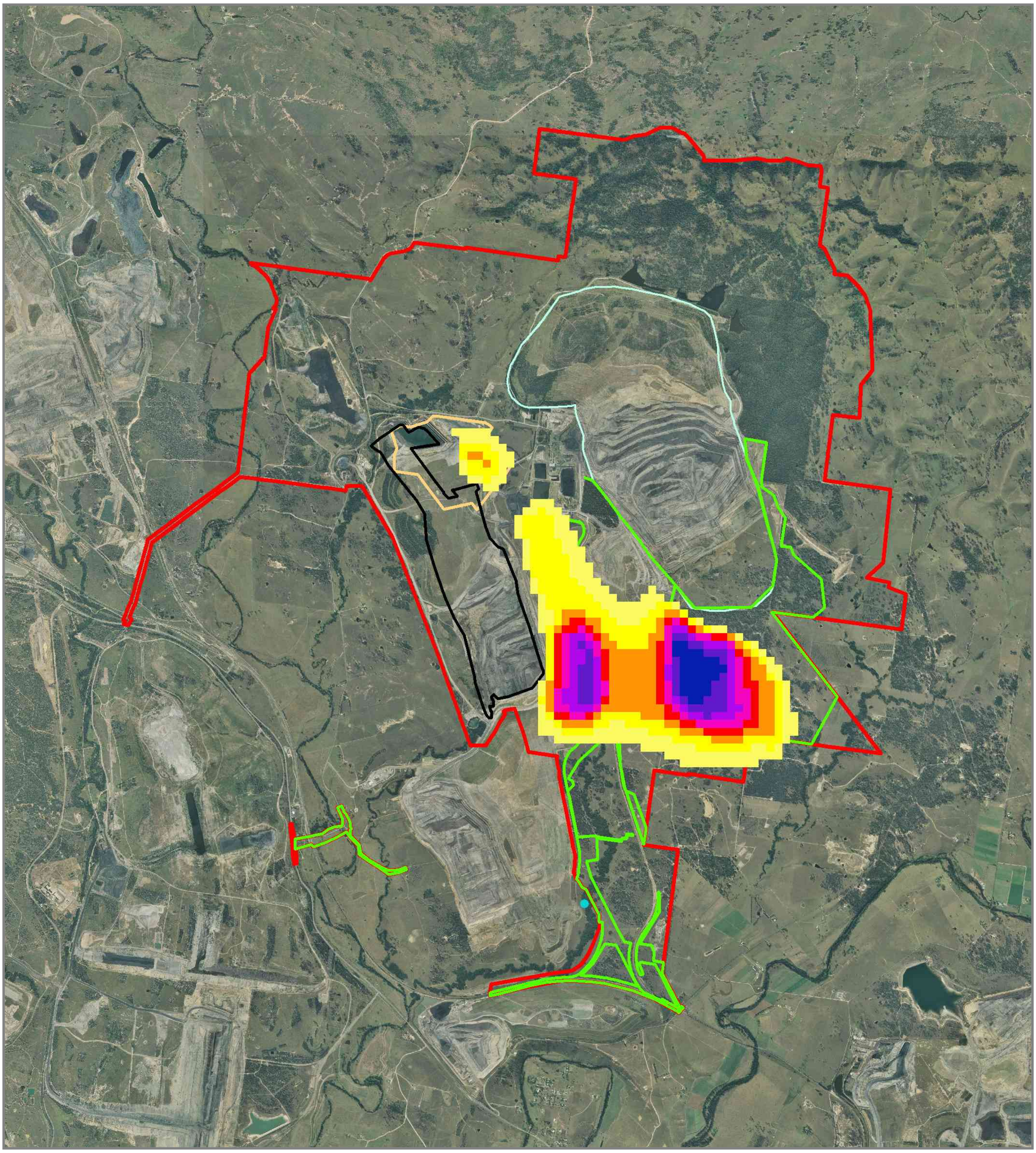


File Name: Figure 3-25 MOCO GIA_BaywaterDDs_84per_2025

Prepared by: LS
Checked by: RC

Figure 3-25 Predicted Median +1SD Incremental Drawdown in Bayswater Seam in 2025

JACOBS



Legend

Predicted Drawdown (m)

- < 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 120
- 120 - 140
- 140 - 160
- > 160

- Mount Owen Project Area
- Mount Owen Disturbance Area
- West Pit
- Bayswater North Pit
- Approved North Pit Shell
- RERR Mining Area

0 0.5 1 2 Kilometers

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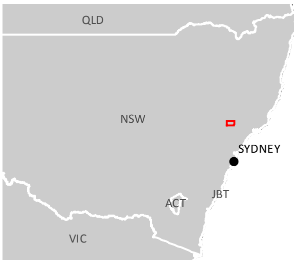
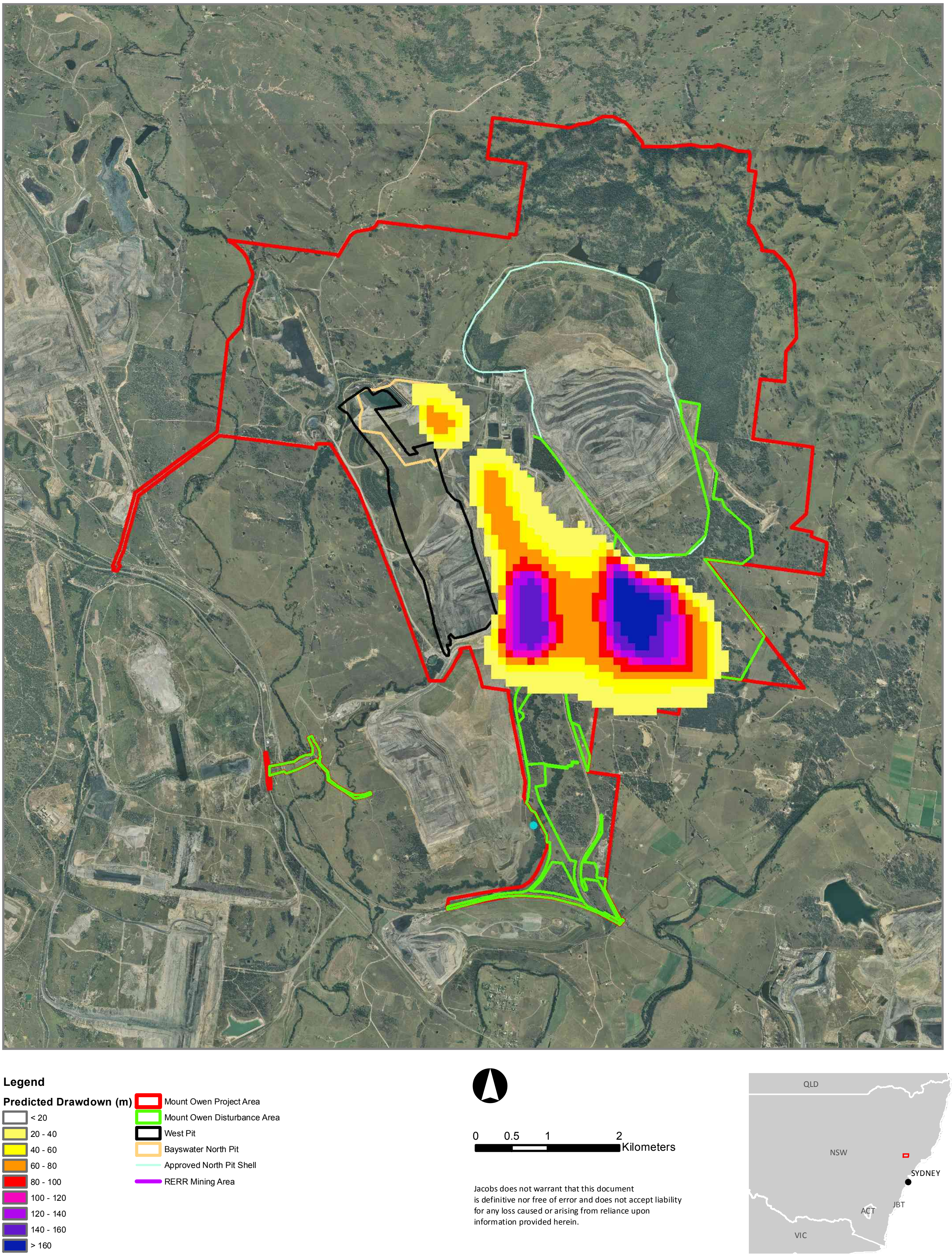


File Name: Figure 3-26 MOCO GIA_BayswaterDDs_50per_2030

Prepared by: LS
Checked by: RC

Figure 3-26 Predicted Median Incremental Drawdown in Bayswater Seam in 2030

JACOBS



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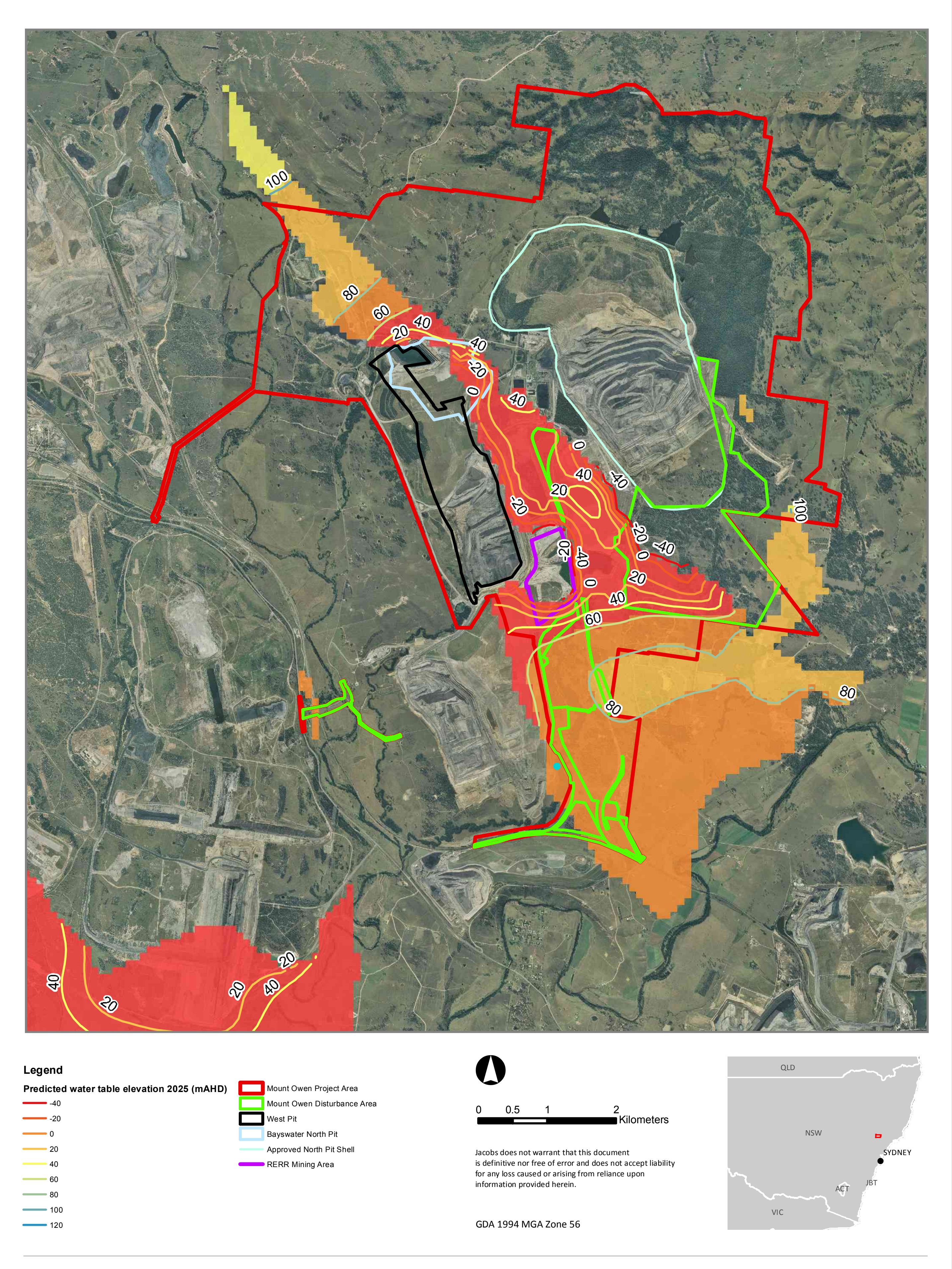
File Name: Figure 3-27 MOCO GIA_BayswaterDDs_84per_2030

Prepared by: LS
Checked by: RC

Figure 3-27 Predicted Median +1 SD Incremental Drawdown in Bayswater Seam in 2030

JACOBS



Prepared by: LS
Checked by: RC

Figure 3-28 Potentiometric surface for groundwater in the Bayswater Seam (model Layer 4) at maximum drawdown (2025)

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3.5.2 Estimated Pit Inflows and Dewatering

In addition to estimates of impacts on groundwater flow to alluvial systems and drawdown predictions, the predictive model simulations also provide estimates of pit inflows and dewatering requirements needed to accommodate the Project. Estimates of total inflows for Mount Owen are required to assess licence requirements and allocations in accordance with relevant legislation (refer **Section 1.4**). The pit inflows will be predominantly sourced from the regional hard rock aquifer, as the maximum predicted groundwater flows from the alluvial aquifers associated with Main Creek and Bettys Creek (refer **Figure 3-14** and **Figure 3-15**) amount to a maximum contribution in 2028 of less than 5% of the total estimated inflows and much less in all other years.

Pumping data for the North Pit collected over the last nine months provides additional observational data to compare to model estimates. Observations by mine personnel indicate pumping is strongly influenced by rainfall runoff, though recent periods of extended dry weather suggest a non-rainfall inflow of approximately 0.8 ML/day (290 ML/year) is currently being received within the North Pit.

Aside from the last year, historical pit inflow data for Mount Owen (as may be determined from pit pumping rates) was not available for this assessment. Following review of initial estimates of pit inflows determined using the calibrated datasets for the Proposed case simulations, discussions with mine personnel and comparison with independent site water balance models indicated the predicted inflow rates were generally higher than current and historical observations of pit inflows at Mount Owen and estimated inflow rates for 2012 were estimated at 1.4 ML/day (510 ML/year) for the North Pit.

Modelled pit inflow rates for the North Pit; West Pit and BNP and the RERR mining area, determined from the calibrated realisations for the Proposed case scenario, are shown in **Figure 3-29**, **Figure 3-30**, **Figure 3-31** and **Figure 3-32,** respectively. **Figure 3-33** shows the total estimated inflows for Mount Owen Complex required to accommodate the Project. Modelled median inflow for North Pit for 2013 was 476 ML/year (1.3 ML/day) and for 2014 447 ML (1.2 ML/day). The model is, therefore, providing a good estimation of the North Pit ingress.

The simulation results show the total estimated inflows under the Project are expected to peak from 2022 through 2026 with a median inflow estimate of approximately 705 ML which coincides with the maximum spatial expansion of all open cuts (**Figure 3-13**). Median predicted groundwater ingress to all pits for the duration of the project is 510 ML/year.

Further, the model assumes that all back-fill emplaced in the RERR mining area in the mid-2000s is first removed in 2022, prior to excavation of overburden starting late in that year. Thus, an additional 570 ML of groundwater accumulated in the backfill since 2006 is also initially removed from the pit and is not included in the calculations for hard rock ingress.

Figure 3-29 – Predicted Pit Inflows to North Pit

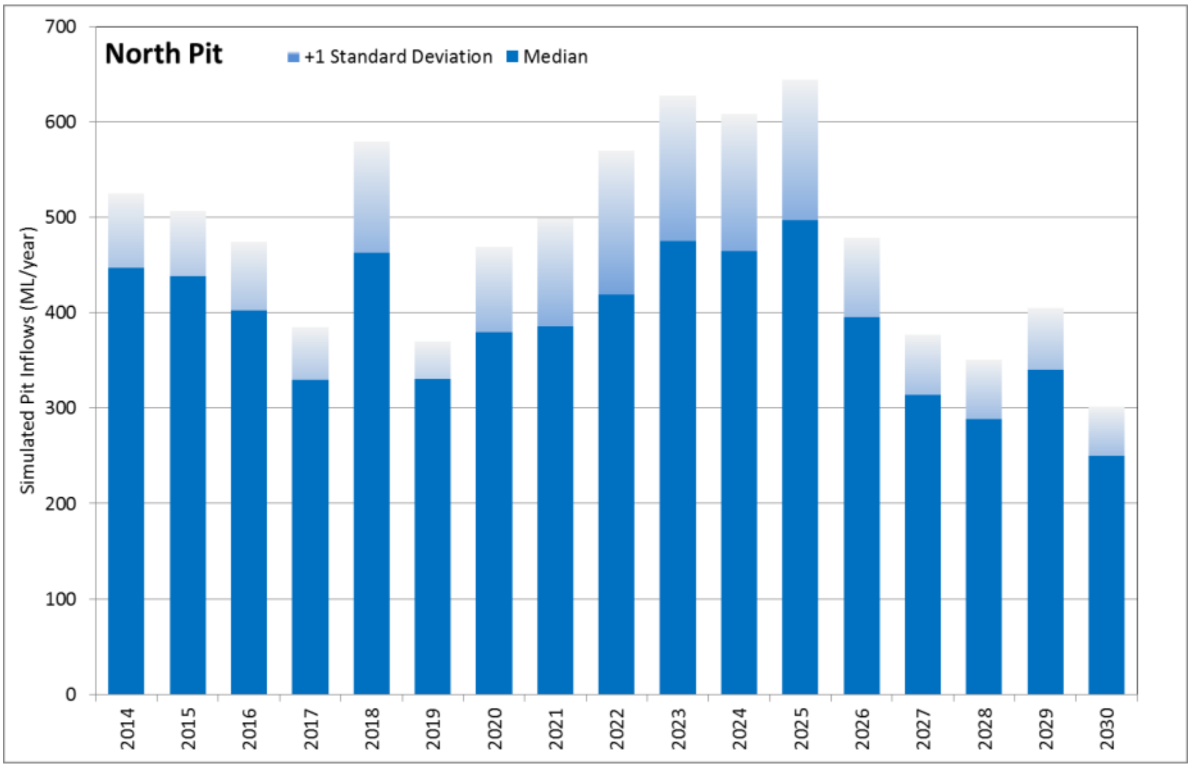


Figure 3-30 – Predicted Pit Inflows to West Pit

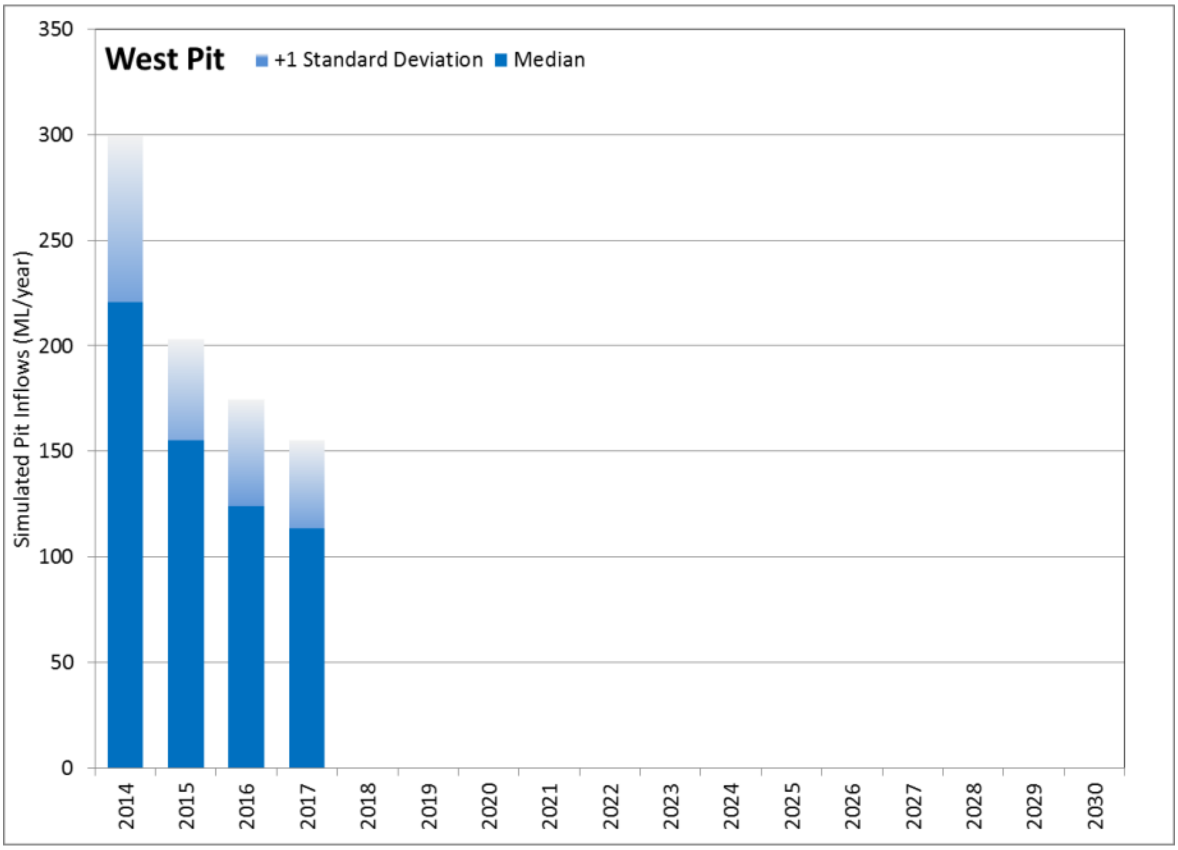


Figure 3-31 – Predicted Pit Inflows to Bayswater North Pit

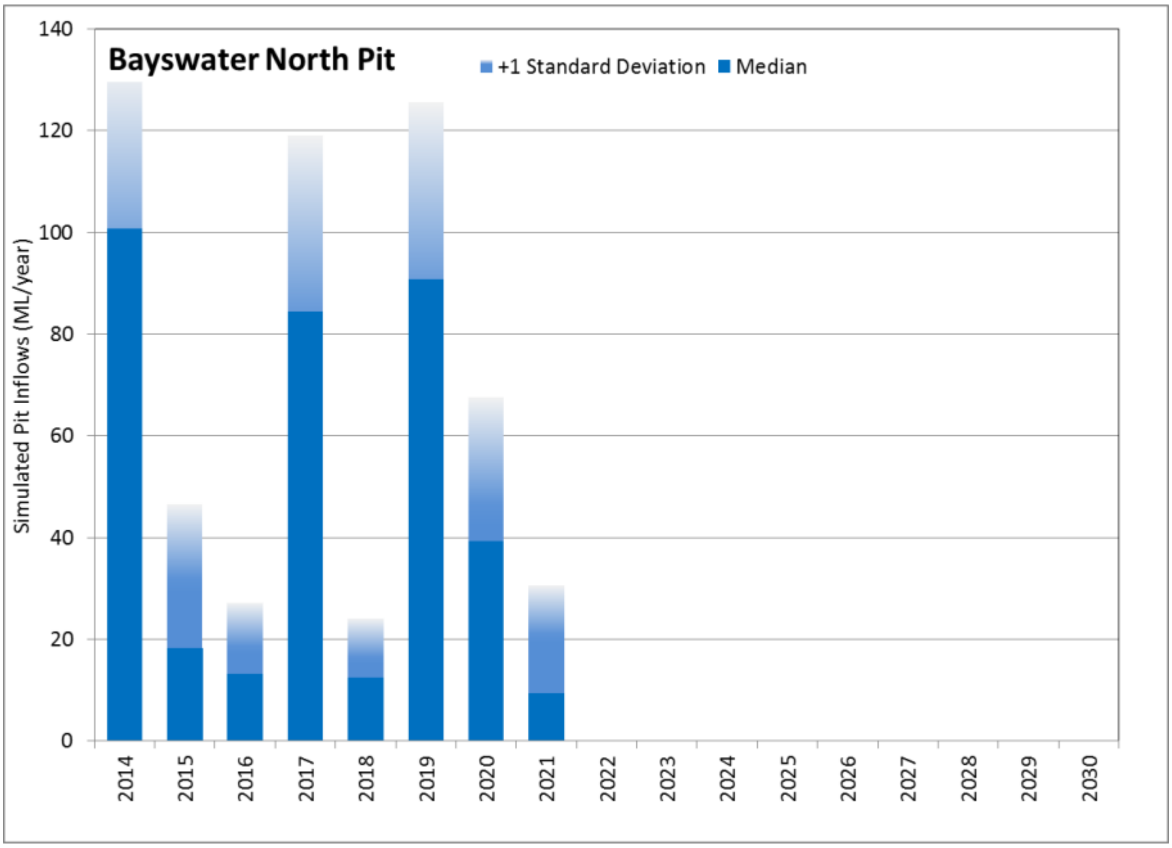


Figure 3-32 – Predicted Pit Inflows to RERR Mining Area

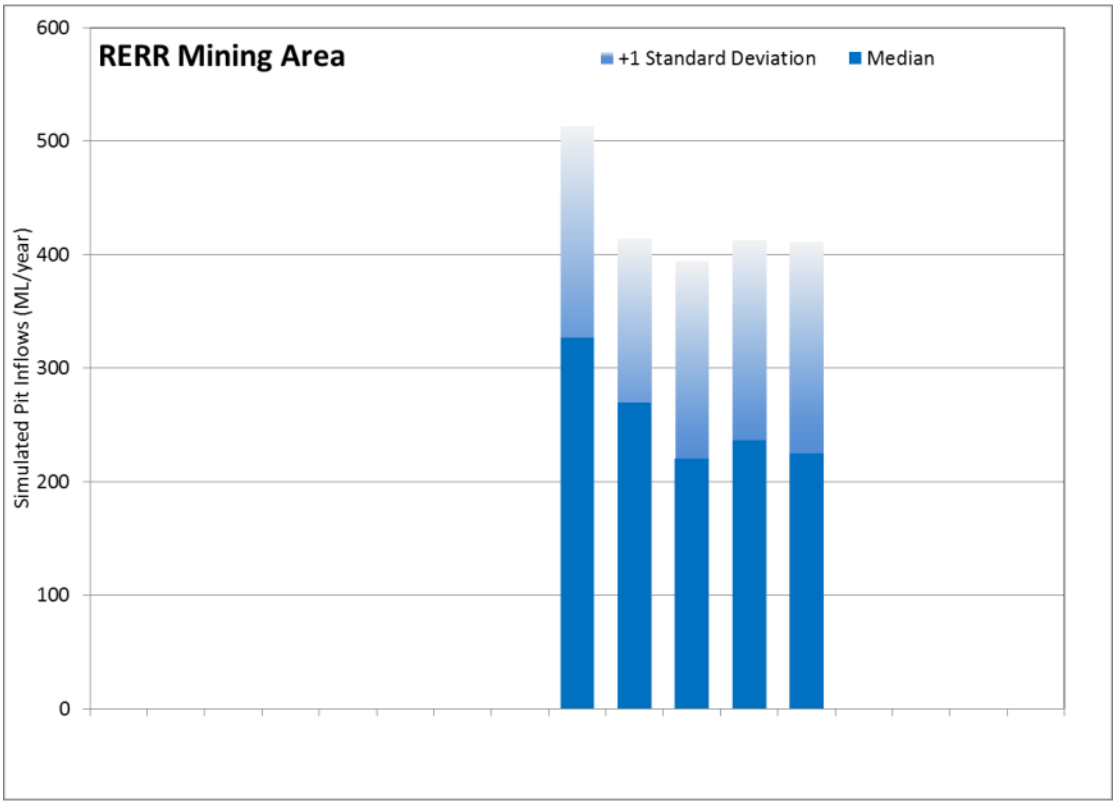
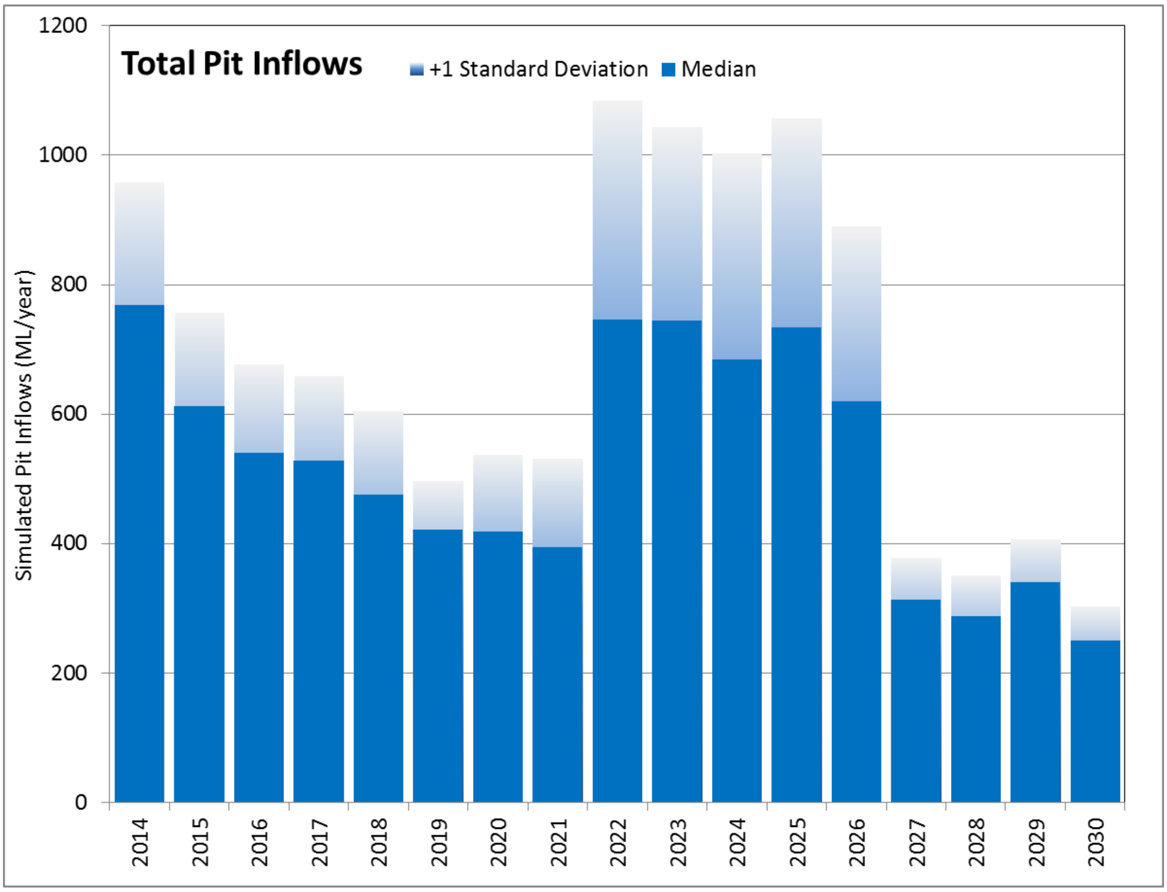


Figure 3-33 – Total Predicted Hard Rock Pit Inflows for the Project



3.5.3 Post Mining Simulations

According to the Umwelt (2014) water balance assessment for the Project, water levels in the North Pit final void are predicted to equilibrate to approximately 19 m AHD; in RERR to -8 m AHD and in BNP to 48 m AHD. This will occur within 200 years following the end of mining for BNP and 500 years for North Pit and RERR voids. Steady state simulations using these equilibrium water levels predict the North Pit and RERR will act as sinks to groundwater, with estimated inflow rates of approximately 0.15 and 0.30 ML/day (from the surrounding hard rock aquifer to the pits), respectively. The elevated nature of the BNP results in the void acting as a source of water to the surrounding hard rock aquifer. This groundwater would naturally flow down-gradient to seep into the RERR Pit (**Figure 3-34**) and this volume is included in the estimated inflow of groundwater to that void (**Table 3-9)**.

Table 3-9 – Final void conditions and status

Final void condition	North Pit	Bayswater North Pit	RERR
Final void water level (RL, m)	19	48	-8
Median steady state inflow (ML/day)*	-0.15	0.11	-0.30
Void status	Sink	Source to RERR	Sink

* positive values denote flux FROM the void; negative values denote flux TO the void

The resulting modelled regional potentiometric surface for groundwater in the Bayswater Seam is shown in Figure 3-35.

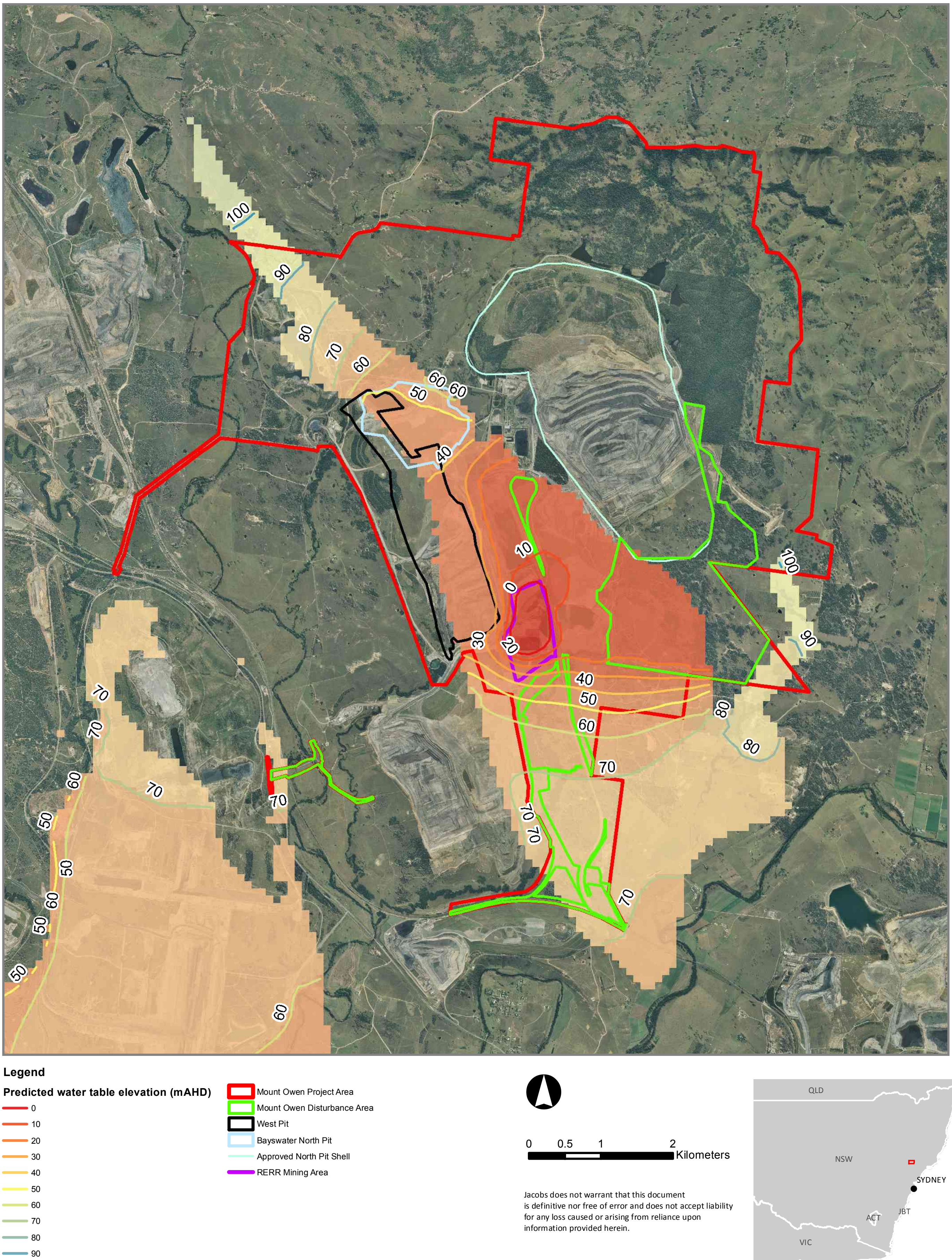
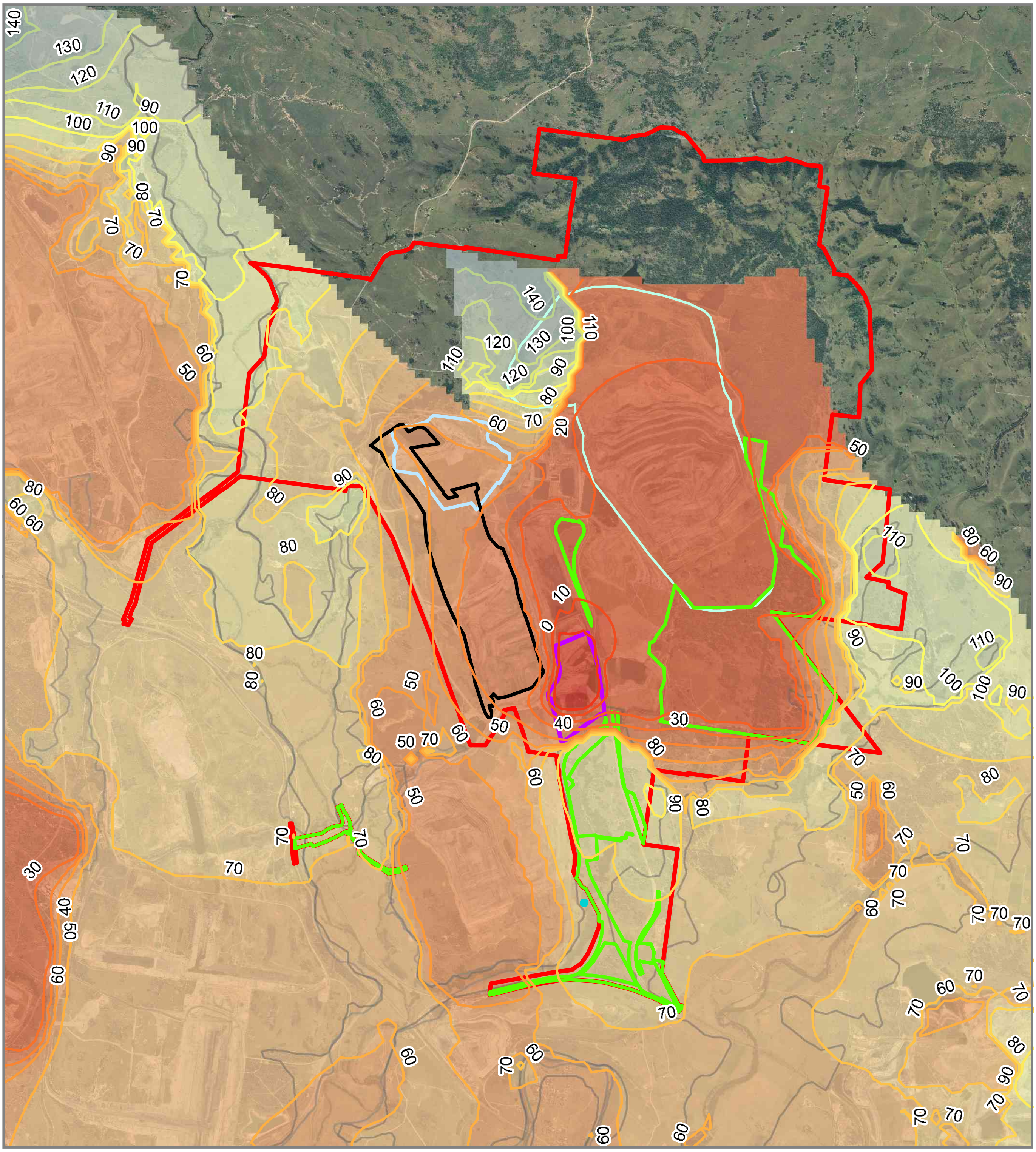


Figure 3-34 Modelled regional post-mining steady state potentiometric surface for groundwater in the Bayswater Seam (Model Layer 4)

JACOBS

File Name: Figure 3-34 MOCO GIA_FinalVoid_Bayswater_potsurface
Prepared by: LS
Checked by: RC



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File Name: Figure 3-35 MOCO GIA_FinalVoid_alluv

Prepared by: LS
Checked by: RC

Figure 3-35 Modelled regional post-mining steady state water table

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3.6 Model mass balance

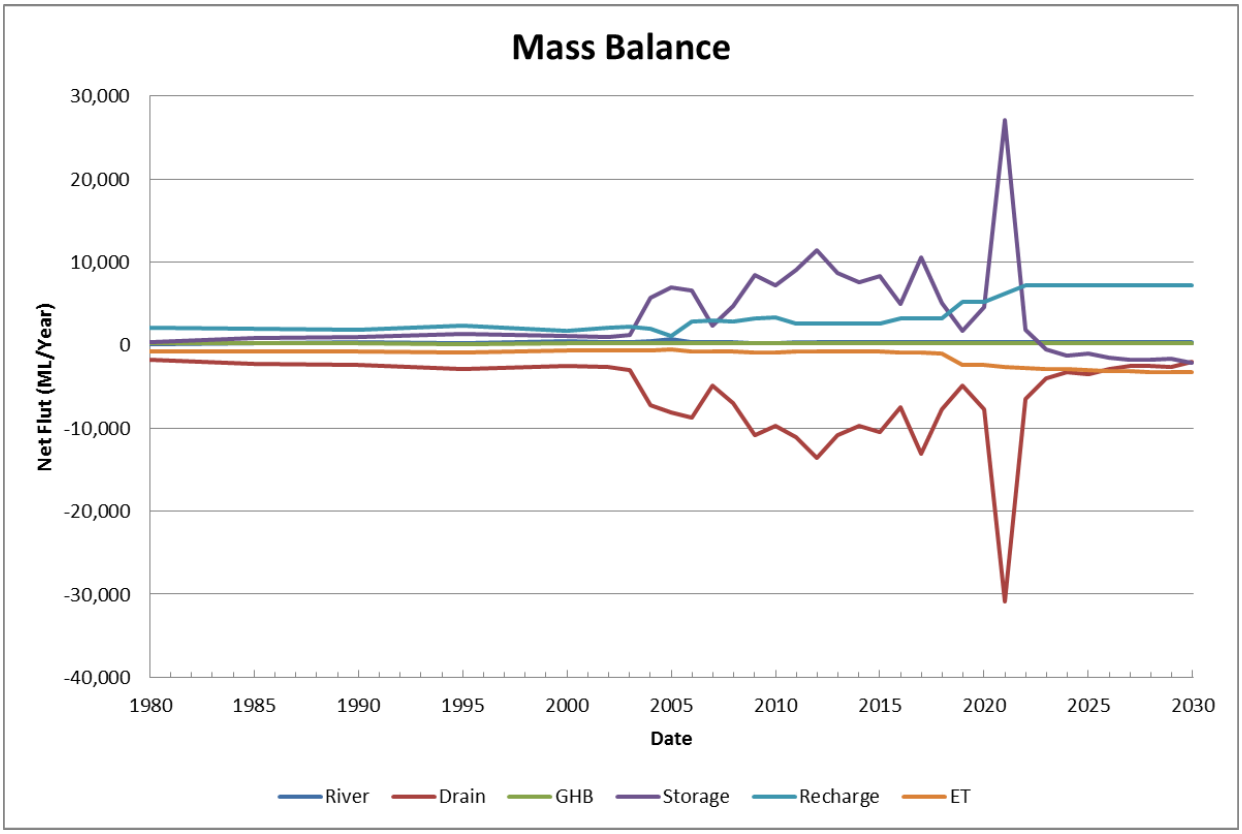
Mass balance was performed on all boundary cells and active drains across the model domain for the full modelled sequence. Steady state results are provided in **Table 3-10** and median fluxes are shown graphically in **Figure 3-36** in terms of Net Flux into (positive) and out of (negative) over time.

The steady state mass balance gave an overall error of 0.32%.

Table 3-10 – Steady state mass balance across the model domain

Boundary Condition	Flux In (ML/year)	Flux Out (ML/year)
Recharge	1,952	0
ET	0	-724
River	867	-680
Drain	0	-1272
GHB	325	-156
Stream	0	-303
Total	**3,145**	**-3,135**
error	**0.32%**	

Figure 3-36 – Temporal change in flux for boundary cells and drains across the model domain



4. Groundwater Impact Assessment

This groundwater impact 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 groundwater impacts can be classified:

- Groundwater quantity – e.g. dewatering activities;
- Groundwater quality – e.g. interaction of water sources of differing salinity and/or chemistry;
- Groundwater – surface water interactions; and
- Physical disruption of aquifers – e.g. through removal of coal and interburden.

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 **Section 3**. Results from predictive model scenarios, combined with other contextual information for Mount Owen, have been used to evaluate the potential impacts to groundwater resulting from the Project.

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 Mount Owen and in the surrounding region have caused depressurisation and dewatering of coal seams of the regional hard rock aquifer to accommodate mining activities. Current operations at Mount Owen extract coal to the base of the Hebden seam (**Figure 2-6**), and Integra Underground Mine has approval to extract coal via underground longwall panels from the Middle Liddell down to the Hebden seam. To maintain safe operations, extensive dewatering across the majority of the Mount Owen Complex is required, resulting in widespread depressurisation of the underlying hard rock aquifer.

4.1.1.1 Impacts to Alluvial Aquifers

Estimated groundwater losses from the alluvial aquifers associated with Glennies Creek and its tributary (Main Creek) and with Bowmans Creek and its tributaries (Bettys, Swamp and Yorks Creeks) are shown in **Figure 3-14** and **Figure 3-15**, respectively. Model simulations predicted negligible incremental changes in groundwater flow to the Glennies Creek and Bowmans Creek alluvial aquifers under the Proposed case scenario (the Project) compared to the Base case scenario (currently approved operations).

Main Creek and Bettys Creek are the most proximal alluvial systems to the Project and would be expected to experience the greatest potential impact. Swamp Creek has undergone significant diversion under previous approvals and no longer follows its original course until it joins Bowmans Creek. Yorks Creek is the closest tributary to BNP, but lies up-gradient from any potential impacts from the operations.

Peak incremental losses (measured as increased groundwater flow from the alluvial model layer) for the Main Creek alluvium are predicted to be less than 15 ML/year and correlate to continuation of the North Pit. Peak losses for the Bettys Creek alluvium are predicted to be less than 6 ML/year and correlate to mining of the RERR area. Mining in the BNP has no impact on the alluvial aquifers.

It should be noted, however, that the numerical model assumes both these systems initially includes baseflow that might be impacted. In reality, both Main Creek and Bettys Creek are ephemeral surface water features that largely act as drainage lines for the local area and only generate incidental baseflow following sustained rain events. Current and historical mining operations in the area have also significantly altered and/or removed the alluvial deposits associated with these features. Previous approved operations at Mount Owen Complex have included diversion works for Bettys Creek to accommodate mining activities (Umwelt, 2013).

4.1.1.2 Impacts to Hard Rock Aquifers

Predicted drawdown plots for the hard rock aquifer associated with the coal seams (*refer **Figure 3-22** through **Figure 3-27***) show significant reductions in groundwater pressures, with maximum predicted drawdown up to 165 m in the Bayswater seam at the end of mining (year 2030). Such significant drawdown is to be expected as the Bayswater seam represents the target depth for the North Pit Continuation. The drawdown within the Bayswater seam is limited to within the Project area and no existing groundwater users are impacted.

Figure 3-33 shows the total estimated groundwater extraction required to dewater the Project, calculated from the sum of the estimated pit inflows for all open pits at Mount Owen and Ravensworth East. Results from predictive simulations estimate that total inflows are currently at their peak and are expected to decrease into the future with a rise between 2022 and 2026 when the North Pit continuation extends south of the current disturbed area (**Figure 3-13**).

4.1.1.3 Final Void Impacts

The Project will modify the long-term hydrologic and 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 receptors for catchment runoff. It must be recognized, however, that long term steady state groundwater levels in the hard rock aquifer will also be significantly influenced by other concurrent mining operations in the local area. At Mount Owen Complex, the post-mining equilibrium water table will be heavily influenced by longwall panel development by Integra Underground Mine beneath the proposed North Pit Continuation. The concurrent and overlapping operations make it extremely difficult to distinguish the relative influence and impacts of the operations on the post mining equilibrium water table.

Regional water tables and potentiometric surface for the deep coal seams are shown in Figure 3-34 and Figure 3-35, respectively.

The model predicts that the North Pit and RERR final voids will act as groundwater sinks and the BNP void will act as a groundwater sink until the water level in that pit exceeds 37 m AHD, above which point water movement will be back into the hard rock aquifers and ultimately flow into the RERR void. It should be noted that the water quality in these aquifers is poor and there are no groundwater users between BNP and RERR Mining Area.

4.1.2 Groundwater Quality

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

- Potential acidification and subsequent mobilisation 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 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 monitoring locations targeting the regional hard rock aquifer indicates groundwater is typically neutral to alkaline (refer **Figure 2-16**). Assessment of future potential impacts at Mount Owen (EGI, 2013) confirms these conditions and, on this basis, impacts to groundwater quality as a result of ARD are considered highly unlikely under the Project.

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.

Available groundwater quality data for alluvial aquifers within and around the Project area is limited (refer **Section 2.6.5**), hence additional shallow bores have been added to the monitoring network from 2012 to 2014 (**Figure 2-9**). This makes it difficult to evaluate potential impacts to groundwater quality resulting from potential upward pressure gradients, though elevated salinities in the surface waters suggests input from aquifers to the surface. Hydrographs for nested alluvial and shallow hard rock bores to the west (mainly along Bowmans Creek in the vicinity of LCO) have revealed potential for upward pressure gradients, however this pressure gradient is reversed further downstream in areas where historical and current mining operations have depressurised the hard rock aquifer (SKM, 2013).

Within the coal seams and interburden comprising the regional hard rock aquifer, groundwater pressure data for VWPs located in the vicinity of the proposed North Pit Continuation indicate upward pressure gradients existing between the interburden and underlying Ravensworth seams (VWP SMC002, refer **Appendix A**) and between the Bayswater and underlying Lemington seams (VWP SMO028, refer **Appendix A**). Limited groundwater data for the local alluvial aquifers, however, makes it difficult to determine whether such upward pressures exist between the alluvium and underlying hard rock aquifer in the vicinity of Mount Owen Complex.

The depressurisation of the hard rock aquifer caused by currently approved and proposed mining operations will serve to limit potential impacts to groundwater quality by reducing upward leakage (where present) from the more saline hard rock aquifer to the fresher alluvial aquifer. The salinity data collected from the existing and recently expanded groundwater monitoring network at the Mount Owen Complex generally confirms differing salinity levels for the shallow and deeper hard rock aquifers, suggesting a lack of connectivity between the deep and shallow formations.

Model simulations undertaken for this impact assessment predict that the Project will have negligible long-term impacts to groundwater quality in the alluvial aquifers associated with Glennies Creek and Bowmans Creek.

Nested bores NPZ1 and NPZ8 are notable exceptions to the water quality data (pH and EC) recorded for other bores within the existing Mount Owen Complex monitoring network (refer **Section 2.6.5**). pH readings for the shallow and deep piezometers at both locations have consistently decreased since monitoring commenced, with initial data indicating alkaline conditions of pH values greater than 9, while more recent pH readings at these bores fall within the neutral range of values (i.e. between pH 7 and 8.5) that is seen in other monitoring bores. In addition, EC data for the deeper piezometer in both bores has increased significantly during the monitoring period, with NPZ1a steadily increasing since 2008 and NPZ8a since beginning of 2011. While the timing of these increases do not correlate to the decreases in pH values, taken together the water quality data for these bores suggests localised changes to the hydrogeological regime in this area. Both monitoring locations are located to the southeast of the current North Pit mining limit and within the proposed continuation area.

Modelling of salinity levels in the final voids has been undertaken by Umwelt (2014a). Evaporative concentration of total dissolved solids in the final voids results in long-term projected salinities that increase over time, with North Pit increasing from end of mine levels of about 4,000 mg/L (approximately 6,500 µS/cm) to reach 5,000 mg/L after about 200 years. Over the same period, the BNP void is not projected to increase in salinity above the end of mine levels of about 600 mg/L. The final void salinity at RERR is projected to increase from 5,000 mg/L to 13,000 mg/L over 200 years post-mining.

EC data for the regional hard rock aquifer at Mount Owen Complex typically ranges between 5,000 and 15,000 µS/cm, indicating that void waters will remain fresher than local groundwaters for at least 200 years following the end of mining. Critically, the BNP and North Pit voids will not generate water of lower quality than local groundwaters while the RERR void will remain a sink to groundwater and hence not pose a threat to aquifer water quality.

4.1.3 Surface Water – Groundwater Interaction

Mining related activities can have substantial effects on surface water – groundwater interactions, usually due to either physical alteration 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. For the Project, potential direct impacts to the exchange of water between surface water and groundwater systems specifically relate to impacts to Glennies Creek and its ephemeral tributary Main Creek, to Bowmans Creek and its ephemeral tributary Bettys Creek, and the alluvial aquifers associated with these features.

Predictive model results indicate the Project has negligible impact on groundwater fluxes and drawdown within the alluvial aquifers associated with Glennies Creek and Bowmans Creek. Whilst the modelling predicts minimal impacts on groundwater flows to the ephemeral tributaries Main Creek and Bettys Creek, drawdown within these alluvial systems is predicted across limited areal extents. The drawdown can be attributed to the small alluvial volume present where drawdown is predicted. The predicted magnitude of drawdown exceeds the minimal impact criteria for aquifer interference activities as specified in the AIP. However the significance of these alluvial aquifers is considered limited, with both creeks being ephemeral surface water features that largely serve as drainage courses for the local area.

4.1.4 Physical Aquifer Disruption

Mining operations can directly impact groundwater resources through physical disruption of an aquifer, which occurs during removal of material (e.g. coal, interburden) as part of mining activities. Current and historical mining operations in the local area, stretching back nearly 100 years, have resulted in significant disruption of the regional hard rock aquifer. In addition, physical changes to local alluvial aquifers have been carried out as part of previously approved mining operations, including diversion works on Swamp Creek and Bettys Creek and physical removal of the alluvial aquifer in those areas.

The additional disruption of the regional hard rock aquifer caused by the proposed continuation of the North Pit is considered minimal. The extent of the North Pit mining limit will never be closer than approximately 450 m from the high bank of the Main Creek Alluvium, satisfying the AIP requirement to remain greater than 200 m from the high bank of an alluvium aquifer.

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.). Lake St Clair, the artificial lake resulting from construction of Glennies Creek Dam, is a popular recreational fishing area; however it is located over 12 km northeast of the Project Area and well beyond the potential zone of influence for groundwater impacts.

Bowmans Creek and Glennies Creek also have inherent social and cultural importance. Results from the groundwater modelling indicate that there will be no change to the current surface or groundwater water flow conditions, hence there are expected to be no social and cultural users of water resources potentially impacted by the Project.

4.2.2 Environmental

Potential environmental receptors that may be affected by the Project include aquatic and riparian ecosystems associated with the Hunter River and its tributaries, which are regulated under the *Water Management Act 2000*. For the Project, Glennies Creek and its alluvial aquifer has been identified as a potential receptor to groundwater impacts in the DGRs and by other government agencies (refer **Section 1.2**).

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

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

As outlined in the Ecology Assessment completed as part of the EIS (Umwelt, 2014b), there are four terrestrial vegetation communities that are expected to be dependent on shallow groundwater resources during periods of reduced surface water flow. The surface water assessment completed for the Project (refer to Section 5.5 of the EIS), however, identified that the changes in annual flow volumes associated with proposed changes to catchment areas for Yorks Creek, Swamp Creek, Bettys Creek and Main Creek are considered to be small within the context of ephemeral streams. The changes in annual flow volumes are also considered to be small on a regional scale, with the change in flows being less than the seasonal and annual variations in flow volumes comparing dry years to wet years. Thus, reductions in surface water flow to the four terrestrial vegetation communities identified in the Ecology Assessment (Umwelt, 2014b) is expected to be negligible, also suggesting negligible dependence on shallow groundwater resources.

The aquatic ecosystems of Glennies Creek and Bowmans Creek and their ephemeral tributaries, Main Creek, Yorks Creek, Swamp Creek, and Bettys Creek, along with their associated riparian vegetation, represent potential environmental receptors that may be impacted by the Project. A review of the Bureau of Meteorology Altas of Groundwater Dependant Ecosystems (BoM Atlas http://www.bom.gov.au/water/groundwater/gde/ accessed in February 2014) identified Bowmans Creek and Glennies Creek as systems with potential GDEs within the vicinity of the Project Area. Impacts to the alluvial aquifers of Bowmans and Glennies Creek, however, are predicted to be negligible (**Section 3.5.1.1**) and therefore impacts to their GDEs are also expected to negligible.

Under the Upper Hunter SRLUP (DPE, 2012), the alluvial aquifers of the Hunter River and its major tributaries (including Bowmans and Glennies Creeks) were classified as BSAL. Although the Project is located in proximity to land mapped as BSAL under the SRLUP (Figure **1-2**), site verification completed as part of the Agricultural Impact Assessment (Umwelt, 2014c) determined that there was no BSAL within the Proposed Disturbance Area.

4.2.3 Economic

Interrogation of NSW Office of Water's PINNEENA database identified 47 registered groundwater bores within 4 km of the Project area (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. Whilst several of the registered bores are listed under private ownership in the database, all of these bores are owned by Mount Owen or other mining operations in the area. The nearest private (non-mine) water supply bores are over 4 km away from the Project area and beyond the extent of drawdown predicted by the groundwater modelling. As such, privately owned bores are not considered potential economic receptors to groundwater impacts caused by the Project.

Neighbouring mining operations are considered potential economic receptors of groundwater impacts caused by the Project. Potential impacts would be most significant for Integra Underground Mine, which is currently approved to extract coal from the Middle Liddell down to the Hebden coal seams beneath Mount Owen. Dewatering required for Integra to operate, however, is likely to impose a greater impact on Mount Owen operations than vice versa; with impacts from the Project likely to result in reduced dewatering requirements for Integra and thus be of beneficial impact to that mine. In this manner the Project is not expected to adversely impact Integra Underground Mine from an economic perspective.

4.3 Impacts to Groundwater Receptors

The groundwater impact assessment provides an evaluation of the magnitude of potential direct impacts resulting from the Project 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 Project. The potential receptors of groundwater impacts arising from the Project were identified amongst social and cultural, environmental, and economic users of groundwater resources and include:

- *Social and cultural:* no historical receptors identified; no groundwater-related Aboriginal sites are present within the potentially impacted area;
- *Environmental:* Alluvial aquifer systems associated with Glennies Creek, Bowmans Creek and their tributaries (Main Creek, Yorks Creek, Swamp Creek and Bettys Creek), including any BSAL and groundwater-dependent riparian and aquatic ecosystems; and
- *Economic:* Neighbouring mining operations. No other groundwater users are present within the potentially impacted area.

Table 4-1 presents the groundwater impact assessment for the Project, relating potential receptors (refer **Section 4.2**) to potential groundwater impacts (refer **Section 4.1)** and summarising the resultant risks.

Table 4-1 – Impacts to Groundwater Receptors

Potential Receptor	Direct Impact	Discussion
Alluvial aquifers associated with Glennies Creek, Bowmans Creek and their tributaries (including groundwater dependent ecosystems)	Groundwater Quantity	• Model simulations predict negligible changes in groundwater exchange with, and negligible drawdown in, the Glennies Creek and Bowmans Creek alluvial aquifers as a result of the Project. • Estimated groundwater losses to Main Creek alluvial aquifer as a result of the Project are predicted to peak between 2025 and 2030 at rates up to 15 ML/year. Mount Owen currently holds licence allocations under the Hunter Regulated River WSP (2003) totalling 1,000 unit shares of high security water, 192 unit shares of general security water and 9 unit shares of stock and domestic water, which are sufficient to accommodate the maximum predicted water take from the Glennies Creek alluvial aquifer as a result of the Project. • Predicted peak leakage rates from Bettys Creek alluvium as a result of the Project are less than 6 ML/year and can be considered as negligible. Mount Owen currently holds licences to extract up to 200 unit shares per year from Jerrys Water Source under the Hunter Unregulated and Alluvial WSP (2009). • Estimated drawdowns in the Main Creek and Bettys Creek alluvial aquifers as a result of the Project may exceed the 2 m minimal impact criteria for aquifer interference activities as specified in the AIP. If the model assumes the alluvium aquifers are full prior to 2022, Main Creek may see potential drawdown up to 6 m. The aquifers associated with these minor tributaries, however, show highly variable water levels, related directly to recent and local rainfall events and they are considered of limited significance due to low natural flow volumes, ephemeral conditions, and the limited extent, depth and condition of the alluvium. Thus, the long-term viability of any water-dependent asset in these areas would not be additionally affected by the temporal changes in water levels predicted by the modelling.
Alluvial aquifers associated with Glennies Creek, Bowmans Creek and their tributaries (including groundwater dependent ecosystems)	Groundwater Quality	• Limited data are available to characterise water quality in the alluvial aquifer systems at Mount Owen. However, considering the water quality data available for Bowmans Creek and its tributaries, and given the characteristics of Main Creek and Bettys Creek as ephemeral drainage features and the magnitude of predicted reductions in groundwater flows to these features, the potential impacts to groundwater quality in these alluvial aquifers are likely to be limited as a result of the Project. • Post-mining equilibrium simulations undertaken by Umwelt (2014a) predicts that the North Pit and RERR final voids will act as long-term groundwater sinks while the BNP final void will act as a groundwater sink until the water level in that pit exceeds 37 m AHD, above which point water movement will be back into the hard rock aquifers and would flow through to emerge as inflow at RERR. It should be noted that the water quality in the receiving aquifers is poor and there are no groundwater users between BNP and RERR Mining Area. • Salinity in the final void will remain below observed levels in the receiving aquifers for at least 200 years post-mining.
Alluvial aquifers associated with Glennies Creek, Bowmans Creek and their tributaries (including groundwater dependent ecosystems)	Surface Water – Groundwater Interaction	• Estimated reductions in groundwater flow to Main Creek represent less than 0.3% of estimated baseflow contributions to Glennies Creek. Estimated leakage rates from Bettys Creek account for less than 0.2% of estimated baseflow to Bowmans Creek. The modelling predicts negligible reductions in groundwater flow to the Glennies Creek and Bowmans Creek alluvial aquifers under the Project.

Potential Receptor	Direct Impact	Discussion
		• Main Creek and Bettys Creek are ephemeral surface water features that largely act as drainage courses for the local area. Bettys Creek has been subject to diversion works as part of approved activities at Mount Owen Complex. Both creeks are included in the Mount Owen Complex surface water monitoring program, however their ephemeral nature often results in samples being collected from stagnant pools (Umwelt, 2014b). • Given these model predictions and ephemeral conditions, the estimated reductions in groundwater flow to the alluvial aquifers of Main Creek and Bettys Creek are considered unlikely to have a significant impact on streamflow. As non-perennial streams, high value aquatic ecosystems and riparian vegetation are unlikely to be present. The predicted leakage and resulting drawdown within these features is therefore unlikely to have a significant impact on surface water-groundwater interactions along Main Creek and Bettys Creek.
	Aquifer Impact	• The Project does not include modifications or works that will physically intercept alluvial aquifer systems (Umwelt, 2014). The proposed North Pit mining limit has been designed to be greater than 200 m (approximately 450 m) from the high bank of Main Creek.
Neighbouring mining operations	Groundwater Quantity	• Predicted depressurisation within the regional hard rock aquifer reaches a maximum of approximately 165 m in the Bayswater seam at the end of mining (2030). • **Figure 3-26** shows that the predicted maximum depressurisation falls entirely within the Project boundary. The predicted depressurisation would affect neighbouring Integra Underground Mine, which has approval to undertake longwall mining in coal seams beneath the Mount Owen Complex, though Integra will also require depressurisation and dewatering to accommodate its own mining operations. As a result, depressurisation of the regional hard rock aquifer caused by the Project is not expected to adversely impact neighbouring mining operations.
	Groundwater Quality	• Monitoring data collected as part of current mining operations at Mount Owen Complex indicate minimal impacts to groundwater quality for the regional hard rock aquifer. Bores NPZ1 and NPZ8 (located in close proximity to neighbouring mining operations (refer **Figure 2-9**)) show some minor impacts, though additional monitoring bores located between these bores and neighbouring operations do not indicate changes to groundwater quality. Hence, current operations at Mount Owen do not appear to be causing impacts to groundwater quality that adversely affect neighbouring mining operations. Predicted changes to groundwater flows and depressurisations as a result of the Project are unlikely to cause impacts to groundwater quality that would affect neighbouring mining operations.
	Surface Water – Groundwater Interaction	• Model predictions indicate the Project would have negligible impact on streamflow in Glennies Creek and Bowmans Creek, and their ephemeral tributaries Main Creek and Bettys Creek. As a result, the potential impacts to neighbouring mining operations that may access these surface water features or their associated alluvial aquifers are expected to be negligible.
	Aquifer Impact	• The Project intercepts portions of the regional hard rock aquifer that contains the target coal seams. Given the extent of coal mining activities in the region that target the same coal seams, the depressurisation of the hard rock aquifer caused by the Project is not expected to adversely impact neighbouring mining operations.

4.4 Regulatory Framework Assessment

In addition to evaluating the potential risks to receptors from predicted groundwater impacts, the Project also requires assessment within the context of relevant legislation and policies. The *Water Management Act 2000* and AIP provide the legislation and requirements for obtaining licences for aquifer interference activities and assessing the potential impacts of mining projects on water sources (refer **Section 1.4**). **Table 4-2** presents the assessment of the Project within this regulatory framework. The 'minimal impact considerations' defined in the AIP and applied for this assessment comprise the criteria for highly productive alluvial water sources (for the Glennies Creek and Bowmans Creek alluvial aquifers) and the less productive fractured and porous rock water sources (for the regional hard rock aquifer). The alluvial aquifers associated with the tributaries Main Creek and Bettys Creek have been considered less productive alluvial water sources (under the AIP guidelines) for this assessment due to their ephemeral nature and limited extent.

Table 4-2 – Regulatory Framework Assessment Summary

Legislation / Policy	Requirement	Assessment
Water Management Act 2000	Water Licences	• The peak predicted water take from Main Creek is 15 ML/year. Mount Owen currently holds licence allocations under the Hunter Regulated River WSP (2003) totalling 1,000 unit shares of high security water, 192 unit shares of general security water and 9 unit shares of stock and domestic water. Mount Owen's allocations are therefore sufficient to accommodate the maximum predicted water take from the Glennies Creek alluvial aquifer, to which Main Creek and its alluvial aquifer is connected. • The peak predicted water take from Bettys Creek as a result of the Project is 6 ML/year. Mount Owen currently holds licences to extract up to 200 unit shares per year from Jerrys Water Source under the Hunter Unregulated and Alluvial WSP (2009), under which the alluvial aquifers of Bowmans Creek and its tributaries are regulated. • Estimates of groundwater extraction rates required to accommodate the Project are generally less than 500 ML/year, with a broad peak from 2022 through 2026 up to 750 ML/year.. • Mount Owen currently holds sufficient licences under Part 5 of the *Water Act 1912* to extract up to 1,160 ML/year groundwater from the regional hard rock aquifer, hence satisfy licensing criteria.
Aquifer Interference Policy	Level 2 impact considerations – highly productive groundwater sources – alluvial water sources	*Water Table* • No high priority GDEs or culturally significant sites have been identified within 40 m of any predicted water table variations. • Model simulations predict negligible drawdown within the Glennies Creek and Bowmans Creek alluvial aquifers. • Model simulations predict drawdown within the Main Creek and Bettys Creek alluvial systems of greater than 2 m. This exceeds the minimal impact criteria specified in the AIP. Further assessment in accordance with the Policy indicates that the impacts would not adversely impact or prevent the long-term viability of any water-dependent asset. • The areal extent of predicted drawdown is localised to small reaches of Main Creek and Bettys Creek. No registered bores are located within the extent of predicted drawdown for either creek. Only monitoring bore NPZ3, which is part of the Mount Owen Complex groundwater monitoring network, is located within the extent of predicted drawdown. No groundwater users or water supply works are identified within the predicted extent of drawdown. *Water Pressure*

Legislation / Policy	Requirement	Assessment
		• Post-mining simulations indicate groundwater levels within the Main Creek and Bettys Creek alluvial aquifers recover to levels equal to or above observed levels at the introduction of the WSPs. For Main Creek, the Hunter Regulated River WSP commenced in July 2004, and for Bettys Creek the Hunter Unregulated and Alluvial WSP commenced in August 2009. *Water Quality* • Model simulations provide no indication that the Project will alter the hydrogeologic regime in a manner that would adversely affect groundwater quality within the Main Creek and Bettys Creek alluvial aquifers.
	Level 2 impact considerations – less productive groundwater sources – porous and fractured rock water sources	*Water Table* • No high priority GDEs or culturally significant sites have been identified within 40 m of any predicted water table variations. *Water Pressure* • No water supply works have been identified within the depressurisation zone predicted in model simulations. *Water Quality* • Monitoring data collected as part of current mining operations at Mount Owen Complex indicate minimal impacts to groundwater quality of the regional hard rock aquifer. • EC data for the regional hard rock aquifer at Mount Owen Complex typically ranges between 5,000 and 15,000 µS/cm. Post-mining simulations predict that void waters will remain fresher than local groundwaters for at least 200 years following the end of mining. Critically, the BNP void will not generate water of lower quality than local groundwaters while the North Pit and RERR voids will remain sinks to groundwater and hence not pose a threat to aquifer water quality.

The AIP specifies that it is the responsibility of the proponent to ensure that necessary licences are held with sufficient share components and water allocations to account for all water taken from groundwater or surface water sources as a result of an aquifer interference activity. Information required under the AIP to determine the type and number of water licences required is summarised in **Table 4-3** together with reference to where this information is provided in this report.

Table 4-3 – Water Licence Information Requirements Specified in the AIP

AIP Requirement	Response
• Described the water source(s) the activity will take water from?	The Project will take water primarily from the hard rock aquifer associated with the Wittingham Coal Measures through dewatering to ensure safe resource recovery from the target coal seams and interburden. In addition, numerical modelling predicts the Project will draw limited quantities of water from alluvial aquifers associated with tributaries of Bowmans Creek and Glennies Creek. Groundwater in the alluvial aquifers associated with Bowmans Creek and its tributaries is accounted for in the Jerrys Water Source under the Hunter Unregulated and Alluvial WSP (2009), and groundwater associated with Glennies Creek and its tributaries is accounted for under the Hunter Regulated River WSP (2003).

AIP Requirement	Response
• Predicted the total amount of water that will be taken from each connected groundwater or surface water source on an annual basis as a result of the activity?	Predicted water take from each water source, as determined through numerical modelling, are provided in **Section 3.5**. Peak median of 15 ML/year from Main Creek (Glennies Creek Groundwater Source) and 6 ML/year from Bettys Creek (Jerrys Water Source) are predicted. Negligible take (<1 ML/year) is predicted from either the Glennies Creek or Bowmans Creek alluvium aquifers. Estimates of groundwater extraction rates required to accommodate the Project are generally less than 500 ML/year, with a broad peak from 2022 through 2026 up to 750 ML/year.
• Predicted total amount of water that will be taken from each connected groundwater or surface water source after the closure of the activity?	Post-mining simulations predict that the North Pit and RERR final voids will act as groundwater sinks while the BNP final void will act as a groundwater sink until the water level in that pit exceeds 37 m AHD, above which point water movement will be back into the hard rock aquifers and thence flow naturally into the RERR void. Long-term, steady-state fluxes into North Pit and RERR voids are predicted to be 55 and 110 ML/year, respectively, with BNP locally providing 40 ML/year of high quality water to the hard rock aquifer.
• Made these predictions in accordance with Section 3.2.3 of the AIP? (refer to Table 3, below)	Predictions have been made using a regional scale numerical groundwater model that was developed, constructed, calibrated and analysed in accordance with the *Australian Groundwater Modelling Guidelines* (Barnett et al., 2012), as prescribed in Section 3.2.3 of the AIP.
• Described how and in what proportions this take will be assigned to the affected aquifers and connected surface water sources?	The numerical groundwater model allows the proportion of water take from affected aquifers to be distinguished. Detailed description of the proportions of water take from the affected aquifers is provided in **Section 3.5**.
• Described how any licence exemptions might apply?	Mount Owen has sufficient licensing allocations to account for the predicted water take from the affected aquifers, comprising the alluvial and hard rock water sources. No exemptions apply.
• Described the characteristics of the water requirements?	Water requirements are described in Umwelt (2014).
• Determined if there are sufficient water entitlements and water allocations that are able to be obtained for the activity?	Mount Owen has sufficient existing licensing allocations to account for the predicted water take from the affected aquifers, comprising the alluvial and hard rock water sources (refer **Table 4-2**).
• Considered the rules of the relevant water sharing plan and if it can meet these rules?	The rules and requirements of the relevant WSPs are outlined in **Section 1.4**. Through licence allocations and management procedures (including monitoring and on-going assessment) the Project has demonstrated that it meets these rules.
• Determined how it will obtain the required water?	No additional water will be required.

AIP Requirement	Response
• Considered the effect that activation of existing entitlement may have on future available water determinations?	The proposed mining period extends to 2030. Beyond this, the aquifer systems are predicted to recover with no adverse impacts on future available water determinations.
• Considered actions required both during and post-closure to minimize the risk of inflows to a mine void as a result of flooding?	Management and action requirements to minimise inflows to mine voids as a result of flooding are provided in the Surface Water Assessment (Umwelt, 2014a).
• Developed a strategy to account for any water taken beyond the life of the operation of the project?	No additional water to that already licensed is predicted to be taken beyond the life of the operation. Details of predicted groundwater conditions post-mining are provided in **Section 4.1.1**.
• Will uncertainty in the predicted inflows have a significant impact on the environment or other authorised water users?	Uncertainties associated with the predicted inflows are provided in the predictive model results shown in **Figure 3-29** through **Figure 3-33**. These uncertainties are not predicted to have a significant impact on the environment or other authorised water users.

In addition to the water licensing information provided in **Table 4-3**, the AIP specifies that a project proponent will need to provide additional information to allow assessment of the activity against the minimal impact criteria and additional considerations. These information requirements are summarised in **Table 4-4**.

Table 4-4 –Information Requirements for Minimal Impact Considerations

AIP Requirement	Proponent Response
• Establishment of baseline groundwater conditions?	Baseline groundwater conditions are reported in **Section 2.6.4** for groundwater levels and flow patterns and in **Section 4.1.2** for groundwater quality. Details of the current groundwater monitoring network and program are provided in **Section 2.6.4**.
• A strategy for complying with any water access rules?	Water meters are being progressively installed at all pumping locations to provide accurate information for annual water balance modelling reported through the Annual Reviews.
• Potential water level, quality or pressure drawdown impacts on nearby basic landholder rights water users?	The estimated extent of impacts resulting from the Project is largely limited to the Project area and there are no registered groundwater users or basic landholder rights within this extent (refer **Section 2.6.2**).
• Potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources?	The estimated areal extent of impacts resulting from the Project is largely limited to the Project area. There are no registered groundwater users or basic landholder rights within this extent (refer **Section 2.6.2**).
• Potential water level, quality	There are no identified GDEs within the Project area or area potentially

AIP Requirement	Proponent Response
or pressure drawdown impacts on groundwater dependent ecosystems?	impacted by the Project (Umwelt, 2014b).
• Potential for increased saline or contaminated water inflows to aquifers and highly connected river systems?	Post-mining equilibrium simulations undertaken by Umwelt (2014) predict the North Pit and RERR final voids will act as groundwater sinks. The Bayswater North void will ultimately act as a source, but will not discharge to the alluvial aquifers and adversely impact groundwater quality. Rather, it will discharge to the hard rock aquifer and thence to the RERR void. The water balance assessment (Umwelt, 2014a) predicts salinity in the North Pit final void will increase continuously over time, resulting in the potential for long term impacts to groundwater quality in the hard rock aquifer due to discharge of increasingly saline water to the surrounding aquifer. However salinity modelling indicates that adverse impacts, which would occur when salinity levels in the final void are greater than the salinity of groundwater in the surrounding hard rock aquifer, are unlikely to occur for at least 200 years after end of mining. Salinity levels in the hard rock aquifer are currently brackish at best and do not provide a viable water resource.
• Potential to cause or enhance hydraulic connection between aquifers?	Enhanced connection between aquifers has been modelled as part of this assessment. Consideration has been made of activities extending over underground mining operations that may result in changed (enhanced) hydraulic connection. No adverse impacts are predicted to occur.
• Potential for river bank instability, or high wall instability or failure to occur?	The mining limit has been designed to be greater than 200 m (approximately 450 m) from the high bank of Main Creek and will not pose an instability risk.
• Details of the method for disposing of extracted activities (for coal seam gas activities)?	Not applicable.

Under Section 3.2.3 of the AIP, if minimal impact criteria are exceeded for any component of the groundwater source, then a number of requirements must be met by the proponent. Numerical groundwater modelling suggests that the Project will exceed Level 1 requirements of the minimal impact criteria and therefore triggers these additional requirements. These requirements are addressed in **Table 4-5**.

Table 4-5 – Additional Requirements for Aquifer Interference Activities

AIP Requirement	Proponent Response
For the Gateway process, is the estimate based on a simple modelling platform, using suitable baseline data, that is, fit-for-purpose?	Not applicable.
For State Significant Development or mining or coal seam gas production, is the estimate based on a complex modelling platform that is: • Calibrated against suitable baseline data, and in the	The predictive scenarios have been modelled using a complex numerical groundwater model based on the MODFLOW-SURFACT modelling platform. Full details of the modelling framework, calibration and results are provided in **Section** 3 of this report. All modelling has been undertaken in accordance with the *Australian Groundwater Modelling Guidelines* (Barnett et al., 2012). The numerical model has undergone an independent peer review specific to

AIP Requirement	Proponent Response
case of a reliable water source, over at least two years? • Consistent with the Australian Modelling Guidelines? • Independently reviewed, robust and reliable, and deemed fit-for-purpose?	this Project. This peer review found the groundwater model to be *fit for purpose* and concluded that this Groundwater Impact Assessment addresses the requirements of the DGRs and NOW. Specifically, the reviewer concluded the model has: • acceptable global calibration performance statistics; • reliable anticipated mine inflows; and • reasonable quantitative estimates of water takes for licensing purposes. A copy of the peer review report has been provided to DP&E under separate cover.
In all other processes, estimate based on a desk-top analysis that is: • Developed using the available baseline data that have been collected at an appropriate frequency and scale; and • Fit-for-purpose?	Not applicable.

5. Monitoring and Management

5.1 Groundwater Monitoring

Mount Owen currently undertakes a groundwater monitoring program for the Mount Owen Complex with results reported in Annual Reviews. The current groundwater monitoring network is shown in **Figure 2-9** and includes a series of nested piezometers (the NPZ-series bores) that target the shallow bedrock overburden and underlying deeper bedrock or coal seams within the regional hard rock aquifer (refer **Section 2.6.4**). These bores are monitored quarterly for groundwater levels, pH and EC, and every six months samples are collected and analysed for a suite of inorganic parameters. In addition to these bores, additional monitoring locations were installed between 2012 and 2014 targeting the shallow alluvial aquifers associated with Yorks Creek, Swamp Creek, Bowmans Creek, Main Creek, Bettys Creek and Glennies Creek, as well as deeper VWPs targeting the regional hard rock aquifer. The VWPs provide continuous water pressure data for coal seams and interburden within the hard rock aquifer.

The current monitoring network has been designed to provide an improved understanding of the dynamics of the alluvial and hard rock aquifers in the region and provide additional data for future model calibration.

Plate 4 – Installing vibrating wire piezometers south of North Pit

5.2 Adaptive Management

Model simulations predict negligible changes in groundwater flows to the alluvial aquifers associated with Glennies Creek and Bowmans Creek as a result of the Project, and minimal reductions in flows to the Main Creek and Bettys Creek alluvium. Glennies Creek and Bowmans Creek, and restricted extents of Main Creek and Bettys Creek near the confluence of these tributaries, are classified BSAL under the regional mapping identified in the Upper Hunter SRLUP (2012). While no BSAL is mapped within the proposed disturbance area (Umwelt, 2014b), Glennies Creek, in particular, was identified in the DGRs and by other government agencies as a potential receptor to impacts from the Project. Based on these classifications, an adaptive management approach is proposed for the monitoring and (if necessary) mitigation of any potential unacceptable impacts (that is, in excess of the minimal harm criteria of the AIP) to these alluvial aquifer systems. 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
Review, update and implement the existing groundwater monitoring plan for the Mount Owen Complex to include the additional monitoring locations installed from 2012 to 2014.	• The Groundwater Monitoring Plan includes bores and standpipes in all potentially impacted formations at a spatial distribution that allows timely and effective mitigation of any observed impacts.
Continued refinement and re-validation of the groundwater model with additional monitoring data.	• As with any model representations of real systems, additional site data will allow continued refinement of the numerical model and provide additional confidence in the results. The groundwater model was initially constructed using a precautionary approach, with results considered to represent conservative estimations of potential impacts. Additional data collected from monitoring programs and mine activities (such as pumping data for North Pit) has been used to progressively improve confidence in the results. Assessment against predicted model results with on-going monitoring will provide a mechanism to assess whether revision and refinement of the numerical model is required.
If and where necessary, adjustment of mining and/or dewatering plans to mitigate unacceptable actual or predicted impacts on the alluvial system	• Drawdowns of the Main Creek and Bettys Creek alluvial aquifers are not predicted to exceed 2 m. Additional monitoring data collected to validate the modelling will allow evaluation of the modelling scenarios within a timeframe that allows mitigation measures to be implemented prior to any impacts, should such data and modelling indicate greater impact than currently predicted.

5.3 Groundwater Extraction

Current operations at Mount Owen Complex require dewatering of areas surrounding open cut pits and the management of pit inflows to accommodate mining activities. Mount Owen implements an integrated Water Management Plan and Groundwater Monitoring Program designed to monitor and mitigate the impact of mining operations on the surrounding environment. Water management includes 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

Groundwater modelling undertaken for this assessment has provided estimates of dewatering rates and pit inflows for the Project (refer **Section 3.5.2**). The current Water Management Plan will be reviewed and updated to ensure the management system can accommodate these estimated volumes. The update will 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 and expansion of open cut pits. Significant amendments to the water management strategy and site water balance (Umwelt, 2014a) are not expected to be required.

5.3.2 Water Licences

Mount Owen currently holds sufficient licence allocations under the Hunter Regulated River WSP (2003) to accommodate the maximum predicted water take from the Glennies Creek alluvial aquifer to which Main Creek and its alluvial aquifer is connected. Mount Owen also holds sufficient licences to extract water from the Jerrys Water Source under the Hunter Unregulated and Alluvial WSP (2009), within which the alluvial aquifers of Bowmans Creek and its tributaries are regulated, to accommodate the predicted water take.

Estimates of groundwater extraction rates required to accommodate the Project are generally less than 500 ML/year, with a broad peak from 2022 through 2026 up to 750 ML/year. Predicted inflows for other years during the Project are generally below 500 ML/year, as shown in **Figure 3-33**.

Mount Owen currently holds sufficient licences under Part 5 of the *Water Act 1912* to extract 1,160 ML/year groundwater from the regional hard rock aquifer. These licence allocations are sufficient to meet the predicted water take from the hard rock aquifer source under the Project.

5.4 Review and Reporting

The existing Water Management and Groundwater Monitoring Plans for the Mount Owen Complex 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 will be reported in Mount Owen's Annual Review. Should any review or monitoring data indicate significant variation 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 and Groundwater Response Plan.

After commencement of the Project, the groundwater model should periodically be reviewed and updated and refined as required to evaluate model predictions with respect to site monitoring data. If groundwater levels or pit inflow rates exceed predicted values, model re-calibration and predictive scenarios should be undertaken to reduce model uncertainty and provide confirmatory predictions.

6. Conclusions

6.1 Groundwater Impact Assessment

This Groundwater Impact Assessment addresses the DGRs in relation to the potential impacts of the Project 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.

Tributaries to the Hunter River, Glennies Creek and Bowmans Creek, are classified as BSAL under the Upper Hunter SRLUP (NSW, 2012). As such the water resources that support these systems are required to be assessed under the AIP. Under the NSW *Water Management Act 2000* any water take from these alluvial systems is required to be licensed and all extractions accounted for.

Results from numerical model simulations allow the evaluation of the magnitude of potential direct impacts resulting from the Project and the likelihood that these impacts will adversely affect potential receptors. The results of the predictive model simulations provide the following conclusions:

Impacts to alluvial aquifers

- Model simulations predict negligible changes in groundwater flow to the Glennies Creek and Bowmans Creek alluvial aquifers.
- Predicted reductions in groundwater flows to the alluvial aquifers associated with Main Creek and Bettys Creek are minimal. Peak predicted water take from the Main Creek alluvium is less than 15 ML/year. Predicted peak water take from the Bettys Creek alluvium is less than 6 ML/year. Mount Owen currently holds sufficient water licence allocations under the applicable WSP for each water source to accommodate these maximum predicted water takes.

Impacts to hard rock aquifer

- Groundwater quality in the hard rock aquifers is poor and there are no groundwater users of this resource. Predicted changes to water quality are minimal and present no potential impacts.
- Estimates of groundwater extraction rates required to accommodate the Project are generally less than 500 ML/year, with a broad peak from 2022 through 2026 up to 750 ML/year. Predicted inflows for other years under the Project are below 500 ML/year. Mount Owen currently holds sufficient licences under Part 5 of the *Water Act 1912* to extract up to 1,160 ML/year from the regional hard rock aquifer and hence satisfies licensing criteria.
- Post-mining, equilibrium simulations predict that the North Pit and RERR final voids will act as long-term groundwater sinks while the BNP final void will act as a groundwater sink until the water level in that pit exceeds 37 m AHD, above which point water movement will be back into the hard rock aquifers and would flow through to emerge as inflow at the RERR void. It should be noted that the water quality in the receiving aquifers is poor and there are no groundwater users between BNP and RERR Mining Area.
- Salinity in the final voids will remain below observed levels in the receiving aquifers for at least 200 years post-mining.

6.2 Management Approach

Based upon the impact assessment and predictive model results, an adaptive management approach is proposed to monitor and, where necessary, mitigate potential impacts to alluvial aquifer systems, affected by the Project, that exceed minimal harm criteria under the AIP. The following adaptive management measures are provided to monitor and manage these potential impacts:

- Review, update and implement the existing groundwater monitoring plan for the Mount Owen Complex to include the additional monitoring locations installed from 2012 to 2014 and other monitoring locations that may be required during the Project;
- Continued refinement and re-validation of the groundwater model with additional monitoring data;
- If and where necessary, adjustment of mining and/or dewatering plans to mitigate unacceptable actual or predicted impacts on alluvial systems.

7. References

AECOM, 2012. Liddell Coal Annual Environmental Management Report, July 2010 – December 2011. *Prepared for* Liddell Coal Operations Pty Ltd.

ANZECC, 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Prepared by the Australian and New Zealand Environment and Conservation Council (ANZECC) and the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), October 2000.

Aquaterra, 2009a. Ashton South East Open Cut Project: Hydrogeological Impact Assessment. Prepared by Aquaterra for Ashton Coal Operations Pty Ltd, July 2009.

Aquaterra, 2009b. Bowmans Creek Diversion: Groundwater Impact Assessment Report. Prepared by Aquaterra for Ashton Coal Operations Pty Ltd, October 2009.

Ashton, 2012. Ashton Coal Water Management Plan MP 3.4.1.8, Version E. Ashton Coal Operations Pty Ltd. Available via internet on 10 April 2013: http://www.ashtoncoal.com.au/Reports--Publications/Environmental/Environmental-Management-Plans/Site-Water-Management-Plan.aspx.

Beckett, J., 1988. The Hunter Coalfield. Notes to accompany the 1:100,000 Hunter Coalfield Geological Map. Dept. of Mineral resources Publication GS1988/051 / CGB 1988/008. 94pp.

Beckett, J., 1987. Bowmans Creek Alluvium – The extent and lithology of the alluvium and an assessment of the impact of mining on the flow of the creek. Letter report dated October 1987.

Brereton, D. and Moran, C., 2008. Cumulative impacts: what are they and how can they be better understood and managed? In: Sustainable Development Conference Workbook, Darwin, Australia, 2008.

DIPNR, 2004. *A guide to the Water Sharing Plan for the Hunter Regulated River Water Source*. NSW Department of Infrastructure, Planning and Natural Resources, September 2004.

DWE, 2009a. *Water sharing in the Hunter Regulated River – Progress report 2004 to 2008*. NSW Department of Water and Energy, 2009.

DWE, 2009b. *Water Sharing Plan – Hunter Unregulated and Alluvial Water Sources: Guide*. NSW Department of Water and Energy, August 2009.

ERM, 2008. Groundwater Assessment, Hunter Valley Operations South Coal Project. Prepared by Environmental Resources Management Australia Ltd for Coal & Allied Operations Pty Ltd.

Geoterra, 2009. Integra Underground Mining Project Area – Groundwater Assessment. Prepared by Geoterra Pty Ltd for Integra Coal Operations Pty Ltd.

GSS, 2011. Liddell Coal Operations, Proposed Modification to DA 305-11-01 – Preliminary Environmental Assessment. Prepared by GSS Environmental for Liddell Coal Operations Pty Ltd, September 2011.

Howe, P., Moran, C., and Vink, S., 2010. Framework for assessing cumulative potential impacts of mining operations on groundwater systems. In: Proceedings of the 2nd International Congress on Water Management in the Mining Industry, GECAMIN, Santiago, Chile, 2010.

JacobsSKM, 2014. Liddell Coal Operations Modification 5 to Development Consent DA 305-11-01: Groundwater Impact Assessment. Update for Water Trigger Assessment for Liddell Coal Operations Pty Ltd, January 2014.

Mackie, C.D., 2009. Hydrogeological characterisation of coal measures and overview of impacts of coal mining on groundwater systems in the Upper Hunter Valley of NSW. PhD Thesis, University of Technology, Sydney, Sydney, Australia, 2009.

MER, 2001. Liddell Coal – Continued Mining Environmental Impact Statement, Surface & Groundwater Management Studies. Prepared by Mackie Environmental Research on behalf of Liddell Coal, September 2001.

MER, 2003. Mt Owen Operations EIS Hydrogeological Studies. Prepared by Mackie Environmental Research on behalf of Hunter Valley Coal Corporation, September 2003.

MER, 2011b. Ravensworth Underground Mine – Assessment of Groundwater Impacts Associated with Modifications to Mining in the Liddell Seam, Draft Report. Prepared by Mackie Environmental Research for Ravensworth Underground Mine, September 2011.

MOC, 2013. Mt Owen Complex Annual Environmental Management Report, 1 January 2012 – 31 December 2012. Prepared by Xstrata Mt Owen Pty Ltd.

Murphy, R., Neal, B., Morden, R., Nathan, R. and Evans, R. (2008). BaseJumper: A Tool for Analysing Time Trends in Baseflow. Water Down Under 2008 (incorporating 31st Engineers Australia Hydrology and Water Resources Symposium), pp 2741-2746.

NSW, 2012. Upper Hunter Strategic Regional Land Use Plan. NSW Department of Planning and Infrastructure, September 2012. ISBN 978-0-7313-3577-0:

NSW, 2012. NSW Aquifer Interference Policy: NSW Policy for the licensing and assessment of aquifer interference activities. Department of Planning and Infrastructure, September 2012. ISBN 978 1 74256 338 1

NWC, 2012. Australian Groundwater Modelling Guidelines. National Water Commission, 2012.

RW Corkery, 2011. Annual Environmental Management Report for the Integra North Open Cut, April 2010 – March 2011. Prepared by R.W. Corkery & Co. Pty Ltd for Integra Coal Operations Pty Ltd, June 2011.

SKM, 2012. Mt Owen Complex Groundwater Investigation Program. Prepared by SKM for Xstrata Mt Owen Pty Ltd, December 2012.

SKM, 2013. Liddell Coal Operations Modification 5 to Development Consent DA 305-11-01: Groundwater Impact Assessment. Prepared by SKM for Liddell Coal Operations Pty Ltd, April 2013.

Umwelt, 2001. Liddell Colliery Continued Operations, Environmental Impact Statement. Prepared by Umwelt (Australia) Pty Ltd for Liddell Coal Operations Pty Ltd, October 2001.

Umwelt, 2006. Environmental Assessment for Liddell Colliery Modifications to Development Consent, January 2006. Prepared by Umwelt (Australia) Pty Ltd for Liddell Coal Operations Pty Ltd.

Umwelt, 2010. Ravensworth Operations Project Environmental Assessment, February 2010. Prepared by Umwelt (Australia) Pty Ltd for Ravensworth Operations Pty Ltd.

Umwelt, 2013. Preliminary Environmental Assessment – Mount Owen Continued Operations Project. Prepared by Umwelt (Australia) Pty Ltd for Xstrata Mount Owen Pty Ltd.

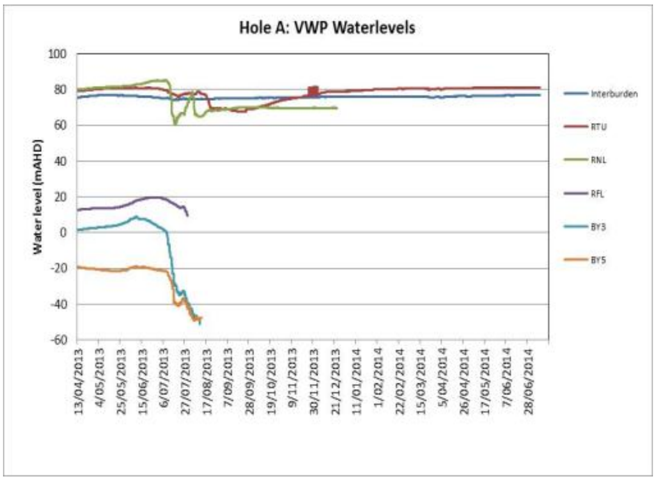
Umwelt, 2014a. Mount Owen Continued Operations – Water Balance Assessment. Prepared by Umwelt (Australia) Pty Ltd for Xstrata Mount Owen Pty Ltd.

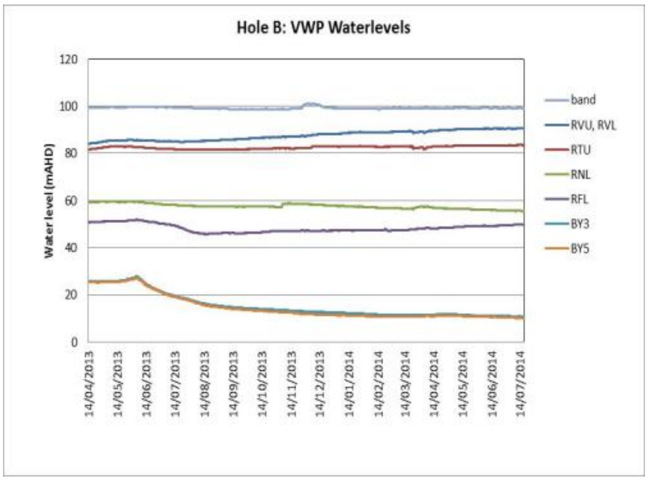
Umwelt, 2014b. Mount Owen Continued Operations Ecological Assessment. Prepared by Umwelt (Australia) Pty Ltd for Xstrata Mount Owen Pty Ltd.

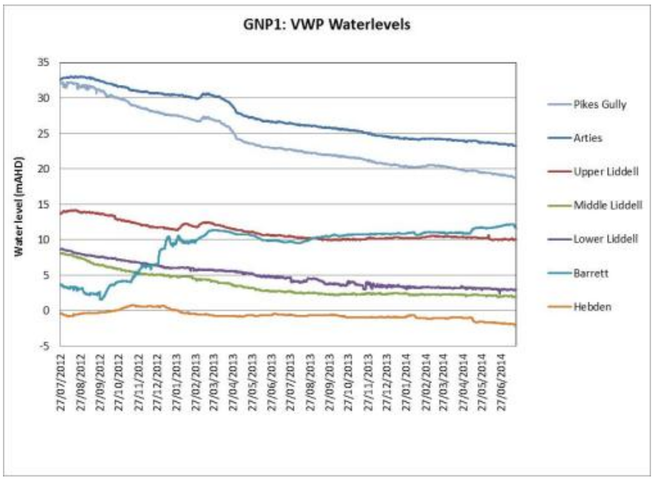
Umwelt, 2014c. Mount Owen Continued Operations Project, Agricultural Impact Statement. Prepared by Umwelt (Australia) Pty Ltd for Xstrata Mount Owen Pty Ltd.

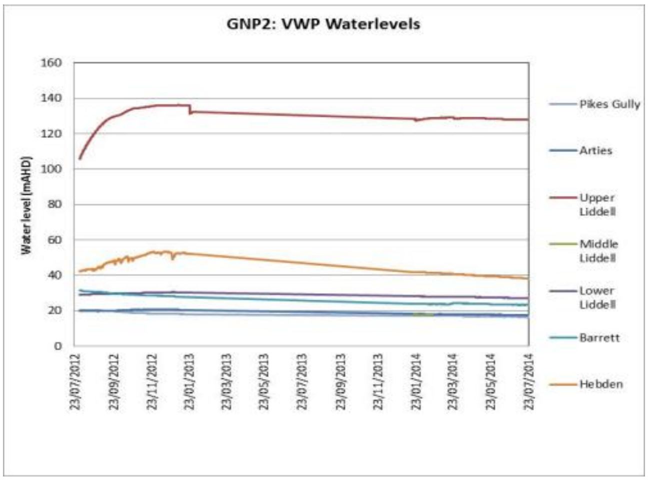
Vale, 2011. Water Management Plan for Integra Mine Complex. Prepared by Vale for Integra Coal Operations Pty Ltd, September 2011.

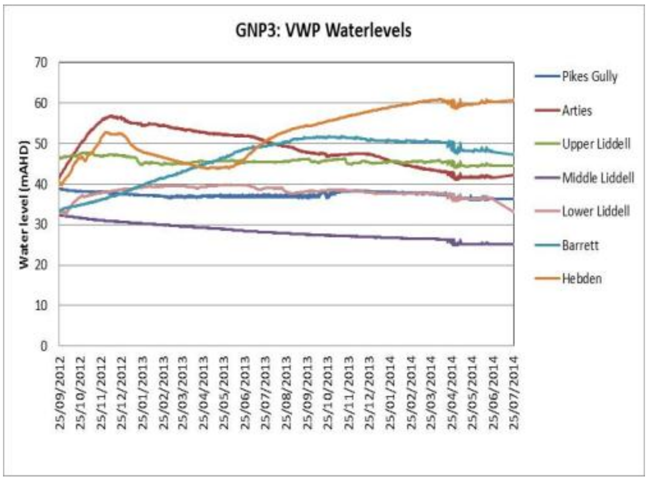
Appendix A. Groundwater Pressure Data for VWPs

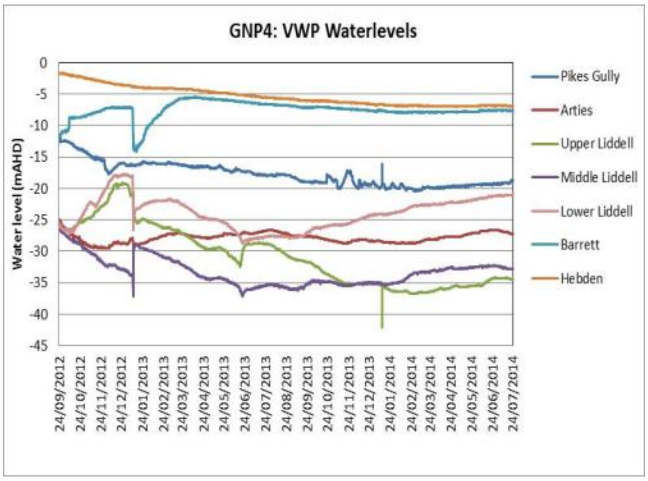


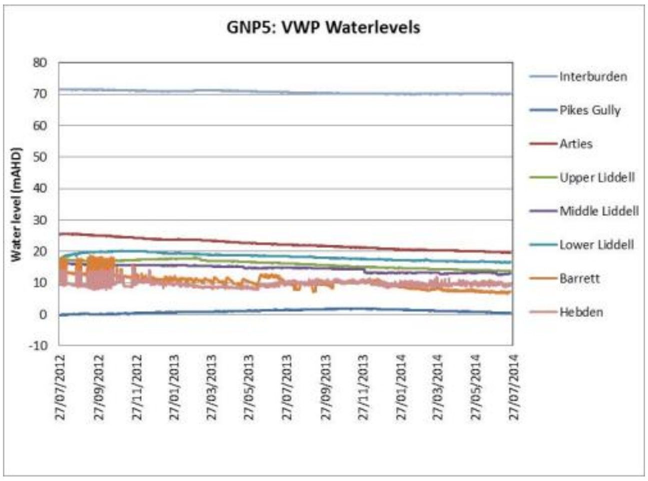








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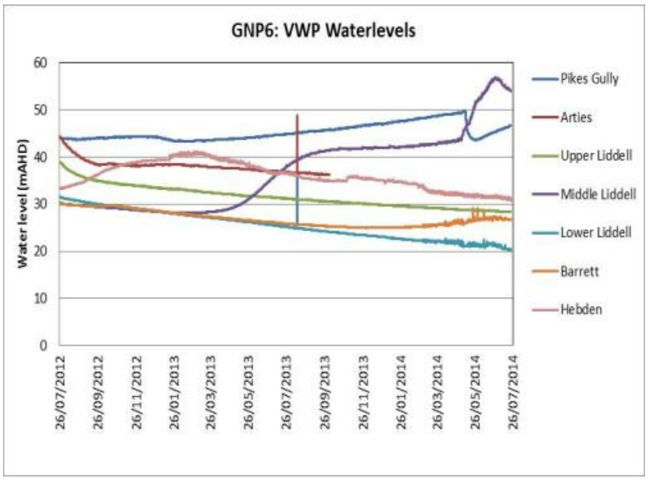
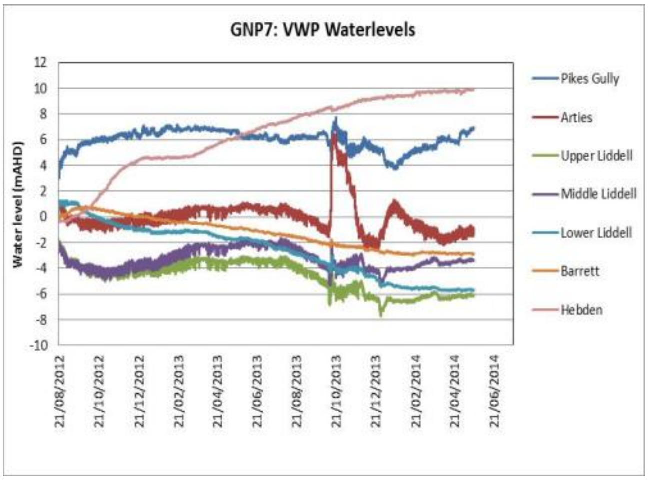
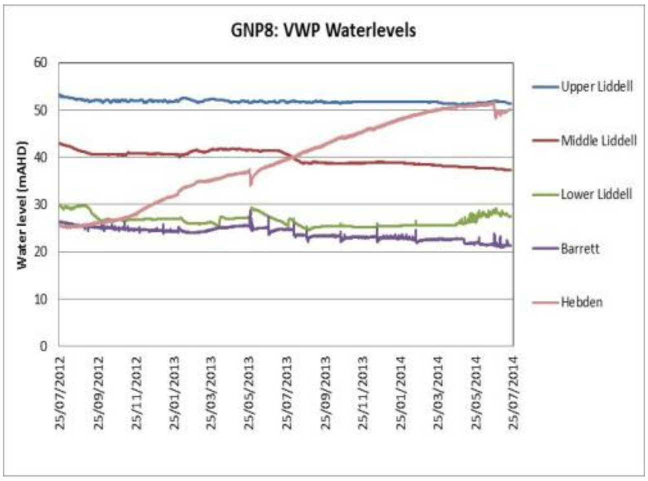
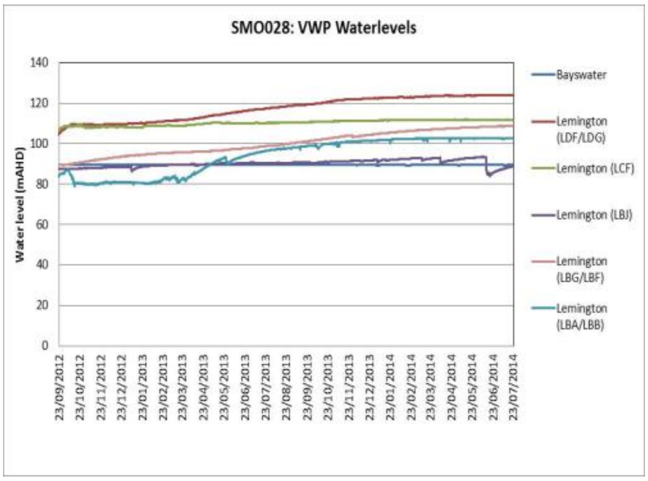
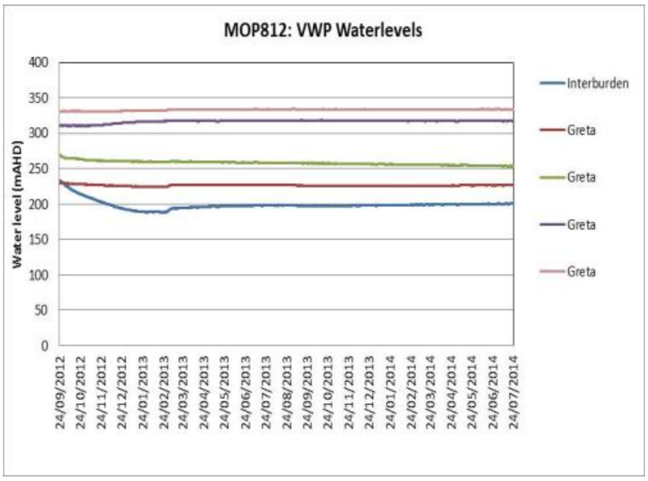
Water level (mAHD)
Interburden
Pikes Gully
Arties
Upper Liddell
Middle Liddell
Lower Liddell
Barrett
Hebden


GNP6: VWP Waterlevels
Water level (mAHD)
Pikes Gully
Arties
Upper Liddell
Middle Liddell
Lower Liddell
Barrett
Hebden


GNP7: VWP Waterlevels
Water level (mAHD)
Pikes Gully
Arties
Upper Liddell
Middle Liddell
Lower Liddell
Barrett
Hebden


GNP8: VWP Waterlevels
Water level (mAHD)
Upper Liddell
Middle Liddell
Lower Liddell
Barrett
Hebden


SMO028: VWP Waterlevels
Water level (mAHD)
Bayswater
Lemington (LDF/LDG)
Lemington (LCF)
Lemington (LBJ)
Lemington (LBG/LBF)
Lemington (LBA/LBB)


MOP812: VWP Waterlevels
Water level (mAHD)
Interburden
Greta
Greta
Greta
Greta

Appendix B. Hunter Valley Regional Groundwater Model – Ancillary Information

B.1 Data Sources

Table B-1 presents a summary of the data sources used in this report.

Table B-1 – 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
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

B.2 Mining operations and sequencing

As described in **Section 3.5**, 38 mining operations (open pit, underground and de-watering activities) were incorporated into the regional model such that each layer affected by each operation is impacted at the time defined by operation plans or information from annual operation reports, environmental impact statements or released reports. **Figure B-1** presents a summary of the mining operations included in the numerical model and the layers affected by each operation, and **Figure B-2** shows temporal sequencing of the 39 mining operations incorporated into the model.

Maps of the model drain cells are illustrated for each layer in **Figure B-3** to **Figure B-21**.

Figure B-1 – Mining operations* included in the numerical model and the layers that are affected by each operation.

Layer		Tributaries	Howick	Cumnock_OC	Rav_North	HV_Complex	Rav_Narama	Ashton_Barrett	Cumnock_Barrett	Cumnock_Liddell	RUM_Liddell	Cumnock_Lower_Pikes_Gully	RUM_Lower_Pikes_Gully	Ashton_LPG	Ashton_Liddell	Liddell_South_Pit	Liddell_Entrance_pit	Liddell_a	Liddell_b	Liddell_c	Liddell_d	Liddell_e	Hazeldine_Dewatering_Coal_Barrier	West_Pit	RW_Pit	TP1	TP2	Eastern_Rail_Pit	South_Bayswater_Pit	BNP	Hazeldine_Dewatering_bore	8_South_Dewatering_Bore	Mt_Owen_Dewatering_bore	M49_Dewatering_Bore	Middle_Liddell_Dewatering_Bore	North_Pit	Integra_Hebden	Integra_Liddell	Integra_Barrett	Glendell
L1	Alluvium	■		■												■	■	■	■	■	■	■																		
L2	Regolith		■	■	■	■	■									■	■	■	■	■	■	■		■	■	■	■	■	■	■						■				■
L3	Overburden		■	■	■		■									■	■	■	■	■	■	■		■	■	■	■	■	■	■						■				■
L4	Bayswater Seam		■	■	■		■									■	■	■	■	■	■	■		■			■		■	■						■				■
L5	Interburden		■	■	■											■	■	■	■	■	■	■		■			■			■						■				■
L6	Interburden w\UPG Final Void		■	■	■											■	■	■	■	■	■	■														■				■
L7	Upper Pikes Gully Seam		■	■	■											■	■	■	■	■	■	■														■				■
L8	Interburden		■	■	■											■	■	■	■	■	■	■														■				■
L9	Mid and Lower Pikes Gully Seam		■	■	■							■	■	■		■	■	■	■	■	■	■														■				■
L10	Interburden		■		■											■	■	■	■		■	■														■				■
L11	Arties Seam		■		■											■	■	■	■		■	■														■				■
L12	Interburden		■		■											■	■	■	■		■	■														■				■
L13	Liddell AB Seam Section		■		■					■	■				■	■	■	■	■		■	■	■								■	■		■		■				■
L14	Liddell C Seam Section		■		■											■	■	■	■		■	■	■								■	■	■	■	■	■		■		■
L15	Liddell D Seam Section		■		■											■	■	■	■		■	■	■								■	■				■				■
L16	Interburden		■		■											■	■	■	■		■	■														■				■
L17	Barrett Seam				■			■	■							■	■	■	■		■	■														■			■	■
L18	Interburden															■	■				■	■														■				
L19	Hebden Seam															■	■				■	■														■	■			
L20	Saltwater Creek Formation																																							

* Mining operations include: open pit development (including back-filling and rehabilitation); underground mining and dewatering activities. In addition, surface water channels (tributaries) are included as receptors of mining operations.

Figure B-2 – Temporal sequencing* of the 38 mining operations, as incorporated into the numerical model.

				Steady State	Transient	1980	1985	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Reach	**Mine**	**Drains**	**Type**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
0		Tributaries	Tributary	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
18	Ashton UG	Ashton_LPG	Underground											■	■	■	■	■	■	■	■	■	■	■	■														
19	Ashton UG	Ashton_Liddell	Underground																		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
11	Ashton UG	Ashton_Barrett	Underground																									■	■	■	■	■	■	■	■	■	■	■	
16	Cumnock UG	Cumnock_Lower_Pikes_Gully	Underground						■	■	■	■	■	■																									
13	Cumnock UG	Cumnock_Liddell	Underground			■	■	■	■																														
12	Cumnock UG	Cumnock_Barrett	Underground								■	■																											
520	Glendell	Glendell	Open Cut															■	■	■	■	■	■	■	■	■	■	■	■										
208	Glendell	South_Bayswater_Pit	Open Cut														■																						
5	Hunter Valley Ops	Howick	Open Cut					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■												
8	Hunter Valley Ops	HV_Complex	Open Cut			■	■	■	■	■	■	■	■	■	■	■																							
512	Integra	Integra_Liddell	Underground							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■															
513	Integra	Integra_Barrett	Underground																																		■	■	■
511	Integra	Integra_Hebden	Underground																						■	■	■	■	■	■	■	■	■	■	■	■			
103	Liddell	Liddell_Entrance_pit	Open Cut					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■									
101	Liddell	Liddell_South_Pit	Open Cut				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■									
104	Liddell	Liddell_a	Open Cut								■																												
105	Liddell	Liddell_b	Open Cut				■	■	■	■																													
106	Liddell	Liddell_c	Open Cut					■	■	■																													
107	Liddell	Liddell_d	Open Cut				■	■																															
108	Liddell	Liddell_e	Open Cut				■	■	■	■	■																												
301	Liddell UG	8_South_Dewatering_Bore	Dewatering										■	■	■	■	■	■	■																				
300	Liddell UG	Hazeldine_Dewatering_bore	Dewatering										■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■									
115	Liddell UG	Hazeldine_Dewatering_Coal_Barrier	Dewatering																	■	■	■	■	■	■	■	■	■	■	■									
303	Liddell UG	M49_Dewatering_Bore	Dewatering												■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■									
304	Liddell UG	Middle_Liddell_Dewatering_Bore	Dewatering																			■	■	■	■	■	■	■	■	■									
302	Liddell UG	Mt_Owen_Dewatering_bore	Dewatering										■	■	■	■	■	■	■	■																			
501	Mount Owen	North_Pit	Open Cut								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
209	Mount Owen	BNP	Open Cut														■	■					■	■	■	■	■	■	■	■									
6	Rav Surface Ops	Cumnock_OC	Open Cut								■	■	■	■	■																								
9	Rav Surface Ops	Rav_Narama	Open Cut			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■															
7	Rav Surface Ops	Rav_North	Open Cut																			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
203	Rav Surface Ops	RW_Pit	Open Cut														■																						
17	Rav UG	RUM_Lower_Pikes_Gully	Underground											■	■	■	■	■	■	■	■	■	■	■	■														
14	Rav UG	RUM_Liddell	Underground																				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
207	RERR	Eastern_Rail_Pit	Open Cut												■	■																							
201	RERR	West_Pit	Open Cut												■	■	■	■	■	■	■	■	■	■	■	■													
205	RERR	TP1	Open Cut											■																									
206	RERR	TP2	Open Cut										■	■																	■	■	■	■	■				

* Note: Time sequence follows modelling time steps (1-36). Steps 1 and 2 represent pre-modelling and steady-state (pre-transient modelling) considerations, respectively.

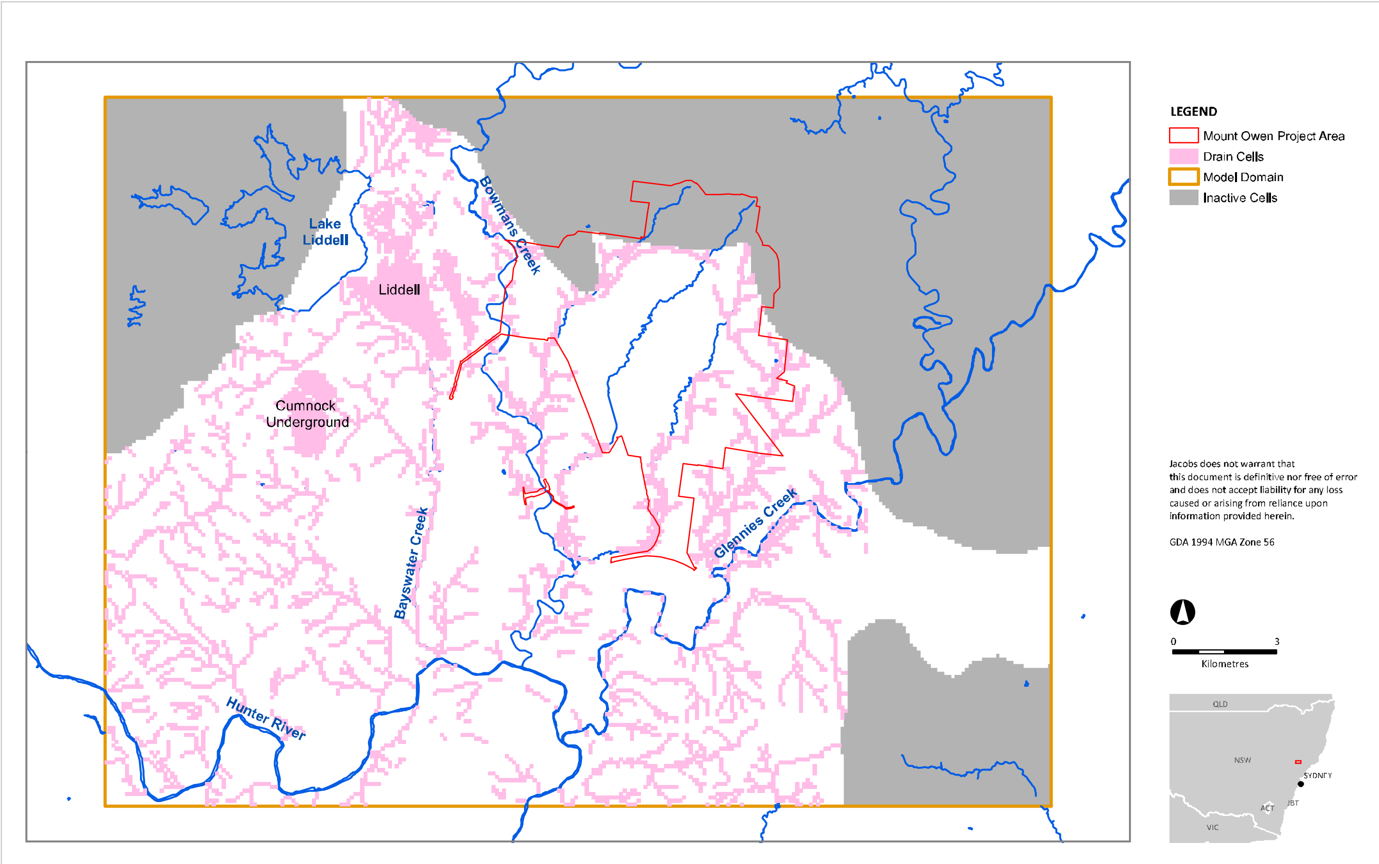


Figure B-5 - Model Drain Cells for Layer 1

File Name: MOCO_Model Domain_L1
Prepared by: LS
Checked by: RC

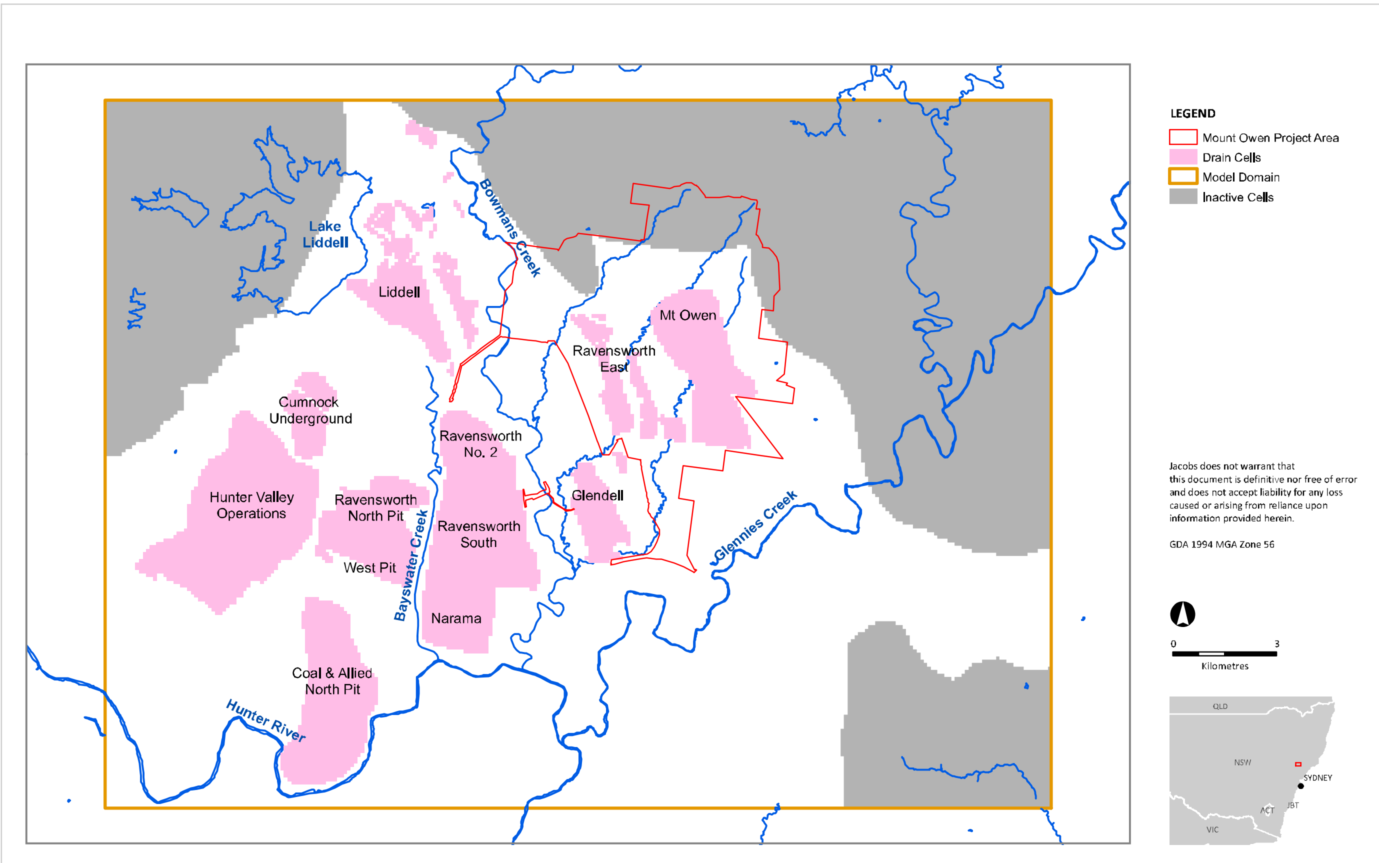


Figure B-6 - Model Drain Cells for Layer 2

File Name: MOCO_Model Domain_L2
Prepared by: LS
Checked by: RC

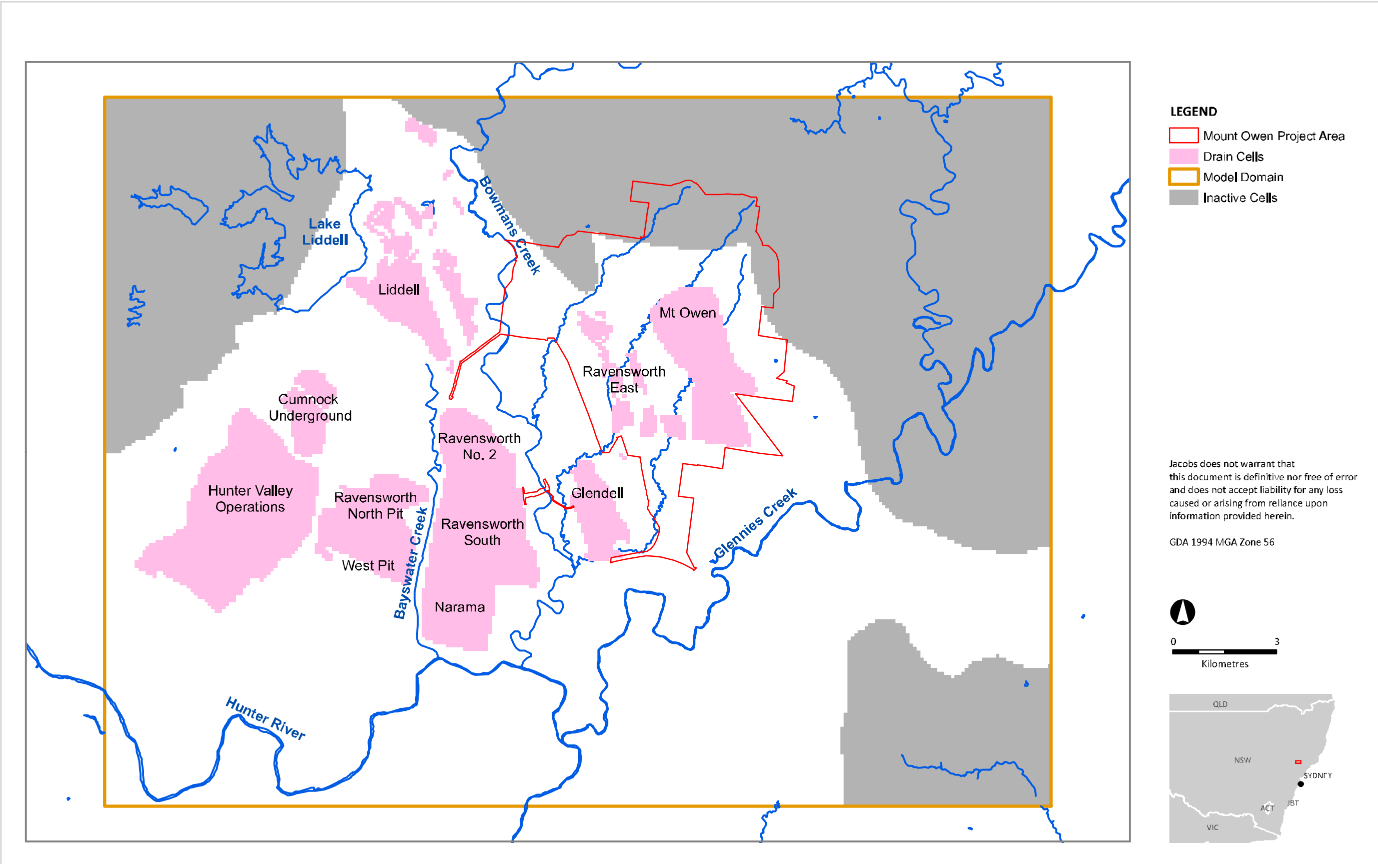


Figure B-7 - Model Drain Cells for Layer 3

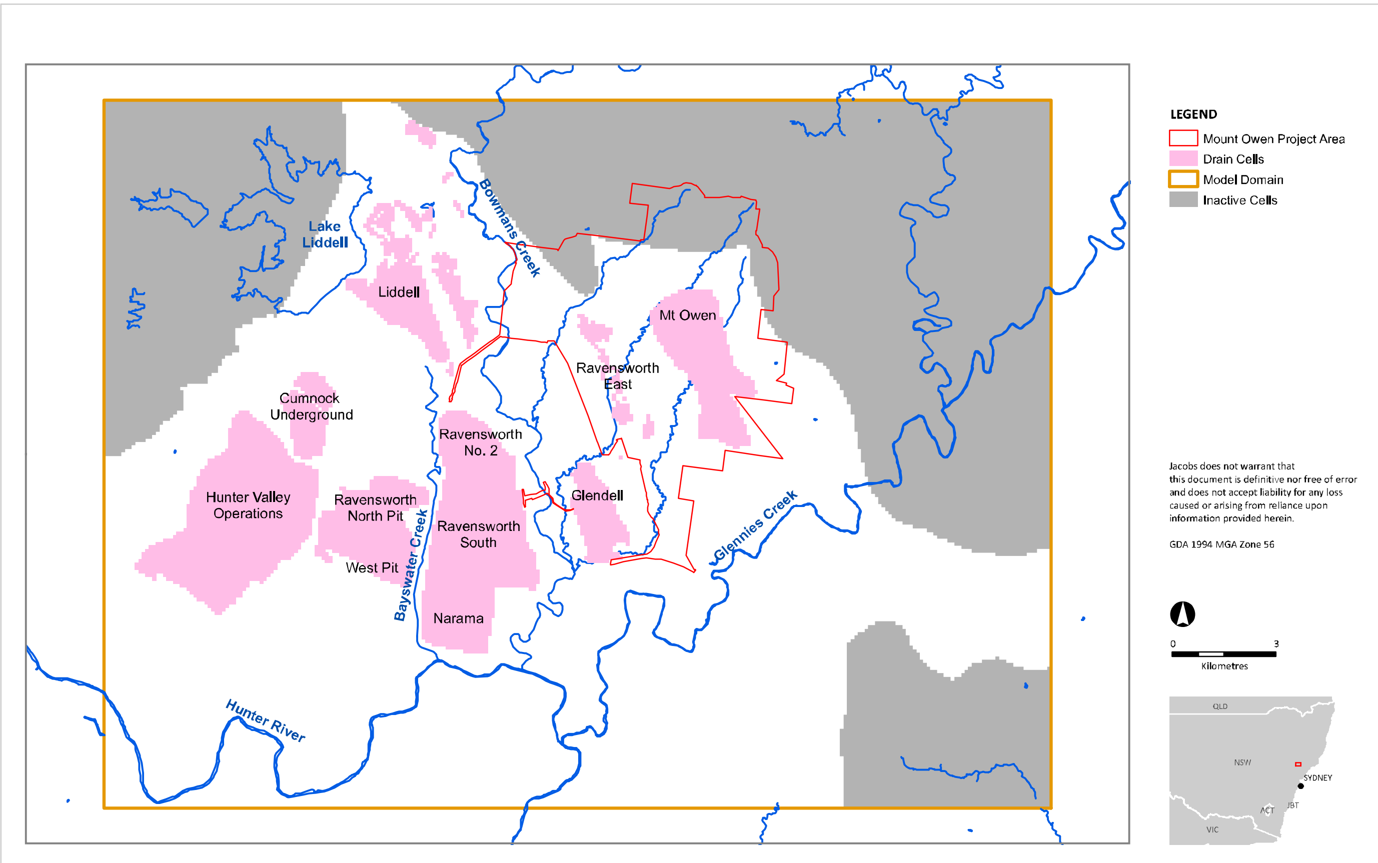


Figure B-8 - Model Drain Cells for Layer 4

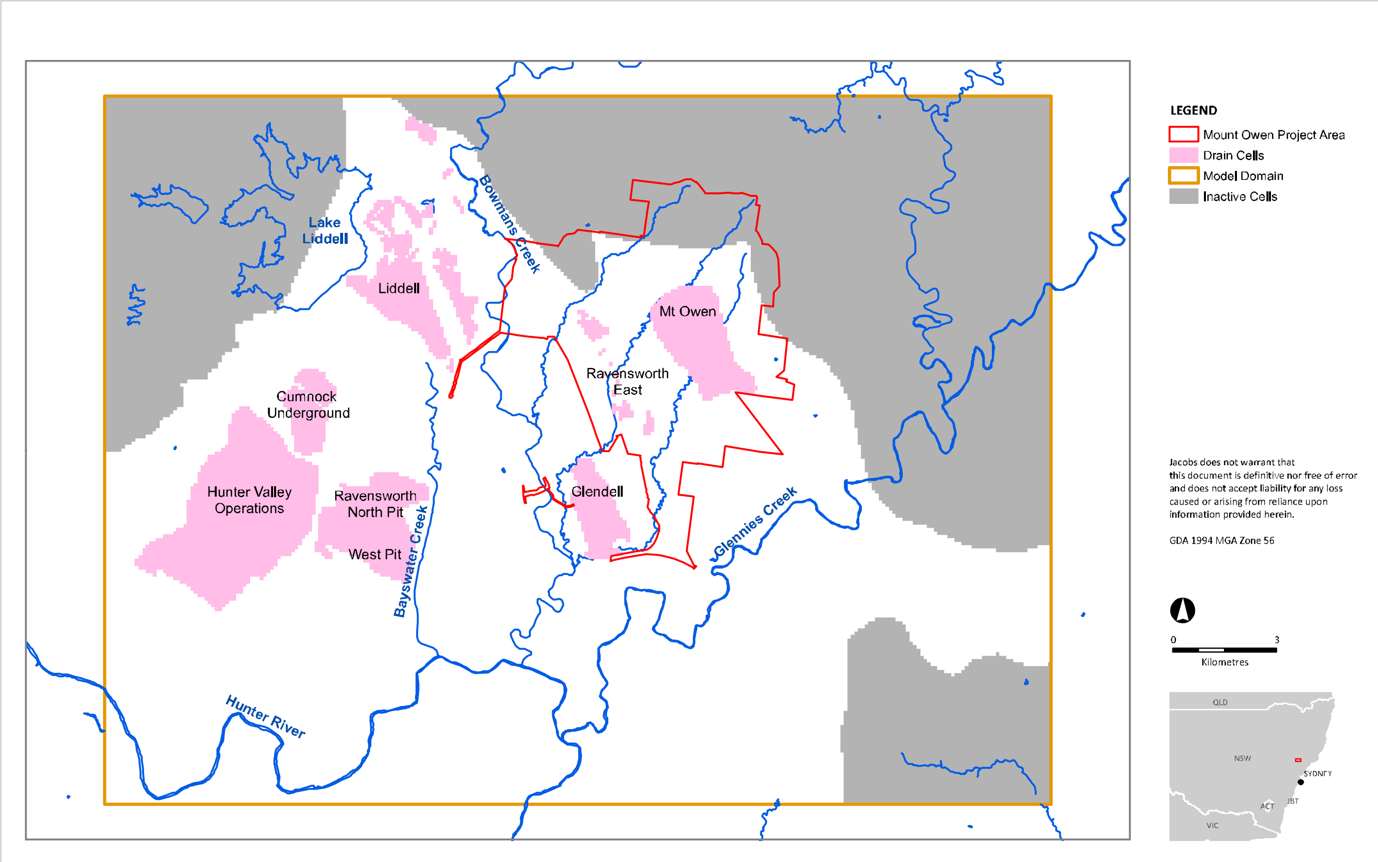


Figure B-9 - Model Drain Cells for Layer 5

JACOBS

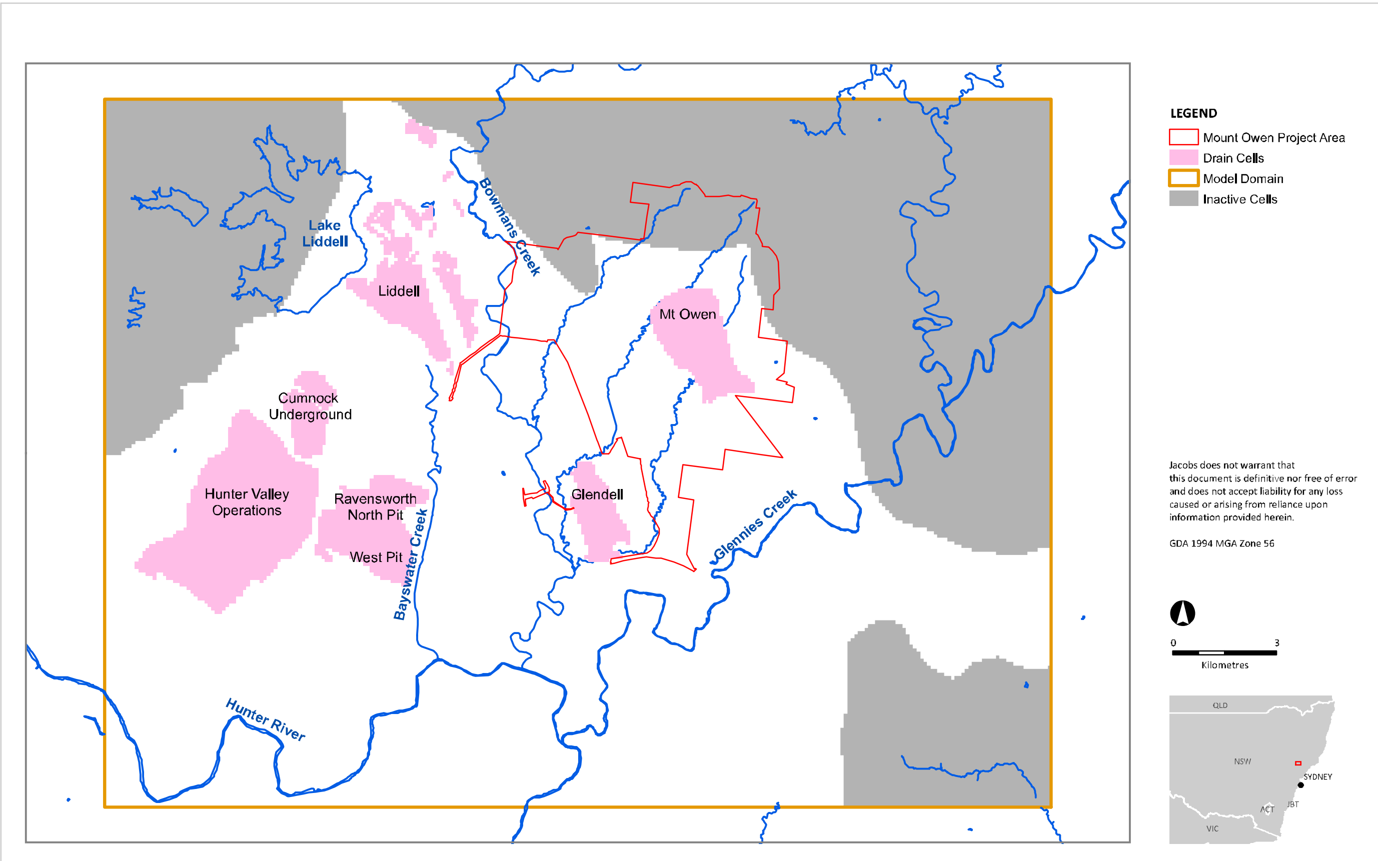


Figure B-10 - Model Drain Cells for Layer 6

JACOBS

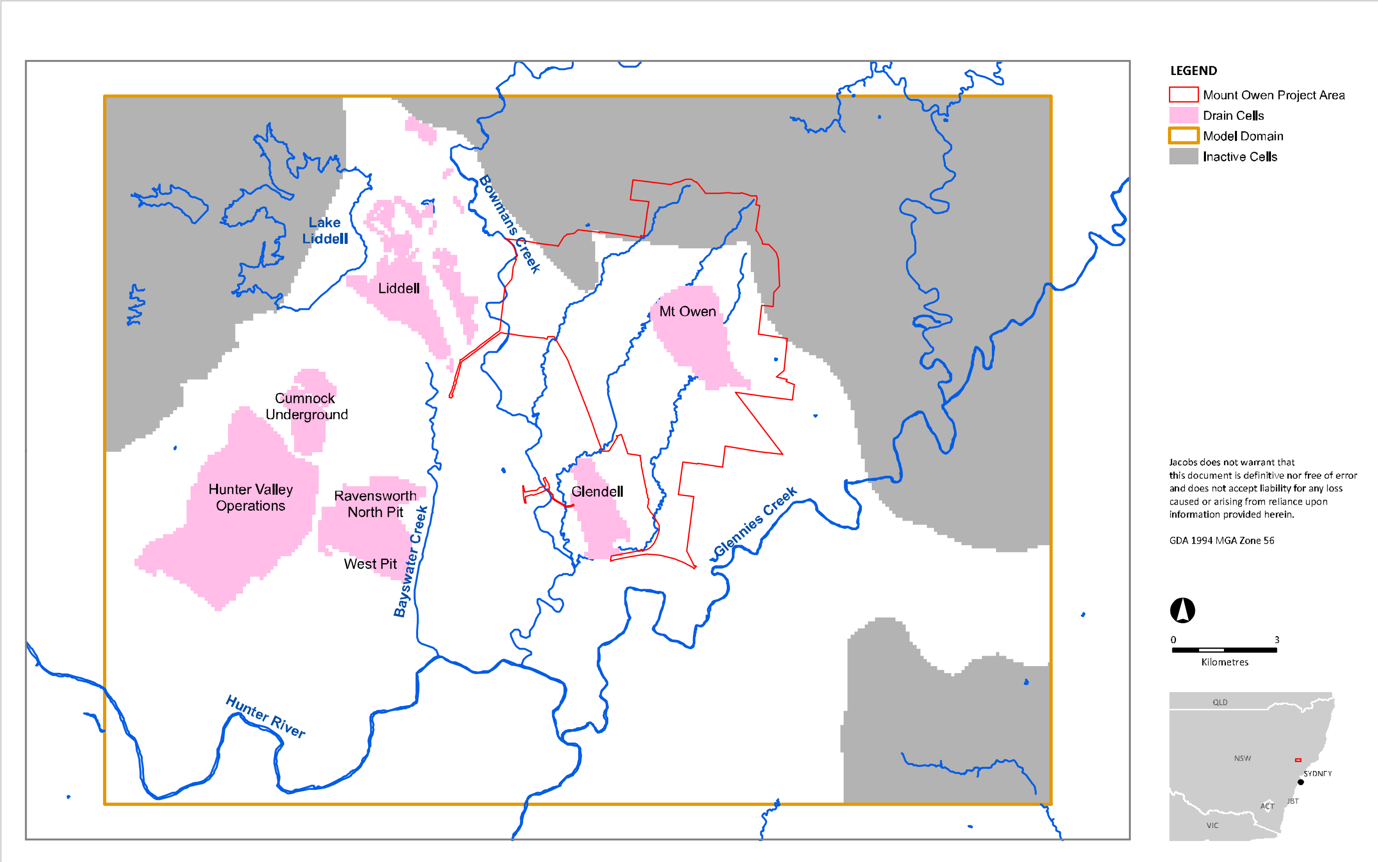


Figure B-11 - Model Drain Cells for Layer 7

File Name: MOCO_Model Domain_L7_v2
Prepared by: LS
Checked by: RC

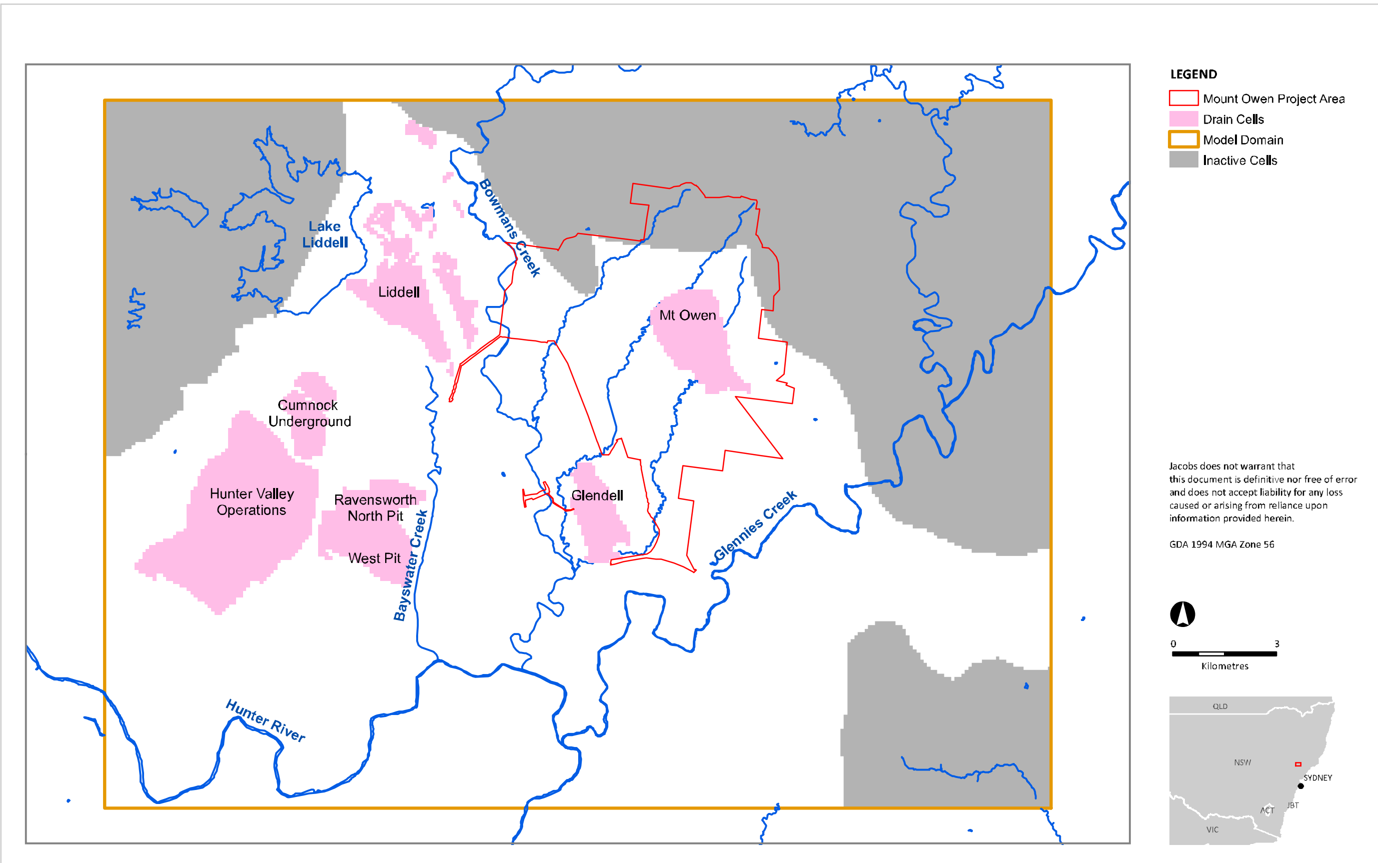


Figure B-12 - Model Drain Cells for Layer 8

File Name: MOCO_Model Domain_L8
Prepared by: CD
Checked by: RC

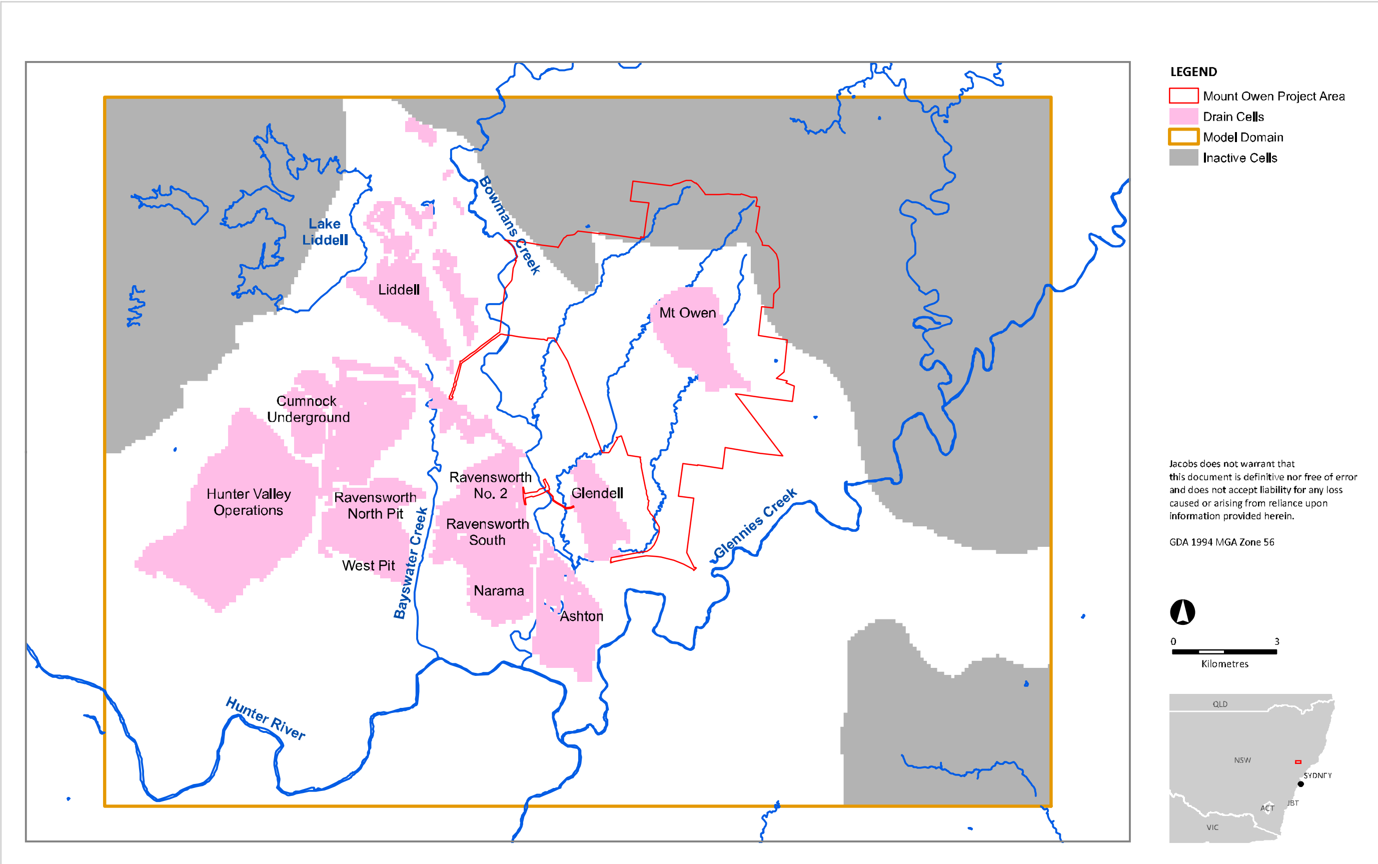


Figure B-13 - Model Drain Cells for Layer 9

File Name: MOCO_Model Domain_L9
Prepared by: CD
Checked by: RC

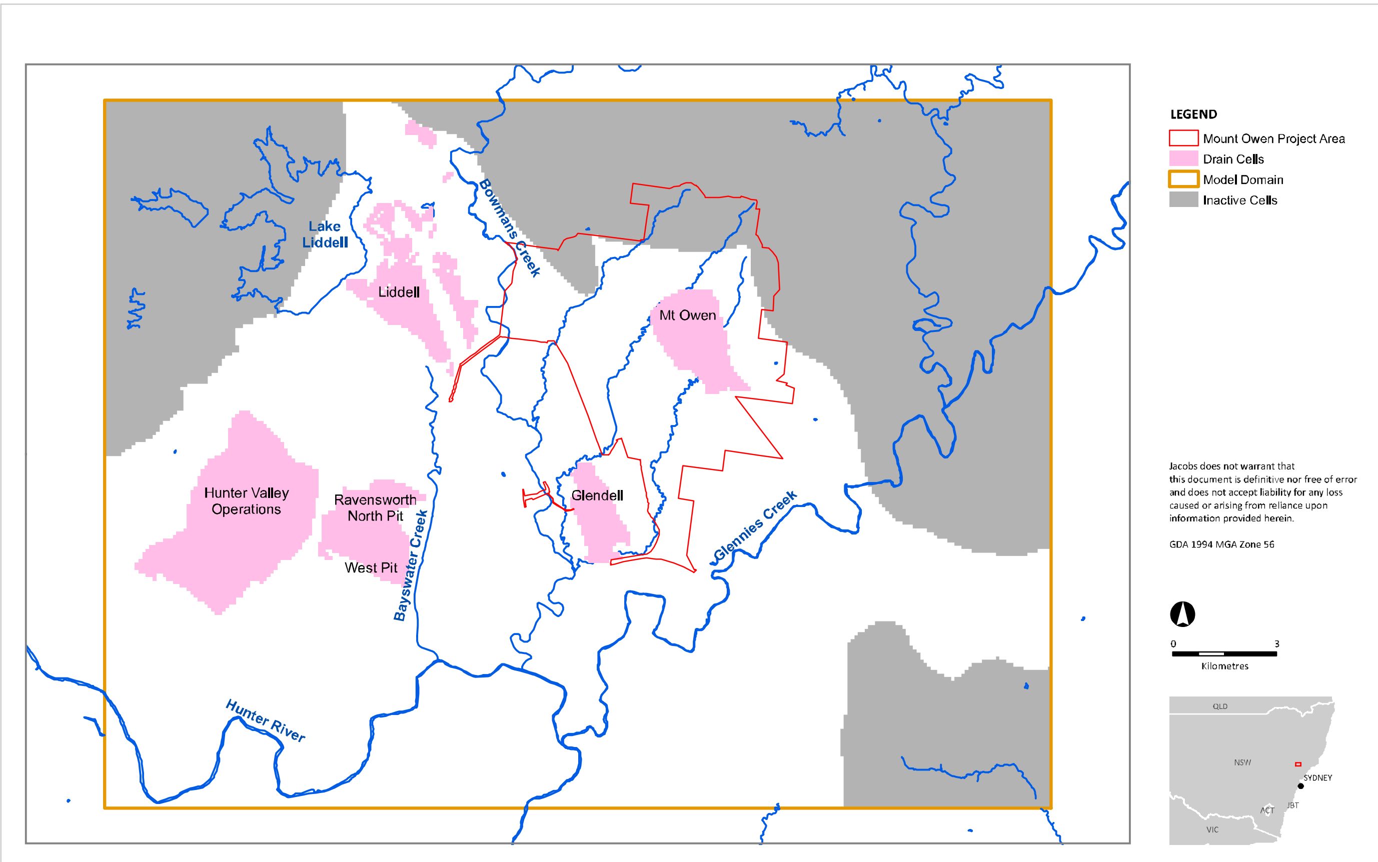


Figure B-14 - Model Drain Cells for Layer 10

File Name: MOCO_Model Domain_L10
Prepared by: CD
Checked by: RC

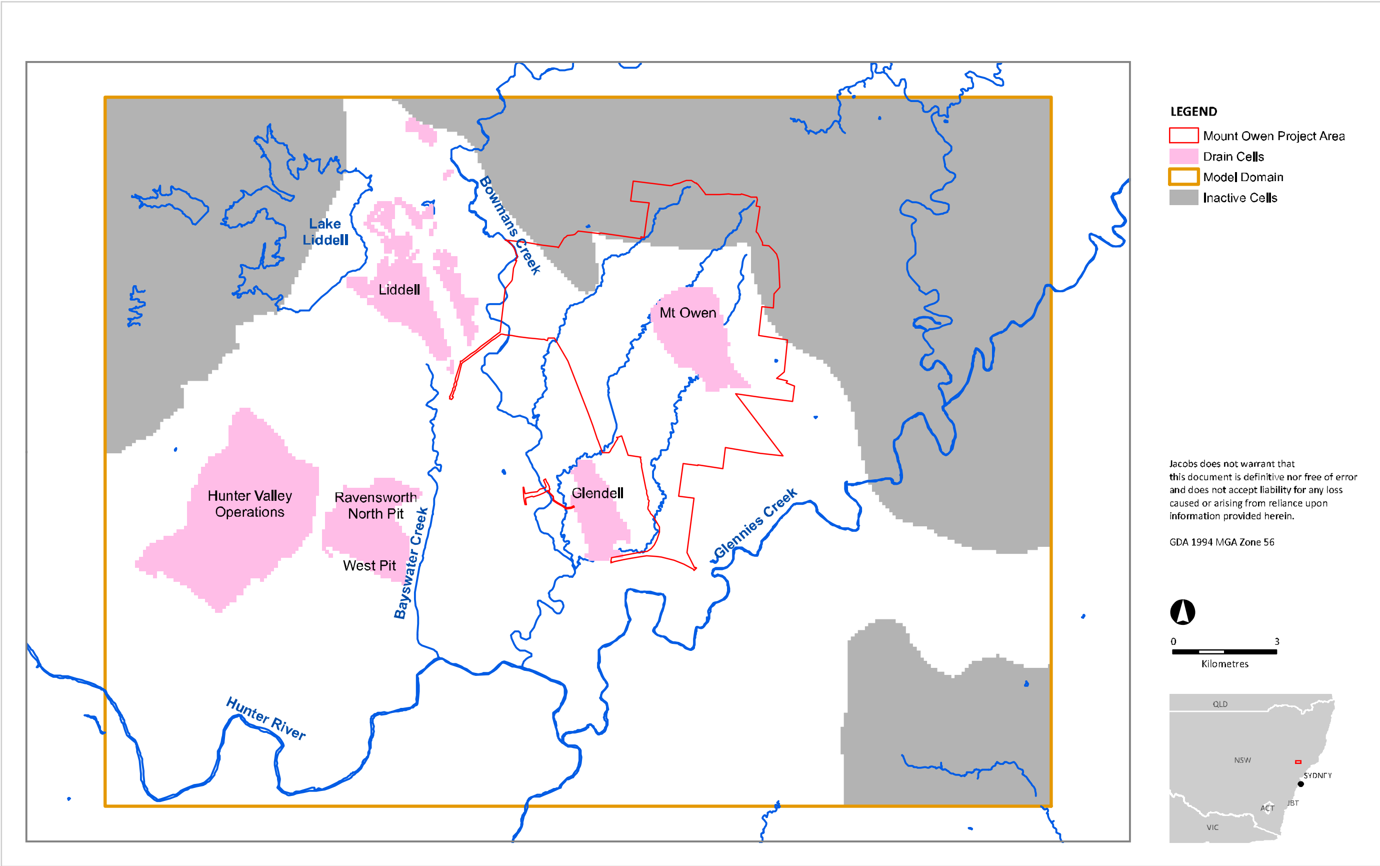


Figure B-15 - Model Drain Cells for Layer 11

JACOBS

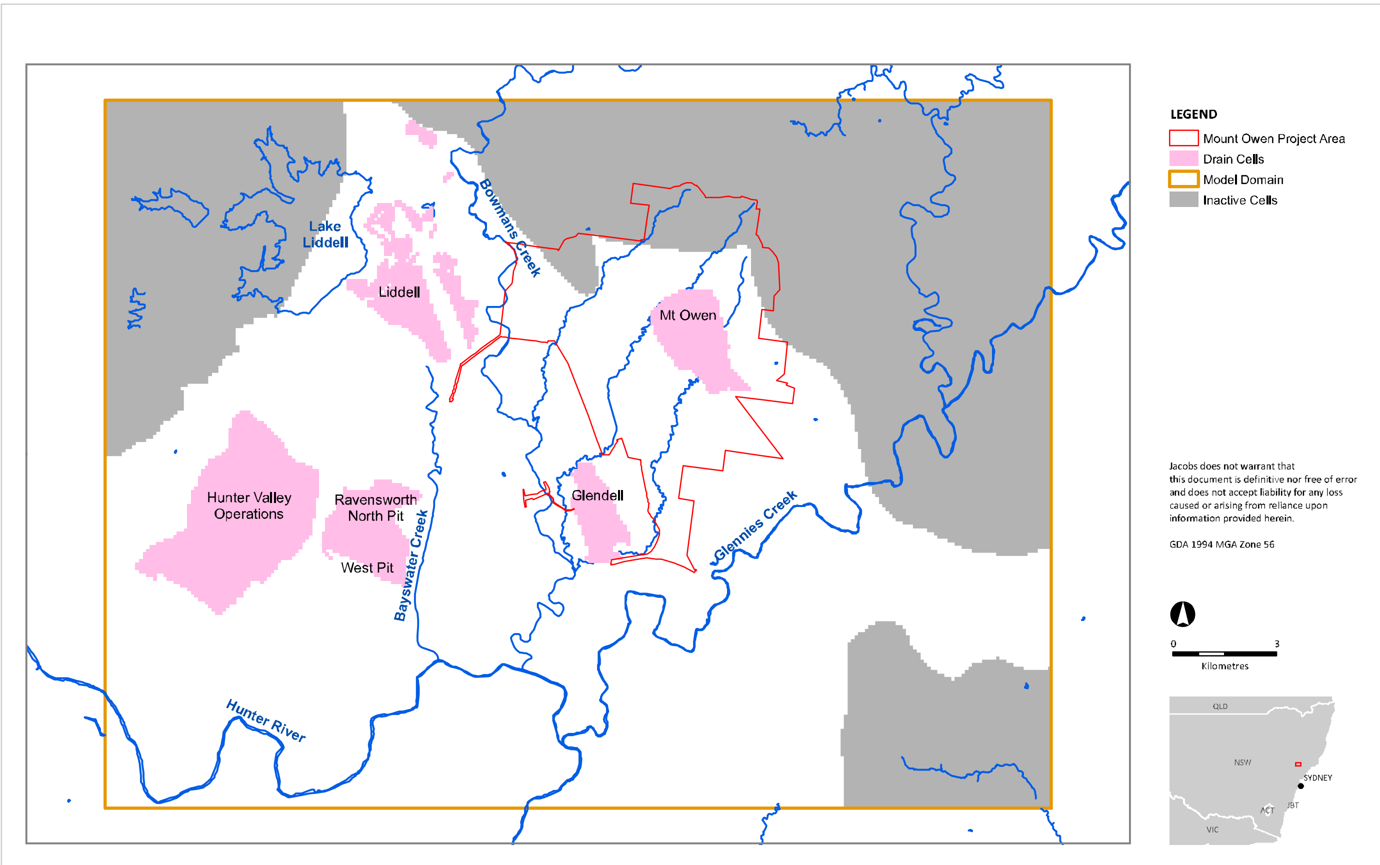


Figure B-16 - Model Drain Cells for Layer 12

JACOBS

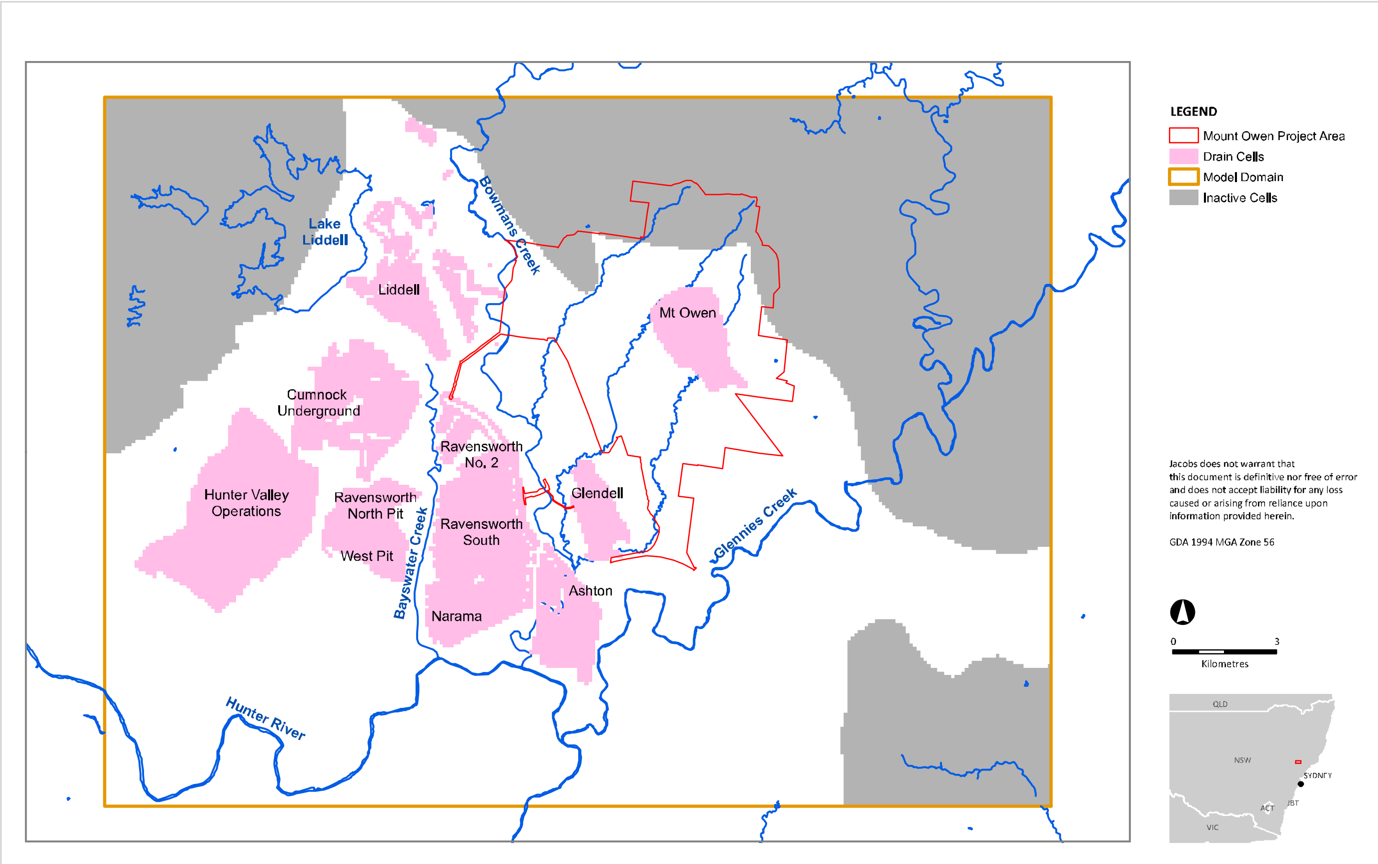


Figure B-17 - Model Drain Cells for Layer 13

JACOBS

File Name: MOCO_Model Domain_L13
Prepared by: CD
Checked by: RC

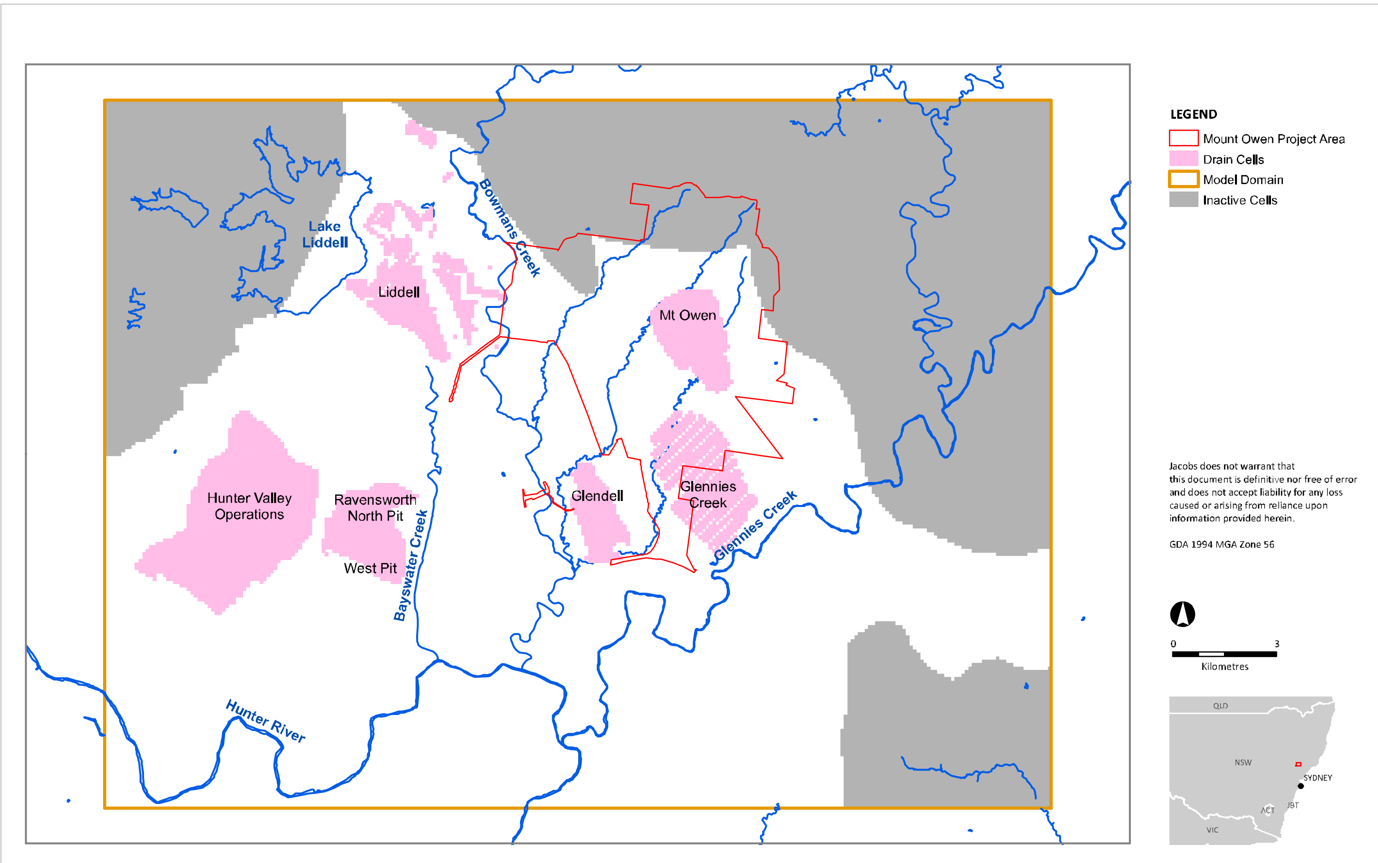


Figure B-18 - Model Drain Cells for Layer 14

JACOBS

File Name: MOCO_Model Domain_L14
Prepared by: CD
Checked by: RC

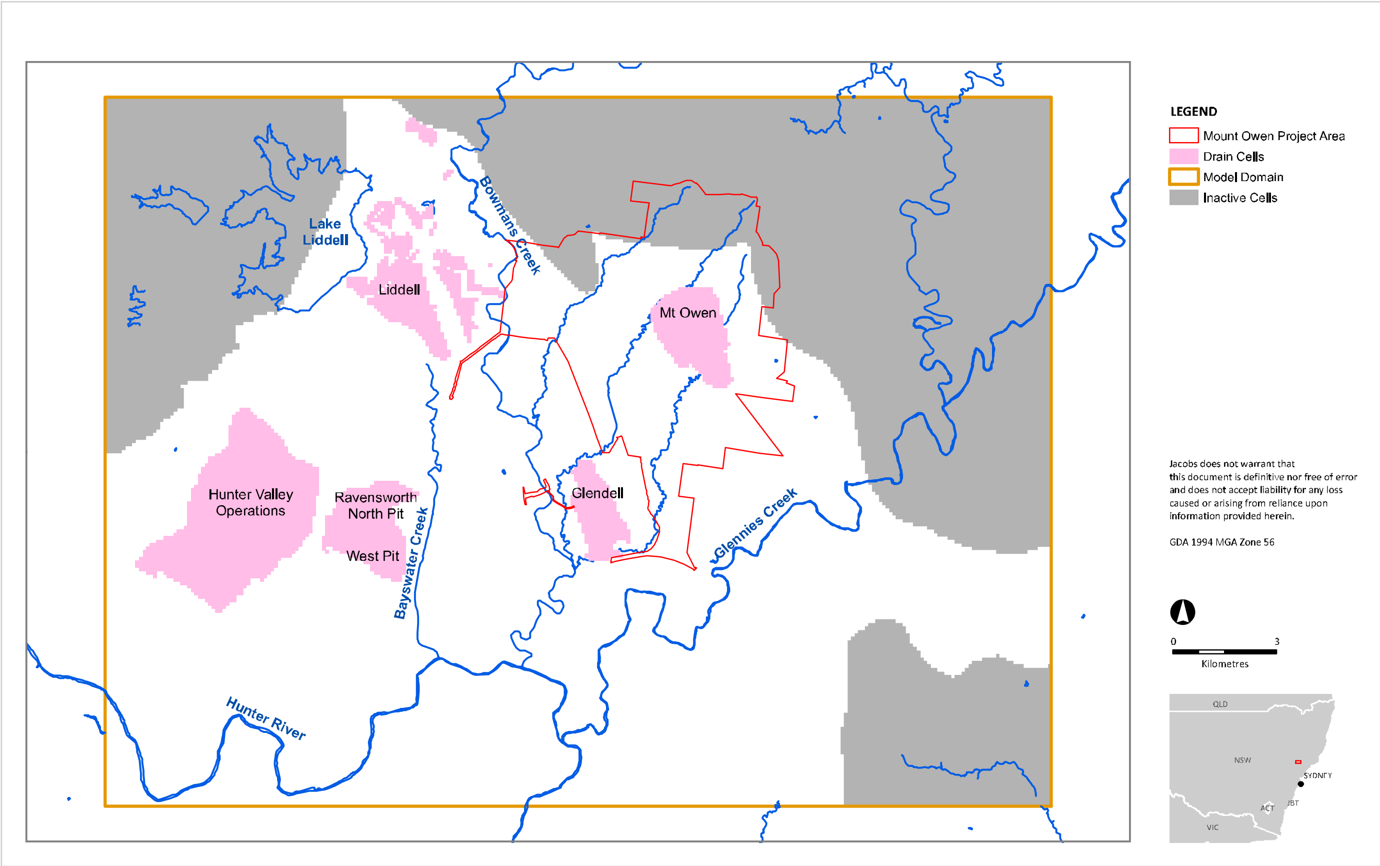


Figure B-19 - Model Drain Cells for Layer 15

JACOBS

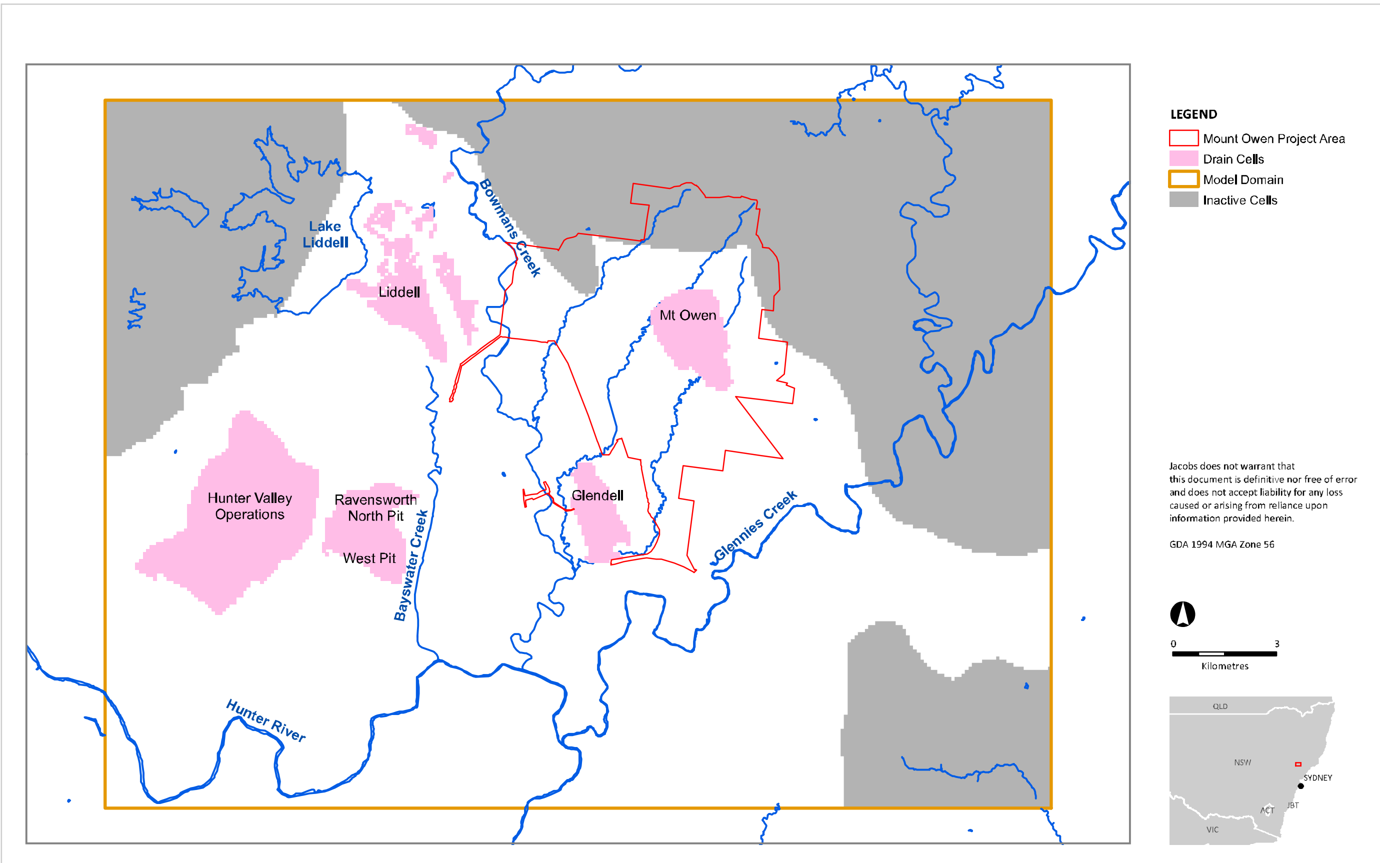


Figure B-20 - Model Drain Cells for Layer 16

JACOBS

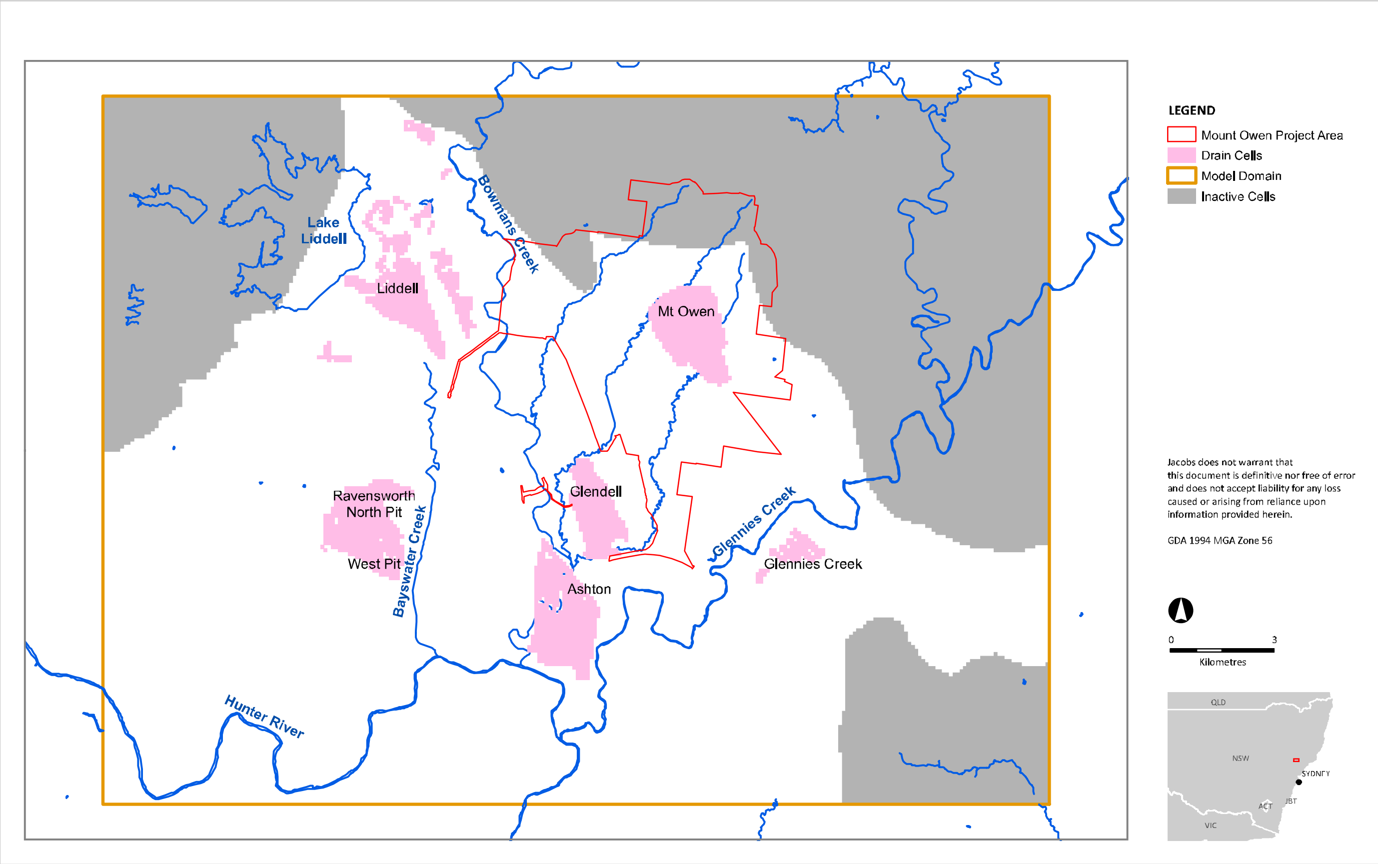


Figure B-21 - Model Drain Cells for Layer 17

JACOBS

File Name: MOCO_Model Domain_L17
Prepared by: CD
Checked by: RC

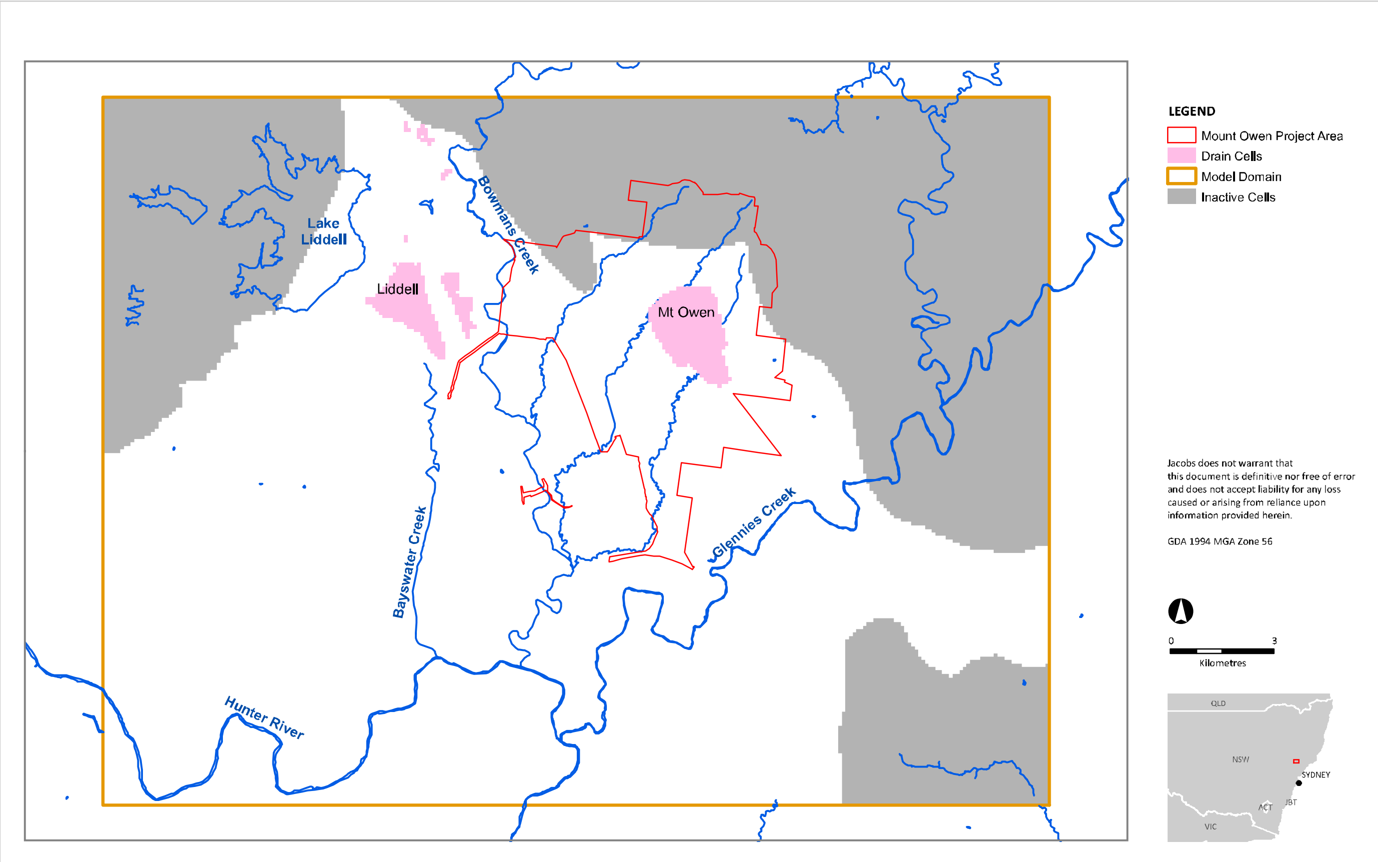


Figure B-22 - Model Drain Cells for Layer 18

JACOBS

File Name: MOCO_Model Domain_L18
Prepared by: CD
Checked by: RC

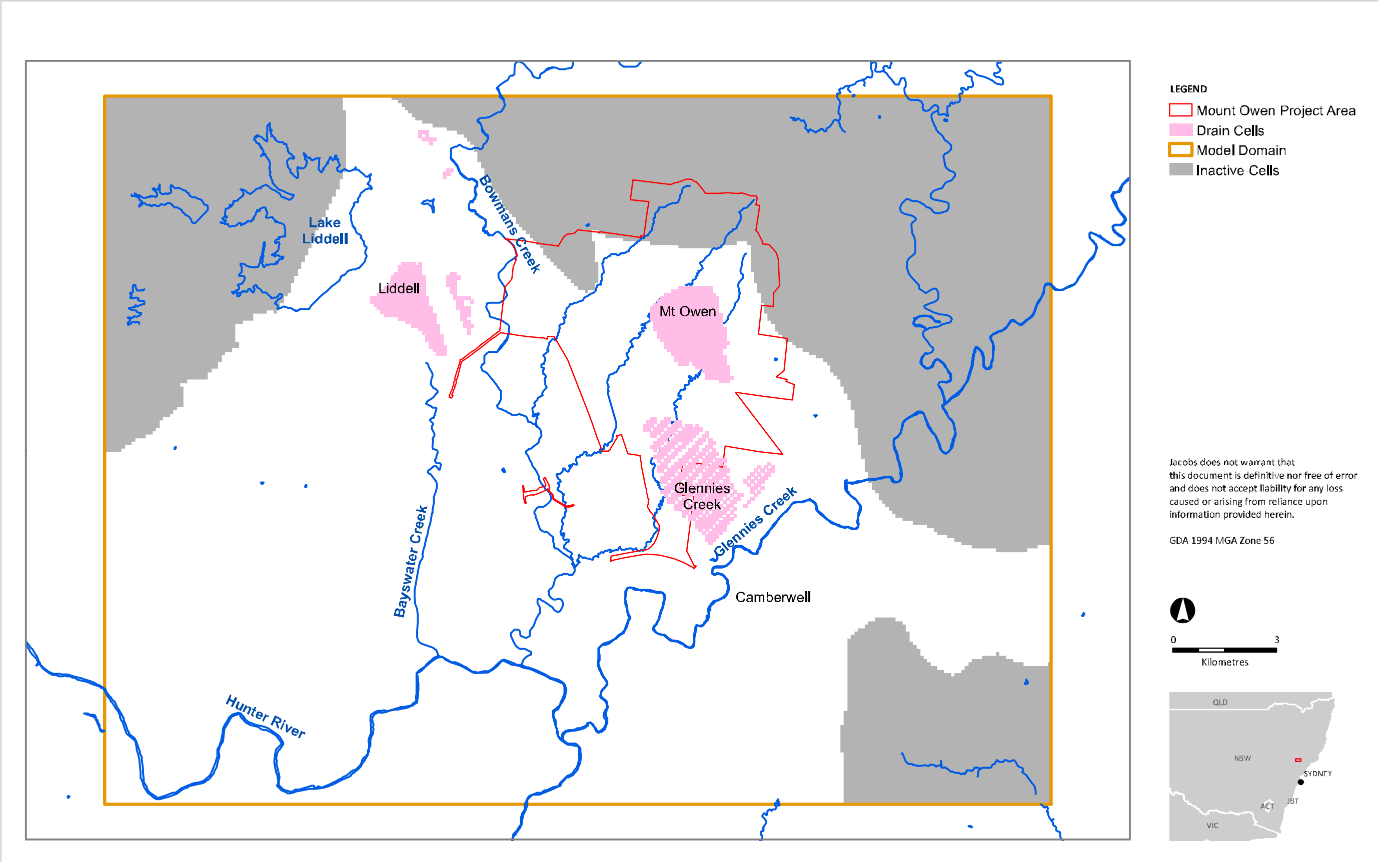


Figure B-23 - Model Drain Cells for Layer 19

File Name: MOCO_Model Domain_L19
Prepared by: CD
Checked by: RC

Appendix C. Hydrographs for Calibration Bores and Calibrated Model Realisations

Observed and modelled hydrographs for the model run period are provided for the bores located on **Figure C-1**. Hydrographs illustrate the median and +/- 1 standard deviation heads for the modelled heads for the 53 model realisations that satisfied all the calibration criteria for bores which have observed time series data. Not included are bores with single point water level data.

The calibration period starts from a steady state optimisation for 1980 and continues through 2013. Three bore “types” are distinguished: Alluvial Bores; Project Bedrock Bores and Other Bores. Project Bedrock Bores include those hard-rock bores considered to have the most relevance to the Project and for which we had adequate confidence in the datasets and knowledge of bore construction to constrain calibration parameters. Other bores (**Table C– 1**) include the Project bedrock bores and other bores in the region that were used in the weighted statistics calculations.

Tables C-1, C-2 and C-3 present a summary of the bore depths and target layers for the Alluvial Bores, Project Bedrock Bores and Other Bores, respectively.

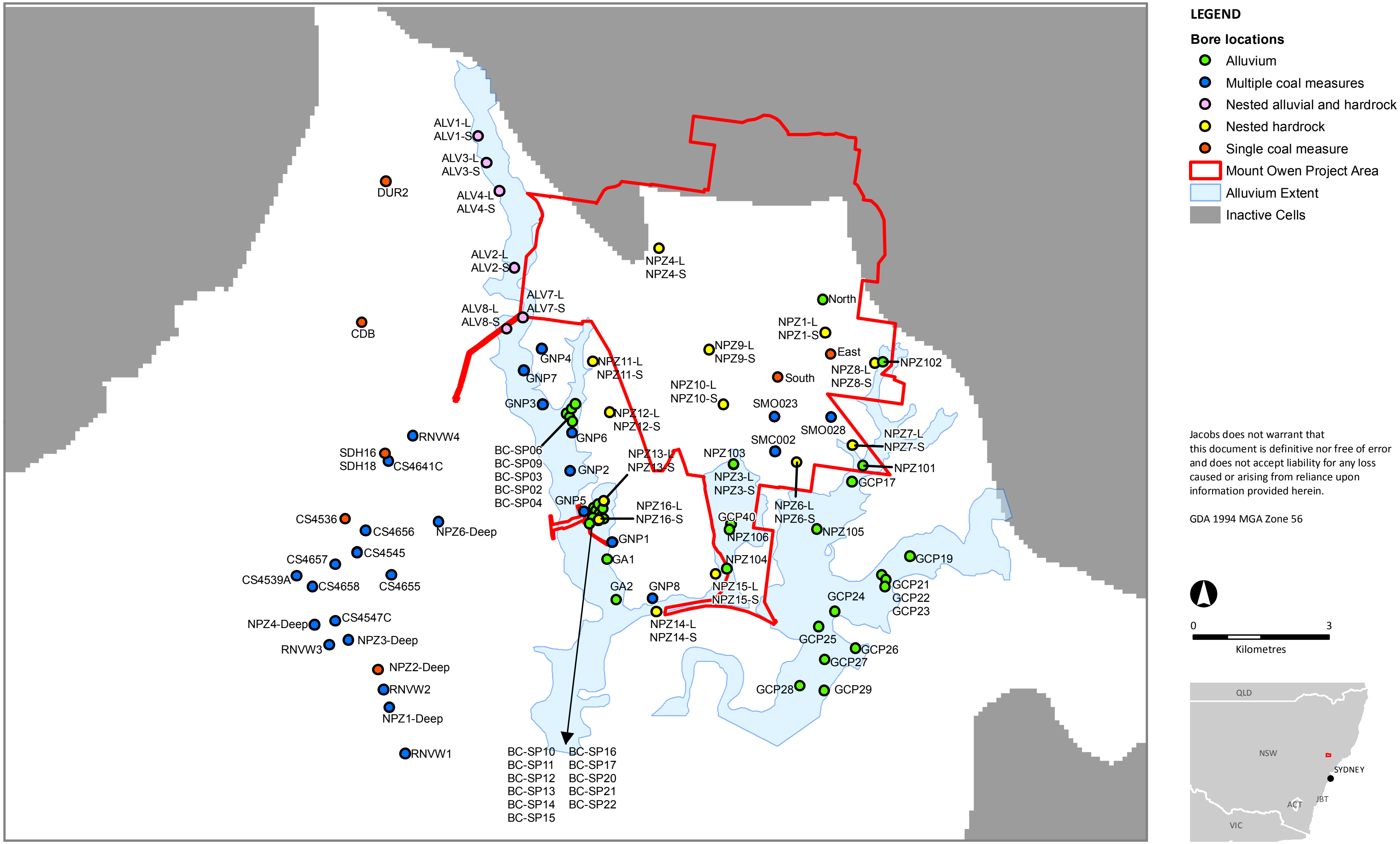


Figure C-1 - Bore locations within the Model Domain classified by Calibration type (Alluvial, Bedrock Project, Other)

JACOBS

File Name: Figure C-1 Alluvial and bedrock bores_model calibration_v2
Prepared by: LS
Checked by: RC

Table C– 1 – Bores used or assessed during calibration and verification process[6]

Observation Points used in statistics					
All Alluvial Bores (unweighted)	Project Bedrock Observations (unweighted)	All Bedrock Observations (includes Project Bedrock and Other Bores) (Weighted)			
ALV1-L	ALV1-S	ALV1-S	CS4657-LPG	GNP3-LLD	GNP8-LLD
ALV1-L	ALV1-S	ALV1-S	GNP1-ART	NPZ10_L	SDH16
ALV2-L	ALV2-S	ALV2-S	GNP1-BRT	NPZ10_S	SDH18
ALV3-L	ALV3-S	ALV3-S	GNP1-HEB	NPZ11_L	SMC002-BY3
ALV4-L	ALV4-S	ALV4-S	GNP1-LLD	NPZ11_S	SMC002-BY5
ALV7-L	ALV7-S	ALV7-S	GNP1-MLD	NPZ12_L	SMC002-RFL
ALV8-L	ALV8-S	ALV8-S	GNP1-PG	NPZ12_S	SMC002-RNL
BC_SP02	East	CDB	GNP1-ULD	NPZ13_L	SMC002-RTU
BC_SP03	North	CS4536	GNP2-ART	NPZ13_S	SMO023-BY3
BC_SP06	NPZ10_l	CS4539A	GNP2-BAR	NPZ14_L	SMO023-BY5
BC_SP09	NPZ10_s	CS4545	GNP2-HEB	NPZ14_S	SMO023-RFL
BC_SP10	NPZ3_l	CS4545B	GNP2-LLD	NPZ15_L	SMO023-RNL
BC_SP11	NPZ3_s	CS4545C	GNP2-MLD	NPZ15_S	SMO023-RTU
BC_SP12	NPZ4_l	CS4545D	GNP2-PG	NPZ16_L	SMO023-RVU
BC_SP13	NPZ4_s	CS4547C	GNP2-ULD	NPZ16_S	SMO028-BAY
BC_SP14	NPZ7_l	CS4641C	GNP3-ART	NPZ1-DEEP	SMO028-LBA
BC_SP15	NPZ7_s	CS4655-BAY	GNP3-BRT	NPZ2-DEEP	SMO028-LBG
BC_SP16	NPZ8_l	CS4655-BRT	GNP3-HEB	NPZ3_L	SMO028-LBJ
BC_SP17	NPZ8_s	CS4655-LLD	GNP3-LLD	NPZ3_S	SMO028-LCF
BC_SP20	NPZ9_l	CS4655-LMA	GNP3-MLD	NPZ3-DEEP	SMO028-LDF
BC_SP21	NPZ9_s	CS4655-LMH	GNP3-PG	NPZ4_L	
BC_SP22	South	CS4655-UAR	GNP3-ULD	NPZ4_S	
GCP19		CS4655-ULD	GNP4-ART	NPZ4-DEEP	
GCP21		CS4655-UPG	GNP4-BRT	NPZ6-DEEP	
GCP22		CS4656-BRT	GNP4-HEB	NPZ6_L	
GCP23		CS4656-LLD	GNP4-LLD	NPZ6_S	
GCP25		CS4656-LMA	GNP4-MLD	NPZ7_L	
GCP26		CS4656-LMF	GNP4-PG	NPZ7_S	

[6] Note: ALV* bores suffixed _L are shallow (alluvial) bores; _S penetrate the shallow bedrock;
NPZ* bores suffixed _L are deep (Coal Measures) bores; _S penetrate the shallow bedrock;
NPZ*-DEEP bores are located in the Cumnock underground workings

Observation Points used in statistics					
All Alluvial Bores (unweighted)	Project Bedrock Observations (unweighted)	All Bedrock Observations (includes Project Bedrock and Other Bores) (Weighted)			
GCP28		CS4656-UAR	GNP4-ULD	NPZ8_L	
GCP29		CS4656-ULD	GNP5-ART	NPZ8_S	
GCP40		CS4656-UPG	GNP5-BAR	NPZ9_L	
NPZ101		CS4657-BRT	GNP5-HEB	NPZ9_S	
NPZ102		CS4657-LLD	GNP5-INT	RNVW1-BAY	
NPZ103		CS4657-LMA	GNP5-LLD	RNVW1-BRT	
NPZ104		CS4657-LMF	GNP5-MLD	RNVW1-LLD	
NPZ106		CS4657-LMH	GNP5-PG	RNVW1-LMA	
		CS4657-LPG	GNP5-ULD	RNVW1-LMH	
		CS4657-UAR	GNP6-ART	RNVW1-UAR	
		CS4657-ULD	GNP6-BAR	RNVW1-ULD	
		CS4658-BAY	GNP6-HEB	RNVW1-UPG	
		CS4658-BRT	GNP6-LLD	RNVW2-BRT	
		CS4658-LLD	GNP6-MLD	RNVW2-LLD	
		CS4658-LMA	GNP6-PG	RNVW2-LMA	
		CS4658-LMH	GNP6-ULD	RNVW2-LMH	
		CS4658-UAR	GNP7-ART	RNVW2-UAR	
		CS4658-ULD	GNP7-BRT	RNVW2-ULD	
		CS4658-UPG	GNP7-HEB	RNVW2-UPG	
		DUR2	GNP7-LLD	RNVW3-BRT	
		east	GNP7-MLD	RNVW3-LLD	
		south	GNP7-PG	RNVW3-LMA	
		north	GNP7-ULD	RNVW3-UAR	
		GA1	GNP8-BAR	RNVW3-ULD	
		GA2	GNP8-HEB	RNVW3-UPG	
		GCP17	GNP8-LLD	RNVW4-BRT	
		GCP24	GNP8-MLD	RNVW4-LLD	
		GCP27	GNP8-ULD	RNVW4-UAR	
				RNVW4-ULD	
				RNVW4-UPG	

Table C– 2 – Known bore depths and target layers for alluvial bores

Bore I.D	Easting	Northing	Depth (mbgl)	Collar (mAHD)	Sampled unit	Model layer
ALV1-L	315528	6417638	-	111.194	Alluvium	1
ALV2-L	316328.5	6414721	-	97.876	Alluvium	1
ALV3-L	315703.6	6417044	-	109.49	Alluvium	1
ALV4-L	315994.6	6416421	-	107.70	Alluvium	1
ALV7-L	316513.7	6413617	-	93.78	Alluvium	1
ALV8-L	316151.4	6413367	-	92.024	Alluvium	1
BC-SP02	317483	6411487	8.7	-	Alluvium	1
BC-SP03	317547	6411405	7.5	-	Alluvium	1
BC-SP06	317596	6411588	9.25	-	Alluvium	1
BC-SP09	317675	6411703	8.15	-	Alluvium	1
BC-SP10	318080	6409400	6	-	Alluvium	1
BC-SP11	318137	6409337	9.4	-	Alluvium	1
BC-SP12	318201	6409265	6.3	-	Alluvium	1
BC-SP13	318253	6409210	3.5	-	Alluvium	1
BC-SP14	318305	6409158	5.9	-	Alluvium	1
BC-SP15	318182	6409484	5	-	Alluvium	1
BC-SP16	318290	6409376	4.6	-	Alluvium	1
BC-SP17	318319	6409543	6.5	-	Alluvium	1
BC-SP20	318184	6409118	4.5	-	Alluvium	1
BC-SP21	318057	6409176	6.7	-	Alluvium	1
BC-SP22	317992	6409051	6	-	Alluvium	1
GCP19	325086	6408333	11.35	-	Alluvium	1
GCP21	324466	6407916	11	-	Alluvium	1
GCP22	324558	6407814	11.1	-	Alluvium	1
GCP23	324535	6407659	7.5	-	Alluvium	1
GCP25	323066	6406766	9.15	-	Alluvium	1
GCP26	323884	6406293	11	-	Alluvium	1
GCP28	322652	6405459	8.73	-	Alluvium	1
GCP29	323194	6405354	6.41	-	Alluvium	1
GCP40	321115	6409047	6	-	Alluvium	1
GA1	318378	6408259	-	-	Alluvium	-
GA2	318578	6407366	-	-	Alluvium	-
NPZ101	324046	6410343	8.5	-	Alluvium	1

Bore I.D	Easting	Northing	Depth (mbgl)	Collar (mAHD)	Sampled unit	Model layer
NPZ102	324489	6412637	8	-	Alluvium	1
NPZ103	321177	6410370	4	-	Alluvium	1
NPZ104	321028	6408055	5	-	Alluvium	1
NPZ105	323022	6408934	8	-	Alluvium	1
NPZ106	321091	6408918	5.5	-	Alluvium	1

Table C– 3 – Known bore depths and target layers for Project Hard Rock bores[7]

Bore I.D	Easting	Northing	Elevation (mAHD)	Total depth (mbgl)	Total depth (mAHD)	Screen interval (mAHD)*	Sampled unit	Model layer
ALV1-S	315528	6417638	111.11	-	-	-	Overburden	3
ALV2-S	316328.5	6414721	97.88	-	-	-	Overburden	3
ALV3-S	315703.6	6417044	109.49	-	-	-	Overburden	3
ALV4-S	315994.6	6416421	107.7	-	-	-	Overburden	3
ALV7-S	316513.7	6413617	93.78	-	-	-	Overburden	3
ALV8-S	316151.4	6413367	92.08	-	-	-	Overburden	3
South	322157.2	6412294	110.93	-	-	-	Unknown	3
East	323332	6412810	153.49	-	-	-	Unknown	3
North	323156.2	6414021	140.65	-	-	-	Unknown	3
NPZ10-L	320960.9	6411696	116.7	61	55.7	115.7 to 55.7	Fractured rock - no seam	3
NPZ10-S	320960.9	6411696	116.7	27	89.7	115.7 to 89.7	Overburden	1
NPZ3-L	321181	6410357	93.5	30 and 60	63.5 and 33.5	92.5 to 63.5 92.5 to 33.5	Fractured rock - no seam	3
NPZ3-S	321181	6410357	93.5	6	87.5	92.5 to 87.5	Overburden	1
NPZ4-L	319532.7	6415152	124.8	110	14.8	123.8 to 14.8	Fractured rock - no seam	3
NPZ4-S	319532.7	6415152	124.8	60	64.8	123.8 to 64.8	Overburden	1
NPZ7-L	323812.2	6410786	95.4	110	-14.6	94.4 to -14.6	Fractured rock – no seam	6
NPZ7-S	323812.2	6410786	95.4	62	33.4	94.4 to 33.4	Lemington seam (regolith)	1
NPZ8-L	324314.4	6412607	120.02	-	-	-	Unknown	3
NPZ8-S	324314.4	6412607	120.02	-	-	-	Overburden	1
NPZ9-L	320643	6412905	113.9	50	63.9	112.9 to 63.9	Fractured rock	3
NPZ9-S	320643	6412905	113.9	22	91.9	112.9 to 91.9	Ravensworth seam (regolith)	1

[7] Note: NPZ bores screened from the base of well to 1m below ground surface

Table C– 4 – Known bore depths and target layers for Other Hard Rock bores

Bore I.D	Easting	Northing	Total depth (mbgl)	Collar elevation (mAHD)	Sampled unit	Model layer
CS4536	312585.7	6409158	-	91.5	Liddell seams	13
CS4539A	311501.4	6407889	-	135.3	Pikes Gully seam	9
CS4545	312852.4	6408418	-	82.65	Liddell seams	13
CS4545B	312852.4	6408414	-	82.65	Liddell seams	13
CS4545C	312852.4	6408414	-	82.65	Liddell seams	13
CS4545D	312852.4	6408414	-	82.65	Liddell seams	13
CS4547C	312360.4	6406897	-	97.44	Upper Liddell	13
CS4641C	313549	6410436	-	81.64	Lower Pikes Gully	9
CS4655-Bay	313604.6	6407913	36.6	-	Bayswater seam	4
CS4655-Brt	313604.6	6407913	250.4	-	Barrett seam	17
CS4655-LLd	313604.6	6407913	225	-	Lower Liddell seam	15
CS4655-LmA	313604.6	6407913	132.1	-	Lemington seam	6
CS4655-LmH	313604.6	6407913	77.7	-	Lemington seam	6
CS4655-UAr	313604.6	6407913	180.94	-	Arties seam	11
CS4655-ULd	313604.6	6407913	203.5	-	Upper Liddell	13
CS4655-UPG	313604.6	6407913	149.77	-	Upper Pikes Gully	9
CS4656-Brt	313030.6	6408901	217.06	-	Barrett seam	17
CS4656-LLd	313030.6	6408901	194.3	-	Lower Liddell	15
CS4656-LmA	313030.6	6408901	100	-	Lemington seam	6
CS4656-LmF	313030.6	6408901	76.9	-	Lemington seam	6
CS4656-UAr	313030.6	6408901	143.8	-	Arties seam	11
CS4656-ULd	313030.6	6408901	172.3	-	Upper Liddell	13
CS4656-UPG	313030.6	6408901	118.6	-	Upper Pikes Gully	9
CS4657-Brt	312358.7	6408152	205.58	-	Barrett seam	17
CS4657-LLd	312358.7	6408152	185.96	-	Lower Liddell	15
CS4657-LmA	312358.7	6408152	96.75	-	Lemington seam	6
CS4657-LmF	312358.7	6408152	75.25	-	Lemington seam	6
CS4657-LmH	312358.7	6408152	48.93	-	Lemington seam	6
CS4657-LPG	312358.7	6408152	114.76	-	Lower Pikes Gully	9
CS4657-UAr	312358.7	6408152	140.07	-	Arties seam	11
CS4657-ULd	312358.7	6408152	165.7	-	Upper Liddell seam	13
CS4658-Bay	311860	6407656	54.2	-	Bayswater seam	4
CS4658-Brt	311860	6407656	239.25	-	Barrett seam	17
CS4658-LLd	311860	6407656	219.5	-	Lower Liddell	15
CS4658-LmA	311860	6407656	134.2	-	Lemington seam	6
CS4658-LmH	311860	6407656	91.86	-	Lemington seam	6
CS4658-UAr	311860	6407656	175.67	-	Arties seam	11
CS4658-ULd	311860	6407656	196.91	-	Upper Liddell	13
CS4658-UPG	311860	6407656	153.42	-	Upper Pikes Gully	9
DUR2	313488	6416643	-	161.4	Liddell seams	14

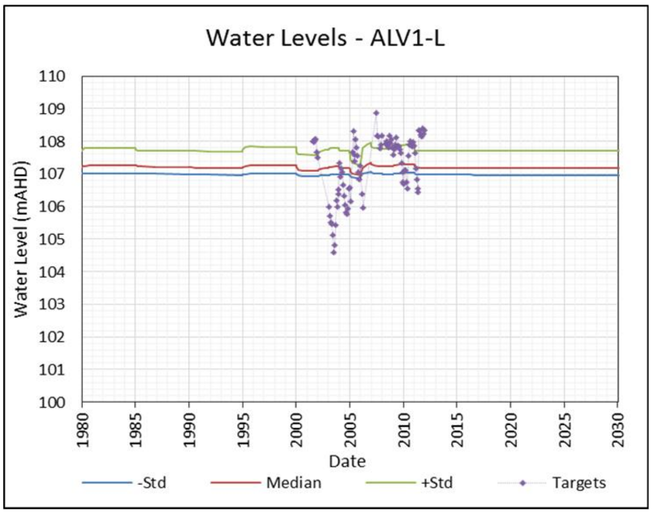
Bore I.D	Easting	Northing	Total depth (mbgl)	Collar elevation (mAHD)	Sampled unit	Model layer
CDB	312953	6413510	-	-	Liddell seams	13
GNP1-Art	318491.9	6408641	112	-	Arties seam	11
GNP1-Brt	318491.9	6408641	186	-	Barrett seam	17
GNP1-Heb	318491.9	6408641	212	-	Hebden seam	19
GNP1-LLd	318491.9	6408641	170	-	Lower Liddell	15
GNP1-MLd	318491.9	6408641	153	-	Middle Liddell	14
GNP1-PG	318491.9	6408641	90	-	Pikes Gully	9
GNP1-ULd	318491.9	6408641	142	-	Upper Liddell	13
GNP2-Art	317563.6	6410220	139	-	Arties	11
GNP2-Bar	317563.6	6410220	228	-	Barrett	17
GNP2-Heb	317563.6	6410220	254	-	Hebden	19
GNP2-LLd	317563.6	6410220	211	-	Lower Liddell	15
GNP2-MLd	317563.6	6410220	190	-	Middle Liddell	14
GNP2-PG	317563.6	6410220	119	-	Pikes Gully	9
GNP2-ULd	317563.6	6410220	185	-	Upper Liddell	13
GNP3-Art	316945.5	6411691	129	-	Arties	11
GNP3-Brt	316945.5	6411691	201	-	Barrett	17
GNP3-Heb	316945.5	6411691	222	-	Hebden	19
GNP3-LLd	316945.5	6411691	182.5	-	Lower Liddell	15
GNP3-MLd	316945.5	6411691	163.5	-	Middle Liddell	14
GNP3-PG	316945.5	6411691	108.5	-	Pikes Gully	9
GNP3-ULd	316945.5	6411691	148.5	-	Upper Liddell	13
GNP4-Art	316930.7	6412932	160	-	Arties	11
GNP4-Brt	316930.7	6412932	238	-	Barrett	17
GNP4-Heb	316930.7	6412932	254	-	Hebden	19
GNP4-LLd	316930.7	6412932	222.8	-	Lower Liddell	15
GNP4-MLd	316930.7	6412932	198	-	Middle Liddell	14
GNP4-PG	316930.7	6412932	145	-	Pikes Gully	9
GNP4-ULd	316930.7	6412932	180	-	Upper Liddell	13
GNP5-Art	317864.7	6409317	170	-	Arties	11
GNP5-Bar	317864.7	6409317	250	-	Barrett	17
GNP5-Heb	317864.7	6409317	272.5	-	Hebden	19
GNP5-Int	317864.7	6409317	40	-	Interburden	3
GNP5-LLd	317864.7	6409317	234	-	Lower Liddell	15
GNP5-MLd	317864.7	6409317	215	-	Middle Liddell	14
GNP5-PG	317864.7	6409317	148	-	Pikes Gully	9
GNP5-ULd	317864.7	6409317	202	-	Upper Liddell	13
GNP6-Art	317604.6	6411061	106	-	Arties	11
GNP6-Bar	317604.6	6411061	176	-	Barrett	17
GNP6-Heb	317604.6	6411061	201.5	-	Hebden	19
GNP6-LLd	317604.6	6411061	160	-	Lower Liddell	15

Bore I.D	Easting	Northing	Total depth (mbgl)	Collar elevation (mAHD)	Sampled unit	Model layer
GNP6-MLd	317604.6	6411061	145	-	Middle Liddell	14
GNP6-PG	317604.6	6411061	85	-	Pikes Gully	9
GNP6-ULd	317604.6	6411061	125	-	Upper Liddell	13
GNP7-Art	316530.7	6412452	147.2	-	Arties	11
GNP7-Brt	316530.7	6412452	220	-	Barrett	17
GNP7-Heb	316530.7	6412452	241	-	Hebden	19
GNP7-LLd	316530.7	6412452	203	-	Lower Liddell	15
GNP7-MLd	316530.7	6412452	191	-	Middle Liddell	14
GNP7-PG	316530.7	6412452	126	-	Pikes Gully	9
GNP7-ULd	316530.7	6412452	168.5	-	Upper Liddell	13
GNP8-Bar	319387.7	6407393	86.5	-	Barrett	17
GNP-Heb	319387.7	6407393	105.5	-	Hebden	19
GNP-LLd	319387.7	6407393	65	-	Lower Liddell	15
GNP-MLd	319387.7	6407393	46	-	Middle Liddell	14
GNP-ULd	319387.7	6407393	31	-	Upper Liddell	13
NPZ11-L	318059.4	6412639	102	-	Upper Pikes Gully	5
NPZ11-S	318059.4	6412639	61	-	Regolith	1
NPZ12-L	318440.4	6411519	97	-	Lower Pikes Gully	5
NPZ12-S	318440.4	6411519	48	-	Regolith	1
NPZ13-L	318302.4	6409556	134	-	Lower Liddell	7
NPZ13-S	318302.4	6409556	70	-	Lower Pikes Gully (regolith)	1
NPZ14-L	319470.6	6407093	91	-	Hebden seam	13
NPZ14-S	319470.6	6407093	51	-	Lower Liddell (regolith)	1
NPZ15-L	320784.3	6407934	130	-	Unknown	6
NPZ15-S	320784.3	6407934	59	-	Lemington seam (regolith)	1
NPZ16-L	318193.4	6409141	173	-	Upper Liddell	6
NPZ16-S	318184	6409127	60	-	Lemington seam (regolith)	1
NPZ6-L	322579.7	6410412	102	-	Ravensworth seam	3
NPZ6-S	314646.7	6409099	70	-	Regolith	1
NPZ1-Deep	313562.4	6404972	122	91.43	Lemington seam	6
NPZ1-Int	313562.4	6404972	91	91.43	Bayswater seam	4
NPZ2-Deep	313315.5	6405817	120	100.86	Lemington seam	6
NPZ3-Deep	312653.8	6406480	110	102.5	Lemington seam	6
NPZ4-Deep	311899.1	6406810	90	125.55	Lemington seam	6
RNVW1-Bay	313911	6403956	68	-	Bayswater seam	4
RNVW1-Brt	313911	6403956	326	-	Barrett seam	17
RNVW1-LLd	313911	6403956	270	-	Lower Liddell	15
RNVW1-LmA	313911	6403956	109	-	Lemington seam	6
RNVW1-LmH	313911	6403956	48	-	Lemington seam	6
RNVW1-UAr	313911	6403956	150	-	Arties seam	11

Bore I.D	Easting	Northing	Total depth (mbgl)	Collar elevation (mAHD)	Sampled unit	Model layer
RNVW1-ULd	313911	6403956	240	-	Upper Liddell	13
RNVW1-UPG	313911	6403956	190	-	Upper Pikes Gully	9
RNVW2-Brt	313433.9	6405372	305	-	Barrett seam	17
RNVW2-LLd	313433.9	6405372	258	-	Lower Liddell	15
RNVW2-LmA	313433.9	6405372	85	-	Lemington seam	6
RNVW2-LmH	313433.9	6405372	43	-	Lemington seam	6
RNVW2-UAr	313433.9	6405372	140	-	Arties seam	11
RNVW2-ULd	313433.9	6405372	239	-	Upper Liddell	13
RNVW2-UPG	313433.9	6405372	180	-	Upper Pikes Gully	9
RNVW3-Brt	312235.3	6406367	254	-	Barrett seam	17
RNVW3-LLd	312235.3	6406367	210	-	Lower Liddell	15
RNVW3-LmA	312235.3	6406367	61	-	Lemington seam	6
RNVW3-UAr	312235.3	6406367	103	-	Arties seam	11
RNVW3-ULd	312235.3	6406367	180	-	Upper Liddell	13
RNVW3-UPG	312235.3	6406367	143	-	Upper Pikes Gully	9
RNVW4-Brt	314086.9	6411002	225	-	Barrett seam	17
RNVW4-LLd	314086.9	6411002	200.5	-	Lower Liddell seam	15
RNVW4-UAr	314086.9	6411002	114	-	Arties seam	11
RNVW4-ULd	314086.9	6411002	163	-	Upper Liddell	13
RNVW4-UPG	314086.9	6411002	101.5	-	Upper Pikes Gully	9
SMCO02-BY3	322098.3	6410658	178	-	Bayswater	4
SMCO02-BY5	322098.3	6410658	188.5	-	Bayswater	4
SMCO02-int	322098.3	6410658	56	-	Interburden	3
SMCO02-RFL	322098.3	6410658	138	-	Ravensworth	3
SMCO02-RNL	322098.3	6410658	107	-	Ravensworth	3
SMCO02-RTU	322098.3	6410658	48	-	Ravensworth	3
SMO023-BY3	322088.1	6411418	208.5	-	Bayswater	4
SMO023-BY5	322088.1	6411418	215	-	Bayswater	4
SMO023-RFL	322088.1	6411418	180.5	-	Ravensworth	3
SMO023-RNL	322088.1	6411418	155.5	-	Ravensworth	3
SMO023-RTU	322088.1	6411418	84	-	Ravensworth	3
SMO023-RVU	322088.1	6411418	59	-	Ravensworth	3
SMO028-Bay	323345.7	6411410	20	-	Bayswater	4
SMO028-LBA	323345.7	6411410	128.5	-	Lemington	6
SMO028-LBG	323345.7	6411410	109.5	-	Lemington	6
SMO028-LBJ	323345.7	6411410	100	-	Lemington	6
SMO028-LCF	323345.7	6411410	77.2	-	Lemington	6
SMO028-LDF	323345.7	6411410	42.5	-	Lemington	6
SDH18	313459.7	6410603	-	82.64	Liddell seam	13
SDH16	313459.7	6410603	-	96.9	Lower Pikes Gully	9
GA1	318378.8	6408259	-	-	Regolith	1

Bore I.D	Easting	Northing	Total depth (mbgl)	Collar elevation (mAHD)	Sampled unit	Model layer
GA2	318578.1	6407367	-	-	Regolith	1
GCP17	323803	6409986	7.5	-	Regolith	1
GCP24	323421	6407105	48	-	Regolith	1
GCP27	323197	6406037	37.5	-	Regolith	1

C.1 Calibration hydrographs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Date
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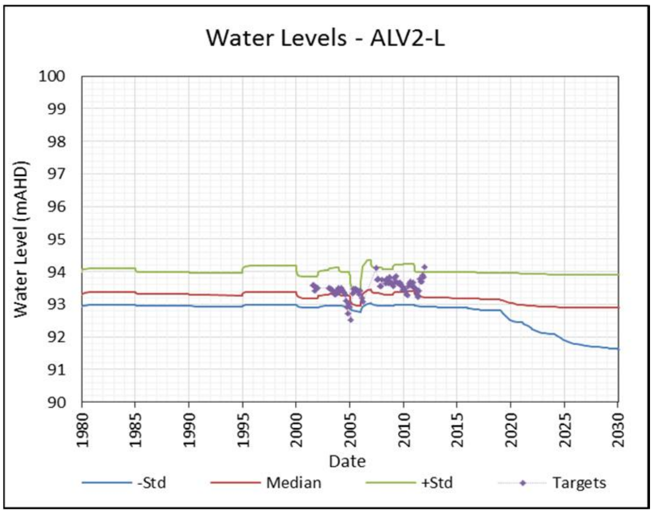
Median
+Std
Targets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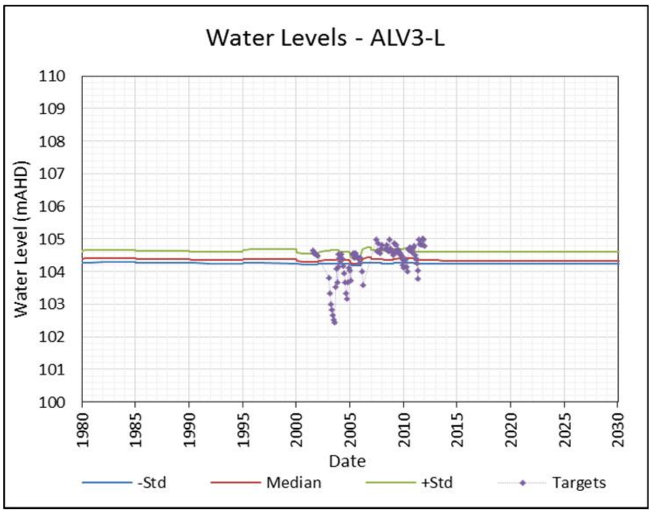
Median
+Std
Targets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Median
+Std
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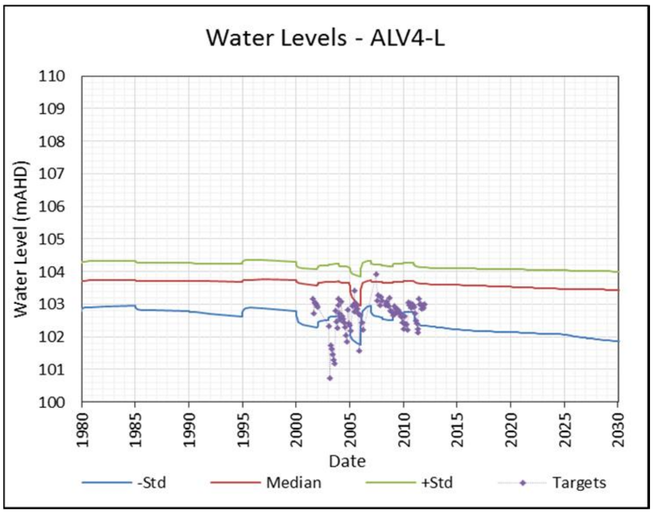
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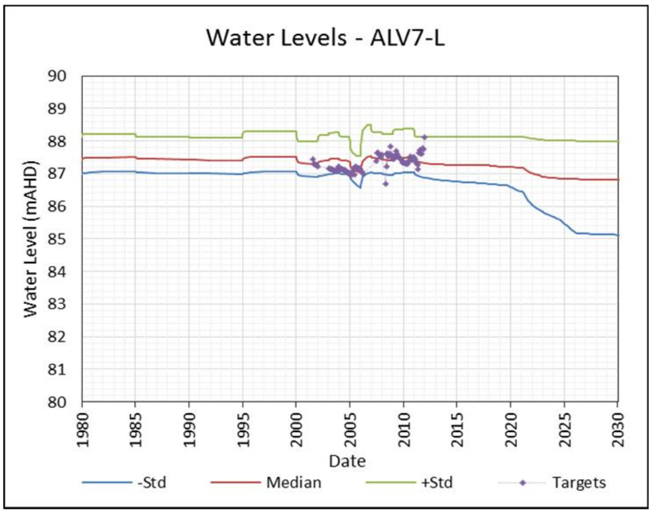
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Median
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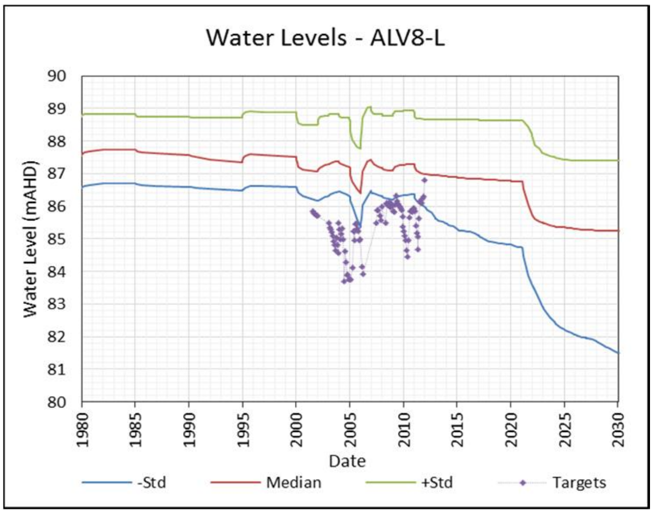
Targets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Water Level (mAHD)
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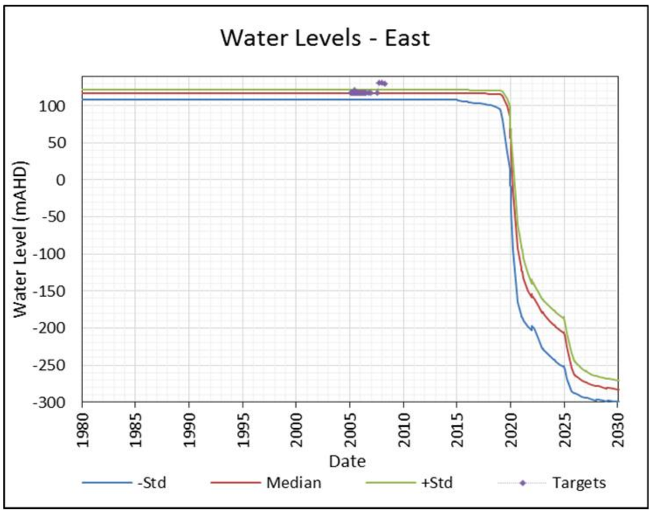
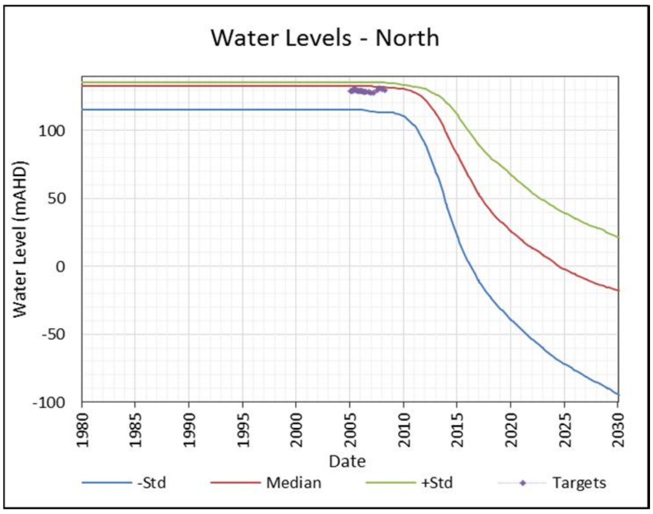
Median
+Std
Targets


Water Levels - East
Water Level (mAHD)
100
50
0
-50
-100
-150
-200
-250
-300
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - North
Water Level (mAHD)
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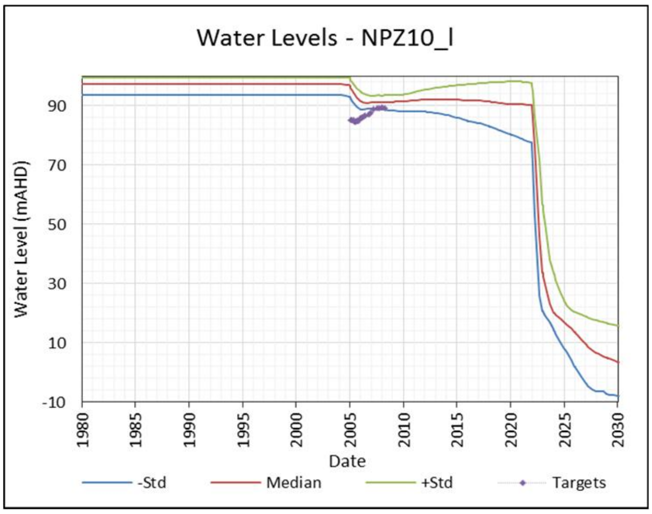
50
0
-50
-100
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - NPZ10_l
Water Level (mAHD)
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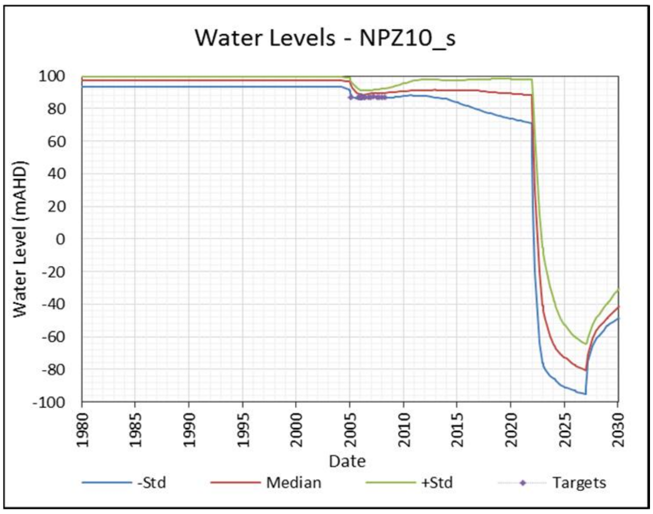
70
50
30
10
-10
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets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Water Level (mAHD)
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60
40
20
0
-20
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-60
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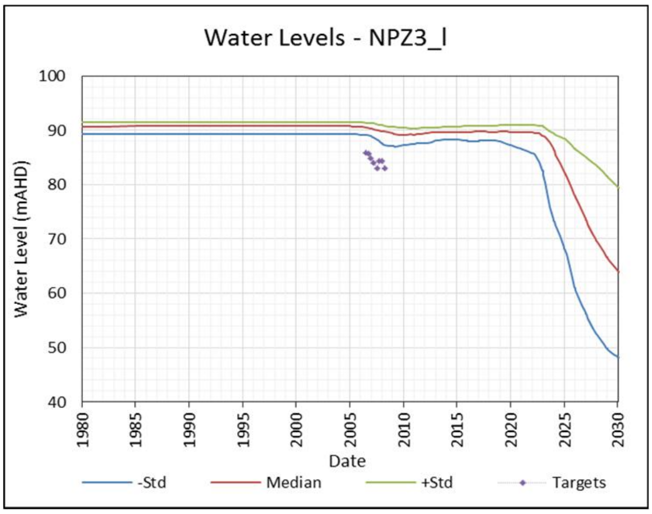
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets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Water Level (mAHD)
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70
60
50
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1990
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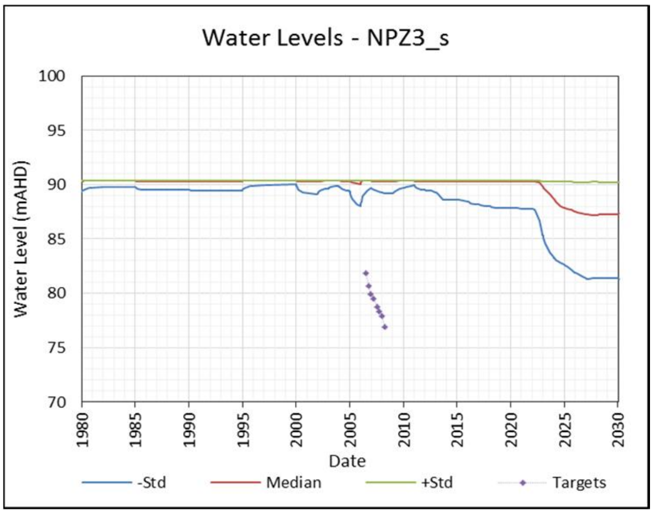
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets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85
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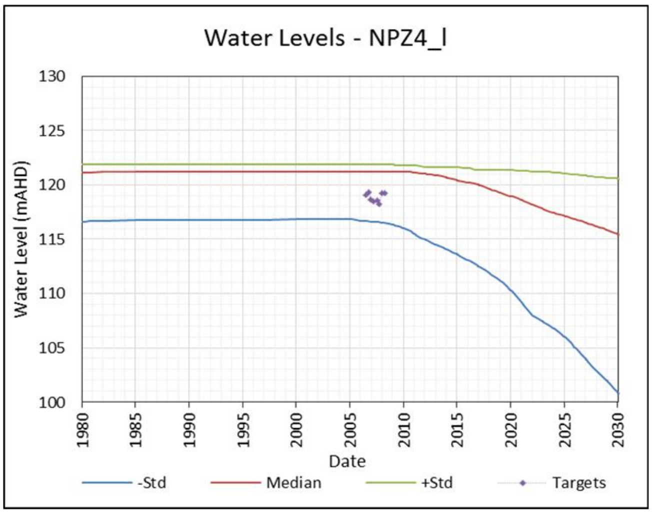
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets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125
120
115
110
105
100
Water Level (mAHD)
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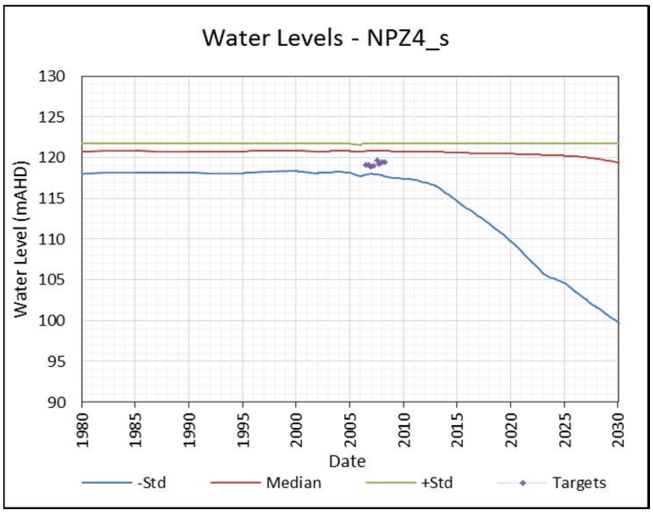
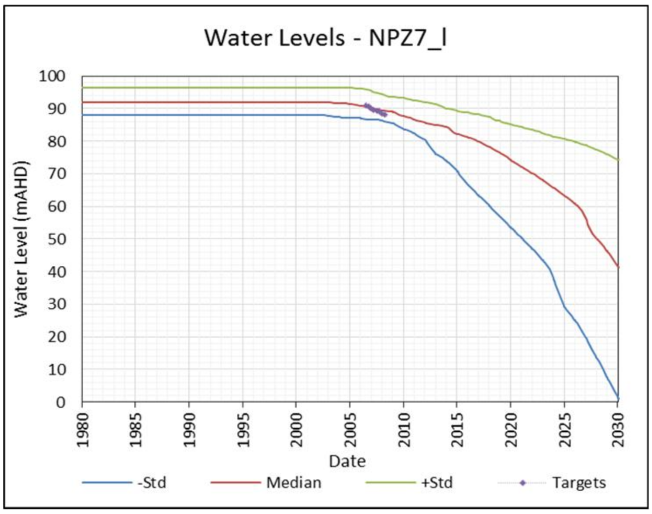
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - NPZ4_s
130
125
120
115
110
105
100
95
90
Water Level (mAHD)
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets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90
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70
60
50
40
30
20
10
0
Water Level (mAHD)
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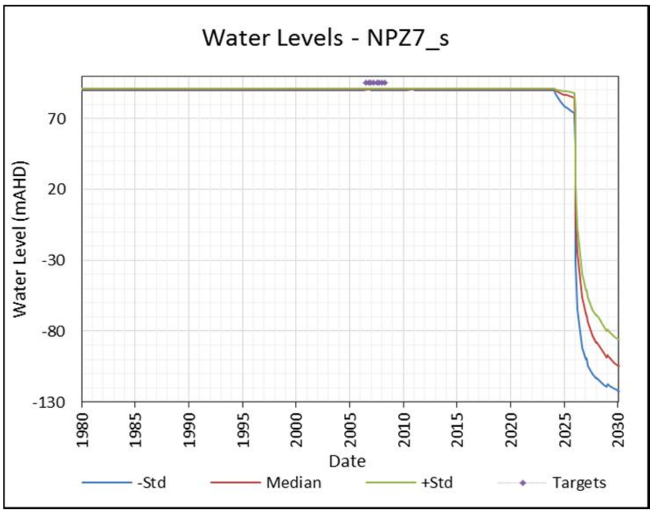
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - NPZ7_s
70
20
-30
-80
-130
Water Level (mAHD)
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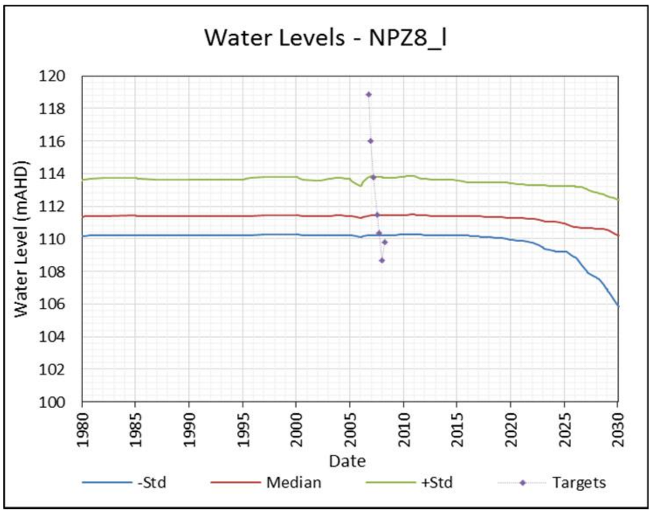
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - NPZ8_l
120
118
116
114
112
110
108
106
104
102
100
Water Level (mAHD)
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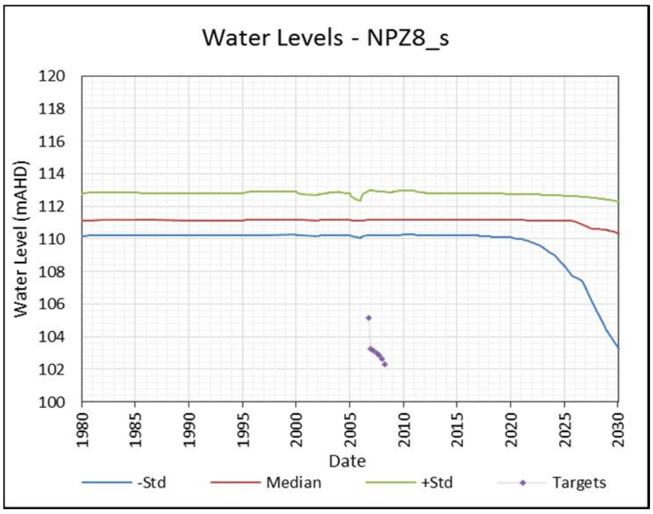
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - NPZ8_s
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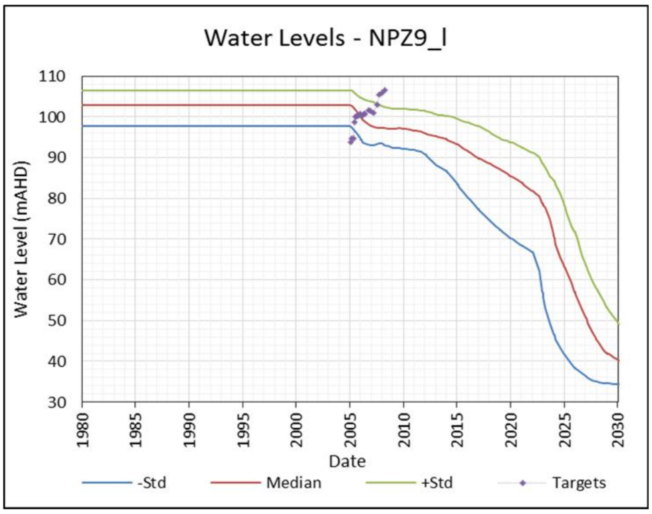
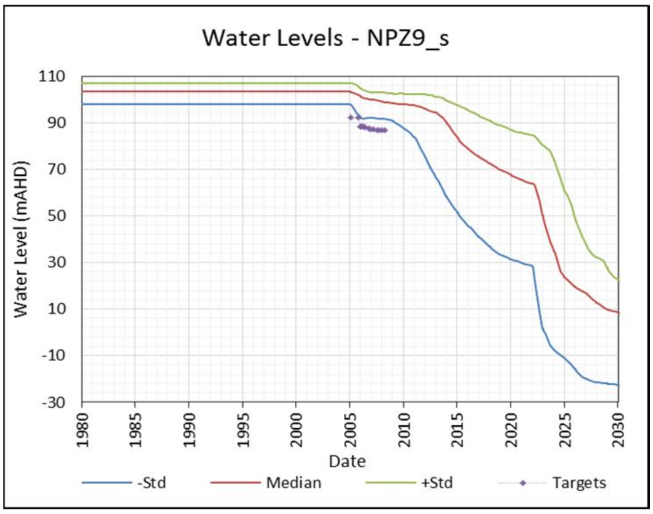
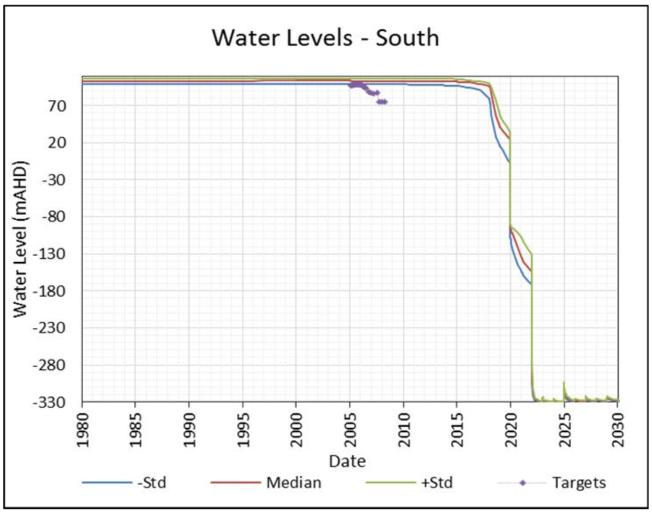
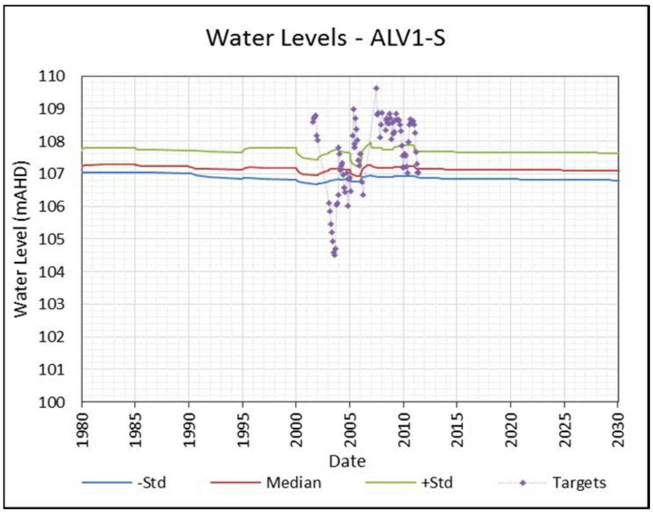
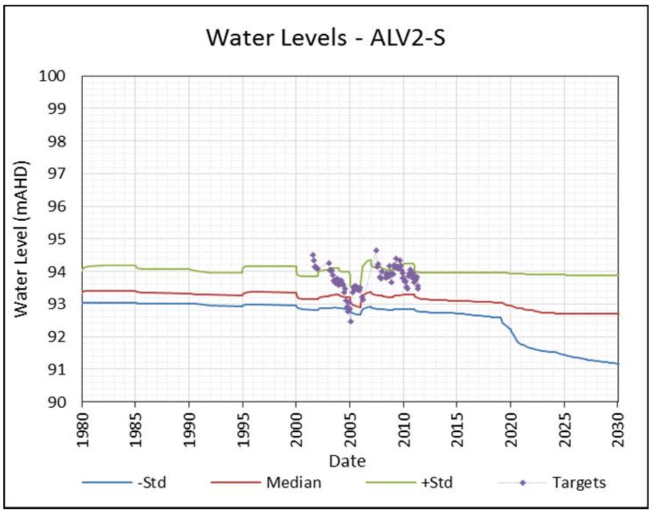
116
114
112
110
108
106
104
102
100
Water Level (mAHD)
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - NPZ9_l
Water Level (mAHD)
Date
-Std
Median
+Std
Targets


Water Levels - NPZ9_s
Water Level (mAHD)
Date
-Std
Median
+Std
Targets


Water Levels - South
Water Level (mAHD)
Date
-Std
Median
+Std
Targets


Water Levels - ALV1-S
Water Level (mAHD)
Date
-Std
Median
+Std
Targets


Water Levels - ALV2-S
Water Level (mAHD)
Date
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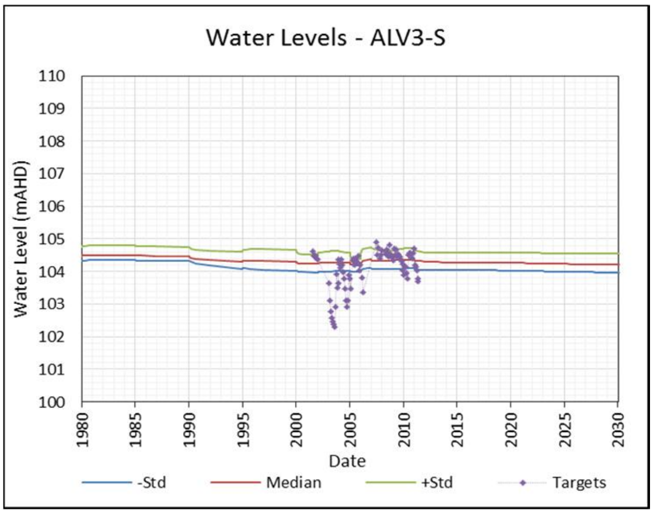
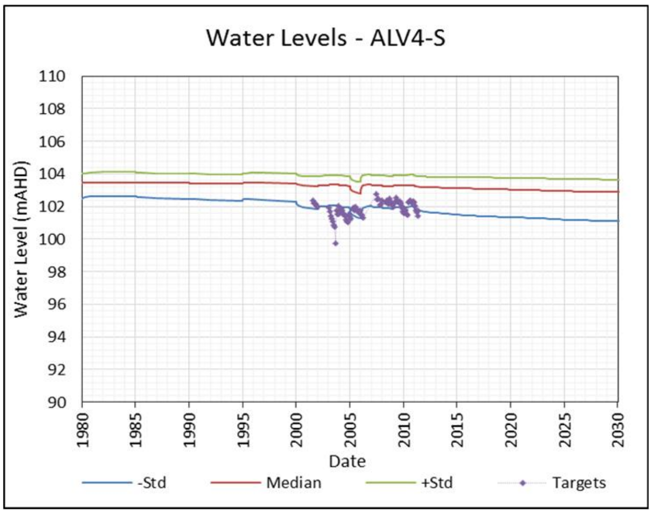
Median
+Std
Targets


Water Levels - ALV3-S
Water Level (mAHD)
Date
-Std
Median
+Std
Targets


Water Levels - ALV4-S
Water Level (mAHD)
110
108
106
104
102
100
98
96
94
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1995
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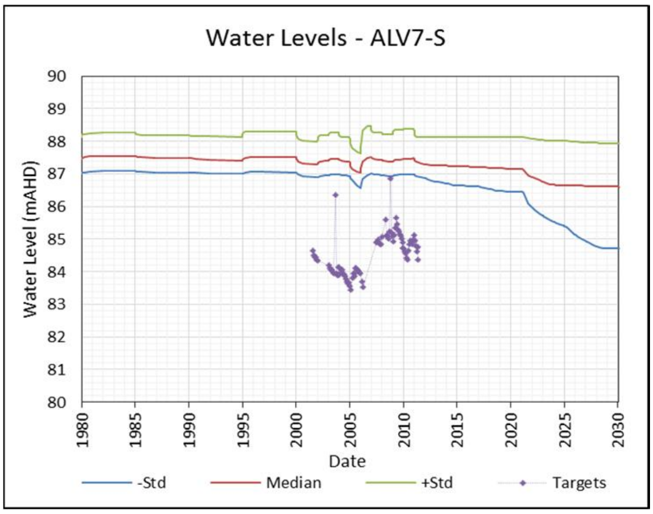
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - ALV7-S
Water Level (mAHD)
90
89
88
87
86
85
84
83
82
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1995
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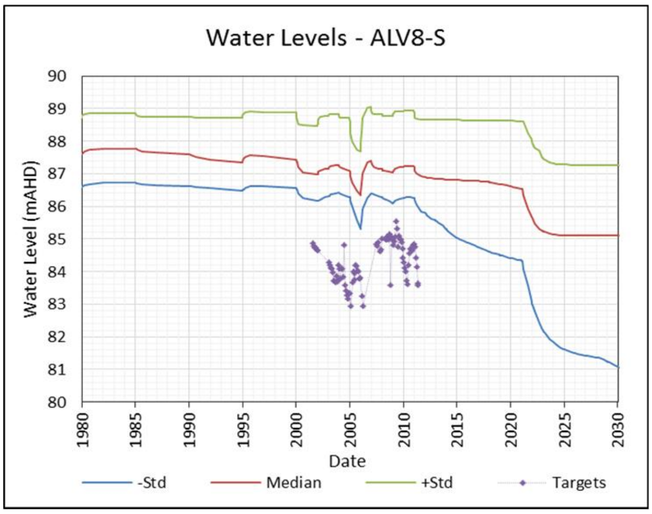
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - ALV8-S
Water Level (mAHD)
90
89
88
87
86
85
84
83
82
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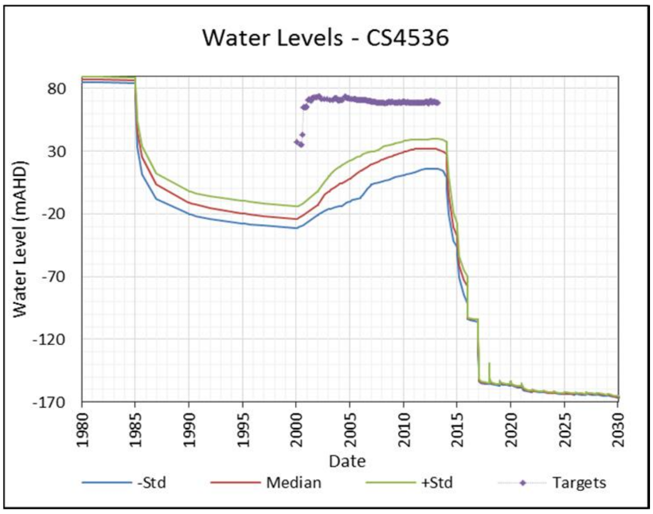
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4536
Water Level (mAHD)
80
30
-20
-70
-120
-170
1980
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1995
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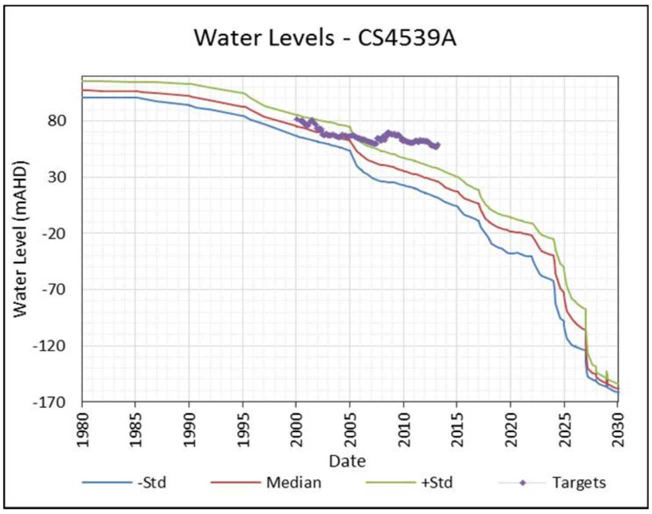
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4539A
Water Level (mAHD)
80
30
-20
-70
-120
-170
1980
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1990
1995
2000
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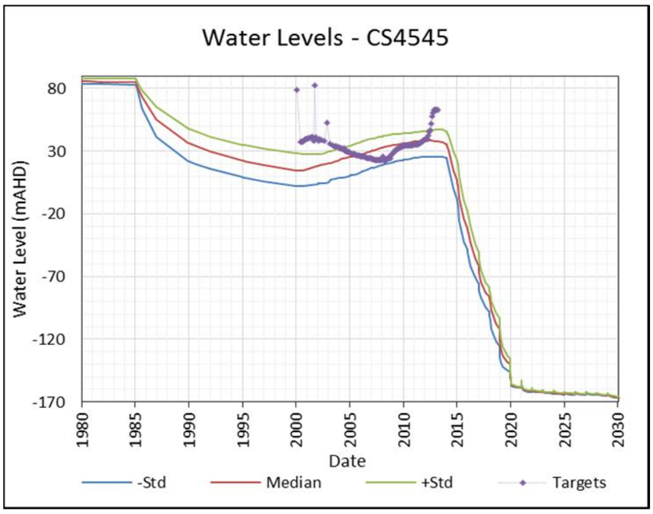
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4545
Water Level (mAHD)
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-70
-120
-170
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1995
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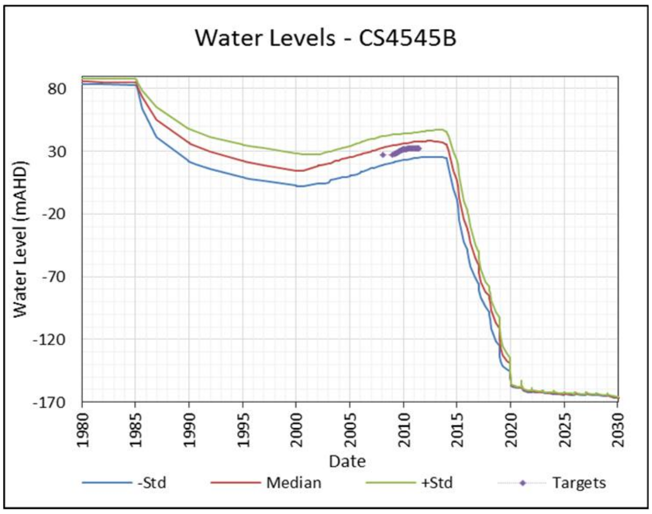
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4545B
Water Level (mAHD)
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-20
-70
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2020
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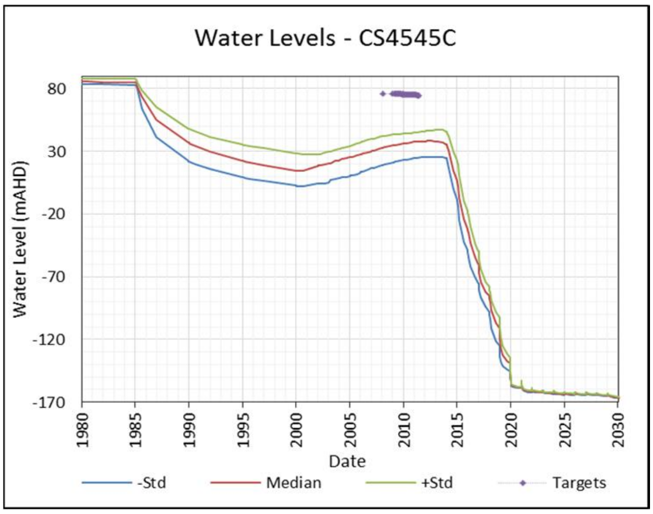
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4545C
Water Level (mAHD)
80
30
-20
-70
-120
-170
1980
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1990
1995
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2010
2015
2020
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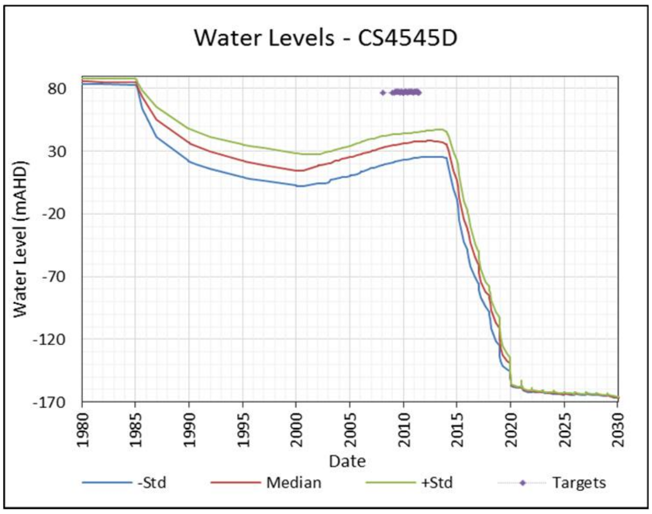
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4545D
Water Level (mAHD)
80
30
-20
-70
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-170
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1990
1995
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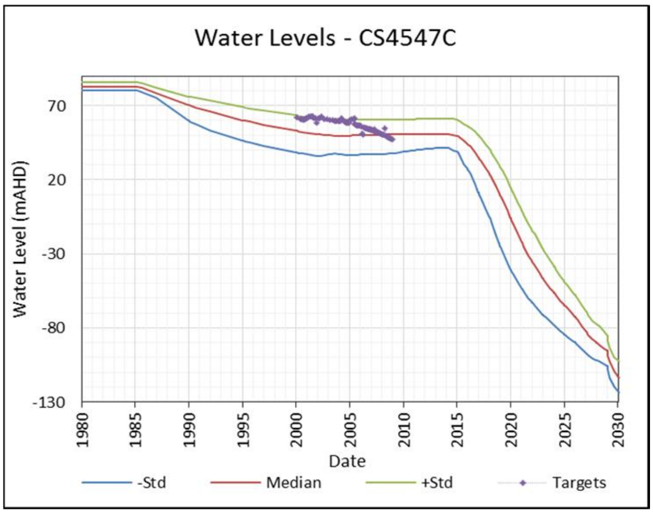
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4547C
Water Level (mAHD)
70
20
-30
-80
-130
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1985
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1995
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2005
2010
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2020
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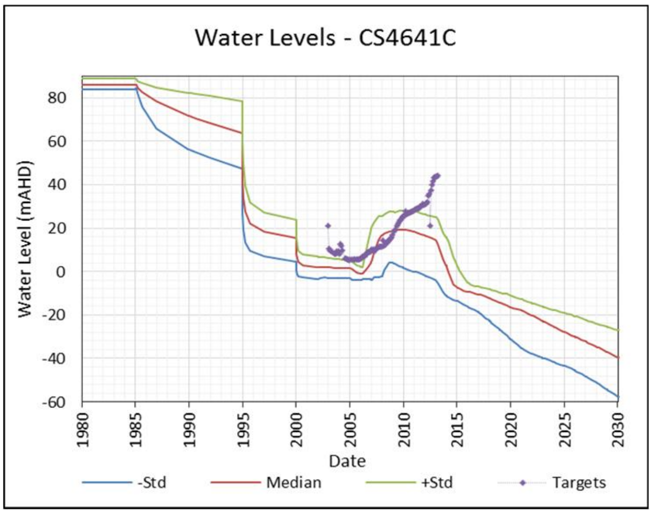
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4641C
Water Level (mAHD)
80
60
40
20
0
-20
-40
-60
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1990
1995
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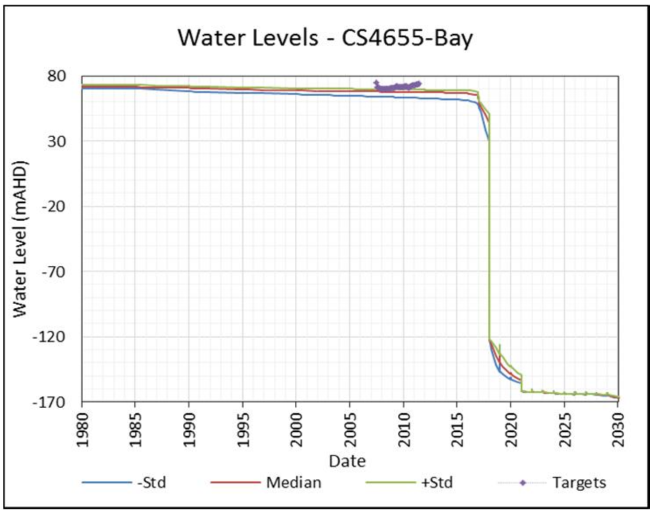
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4655-Bay
Water Level (mAHD)
80
30
-20
-70
-120
-170
1980
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1990
1995
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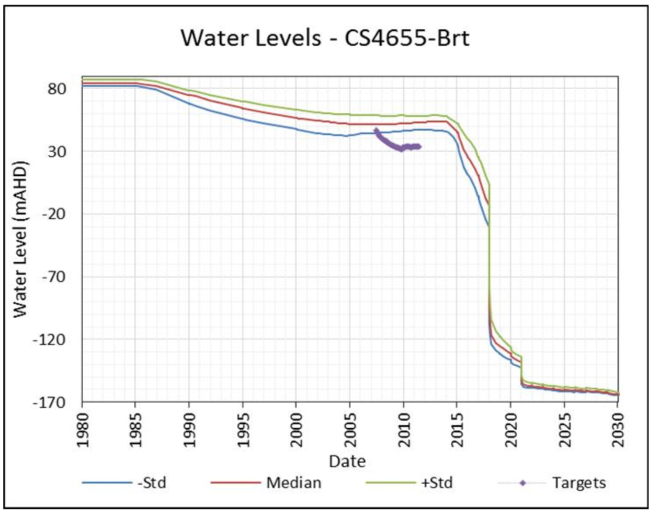
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4655-Brt
Water Level (mAHD)
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30
-20
-70
-120
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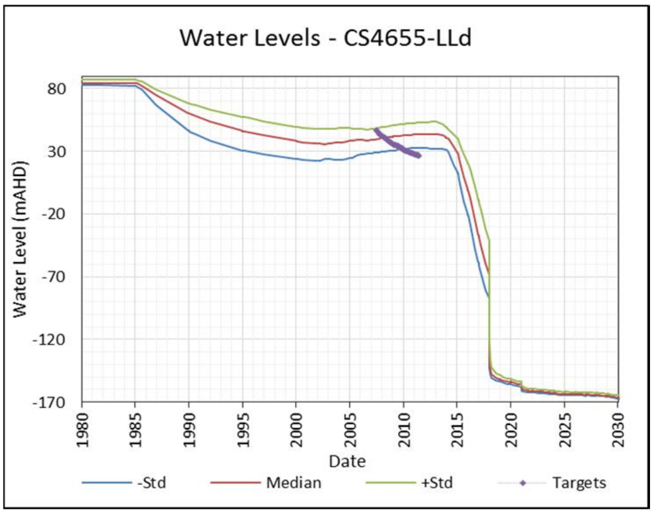
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4655-LLd
Water Level (mAHD)
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-20
-70
-120
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1995
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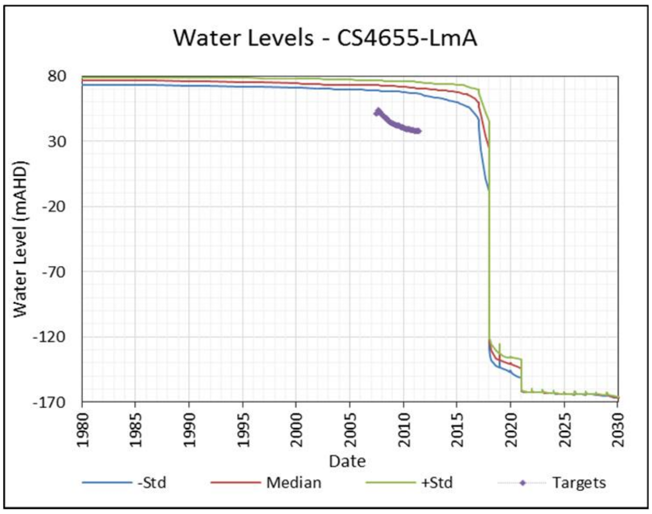
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4655-LmA
Water Level (mAHD)
80
30
-20
-70
-120
-170
1980
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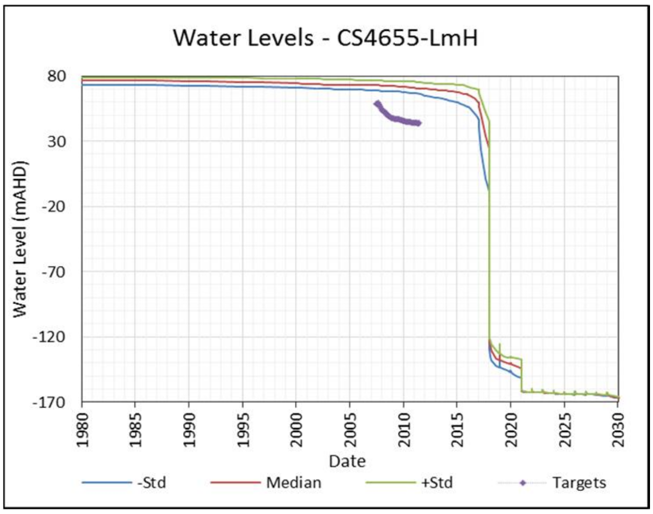
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4655-LmH
Water Level (mAHD)
80
30
-20
-70
-120
-170
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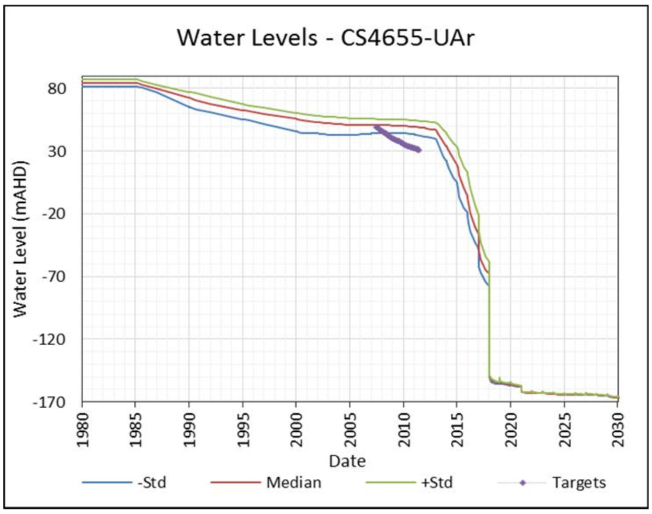
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4655-UAr
Water Level (mAHD)
80
30
-20
-70
-120
-170
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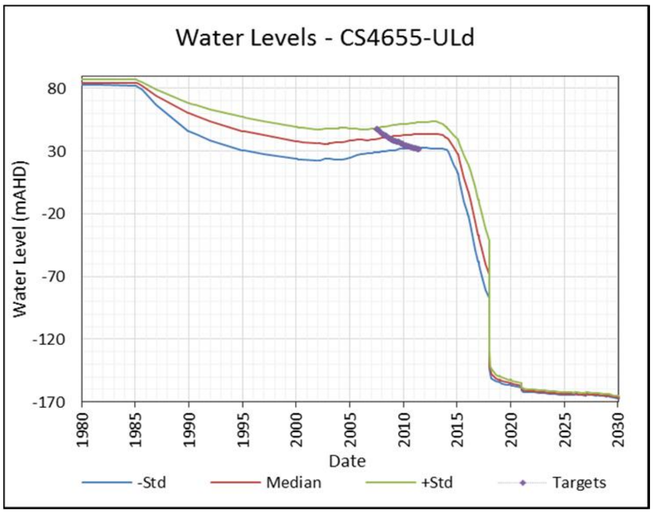
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4655-ULd
Water Level (mAHD)
80
30
-20
-70
-120
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2020
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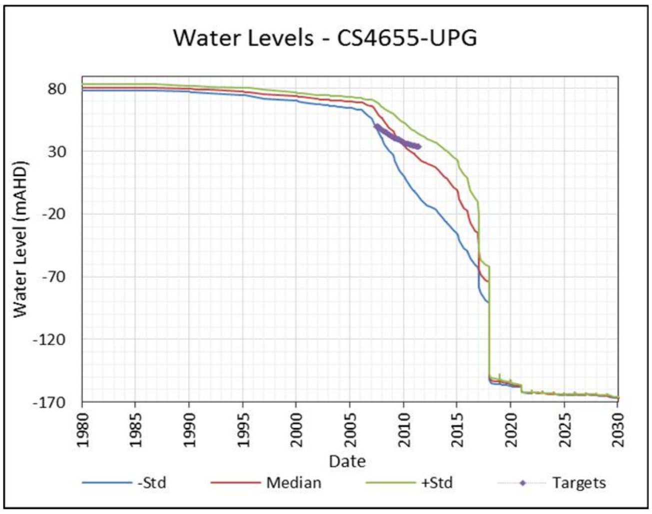
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4655-UPG
Water Level (mAHD)
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-20
-70
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2020
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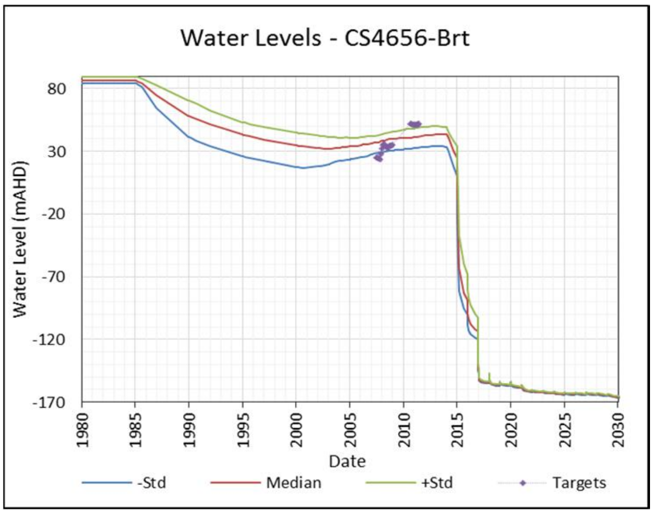
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4656-Brt
Water Level (mAHD)
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30
-20
-70
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2010
2015
2020
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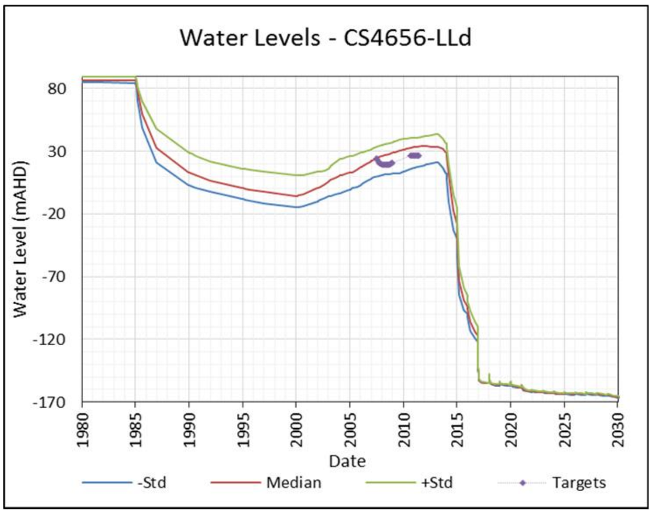
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4656-LLd
Water Level (mAHD)
80
30
-20
-70
-120
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2010
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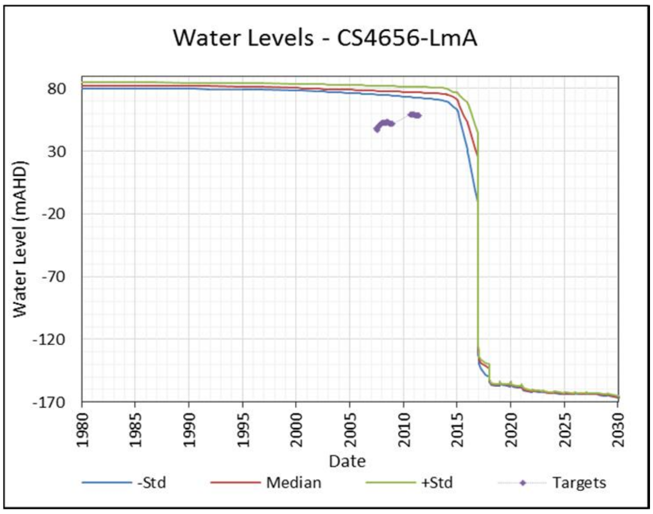
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4656-LmA
Water Level (mAHD)
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2020
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2030
Date
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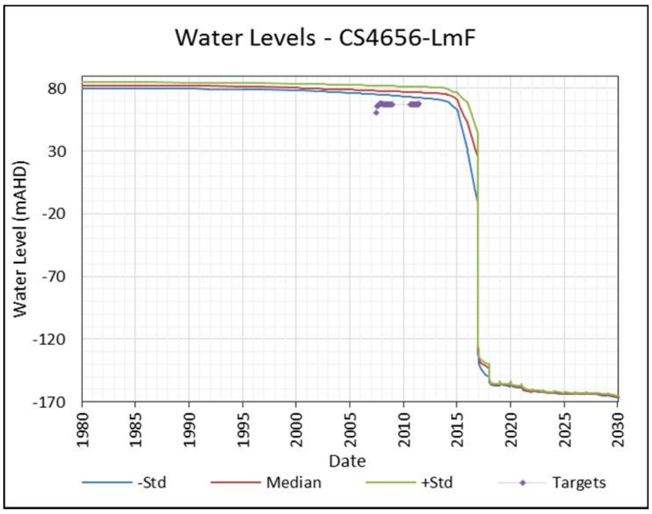
Median
+Std
Targets


Water Levels - CS4656-LmF
Water Level (mAHD)
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-70
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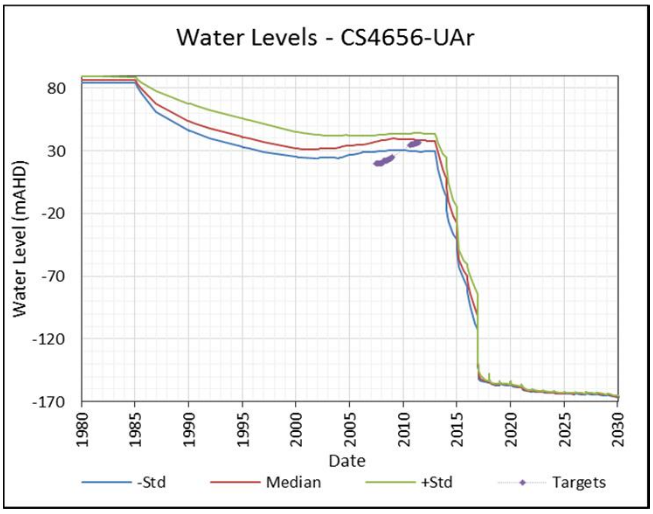
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4656-UAr
Water Level (mAHD)
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30
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-70
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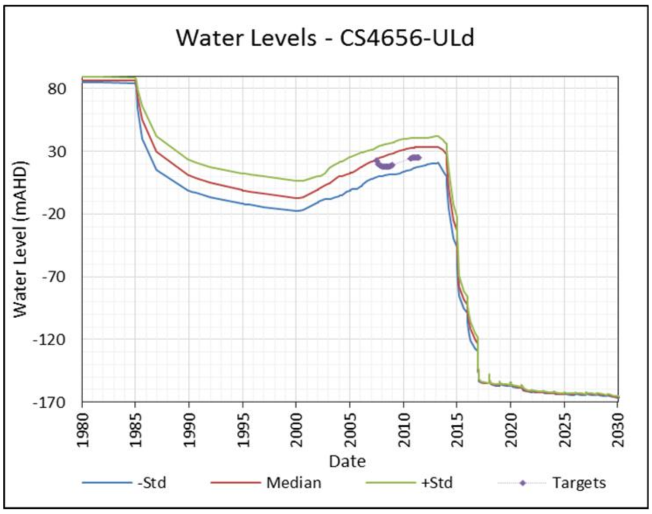
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4656-ULd
Water Level (mAHD)
Date
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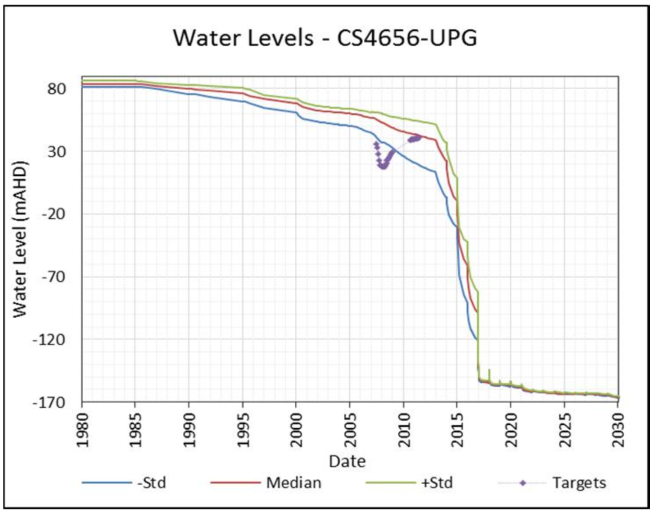
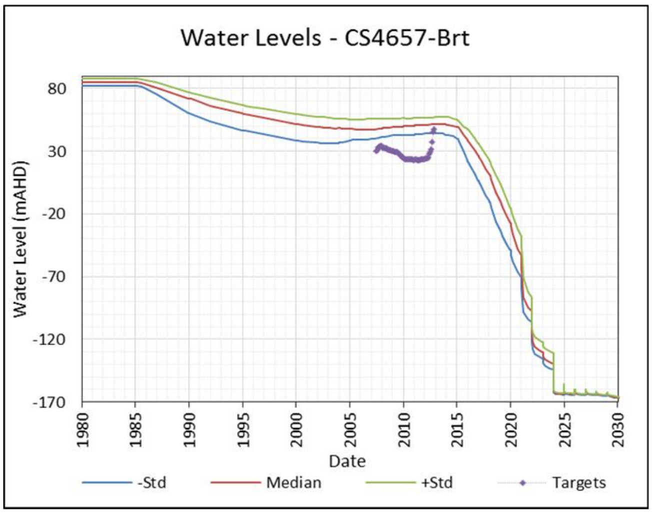
Median
+Std
Targets


Water Levels - CS4656-UPG
Water Level (mAHD)
Date
-Std
Median
+Std
Targets


Water Levels - CS4657-Brt
Water Level (mAHD)
Date
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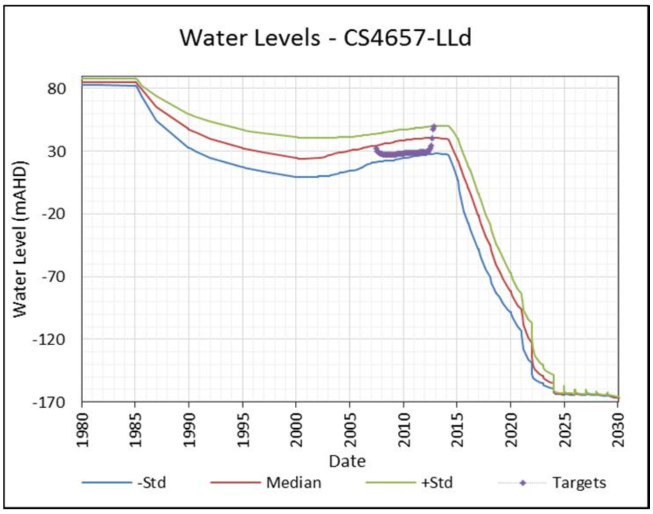
Median
+Std
Targets


Water Levels - CS4657-LLd
Water Level (mAHD)
Date
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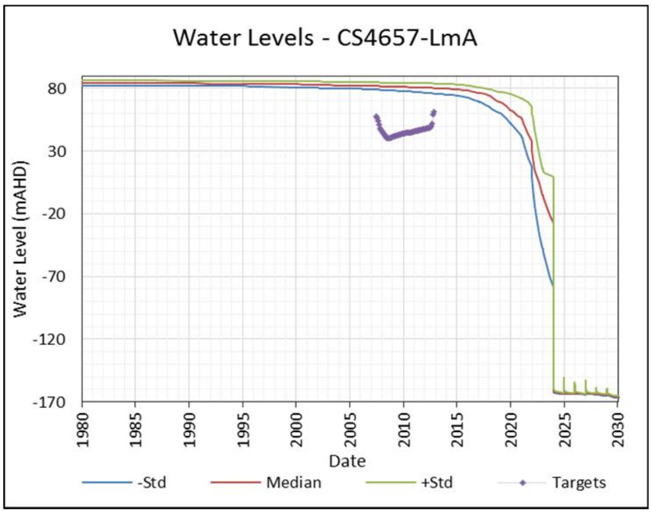
Median
+Std
Targets


Water Levels - CS4657-LmA
Water Level (mAHD)
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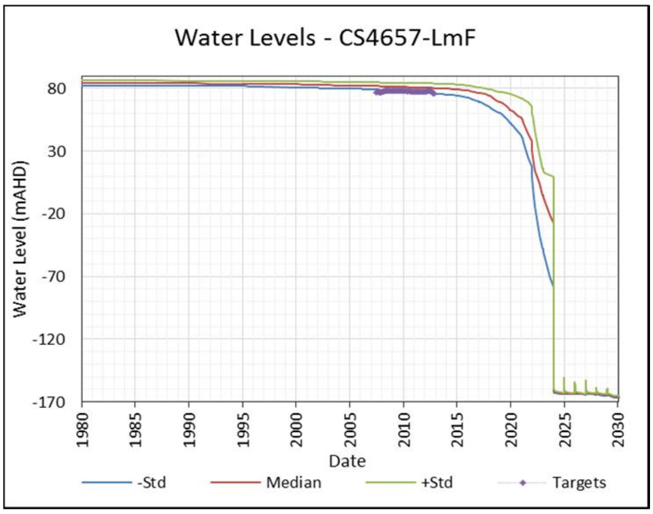
Median
+Std
Targets


Water Levels - CS4657-LmF
Water Level (mAHD)
Date
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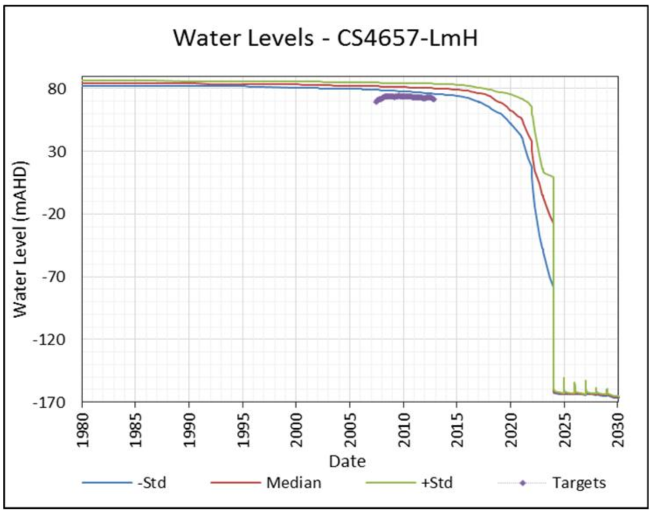
Median
+Std
Targets


Water Levels - CS4657-LmH
Water Level (mAHD)
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-70
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2000
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2010
2015
2020
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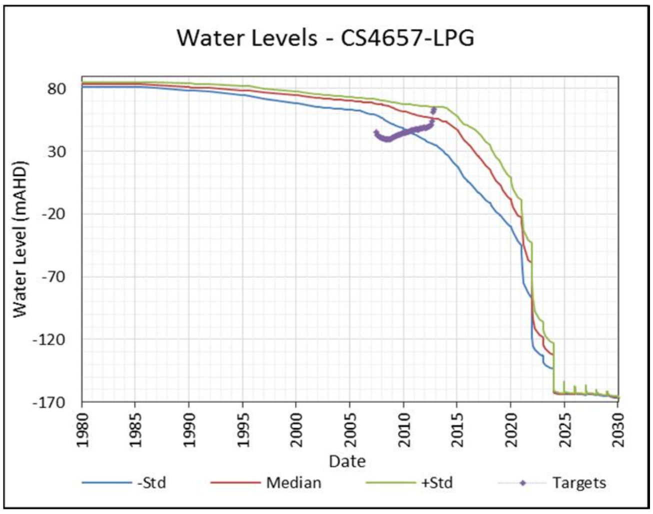
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4657-LPG
Water Level (mAHD)
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-20
-70
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2000
2005
2010
2015
2020
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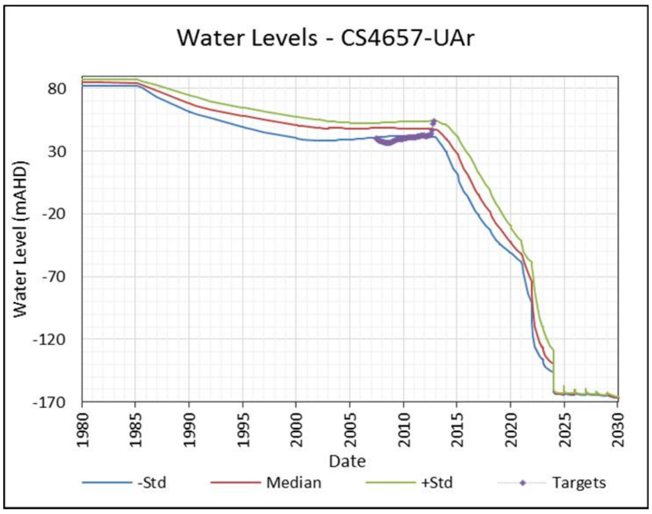
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4657-UAr
Water Level (mAHD)
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30
-20
-70
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2030
Date
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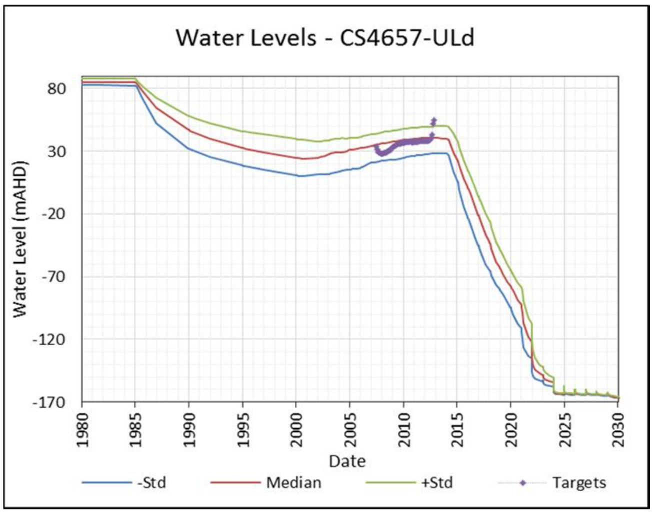
Median
+Std
Targets


Water Levels - CS4657-ULd
Water Level (mAHD)
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-20
-70
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2010
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2020
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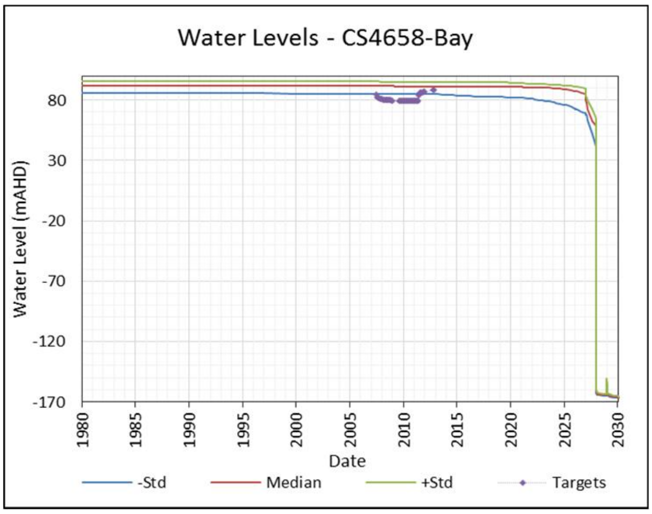
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4658-Bay
Water Level (mAHD)
80
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-20
-70
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-170
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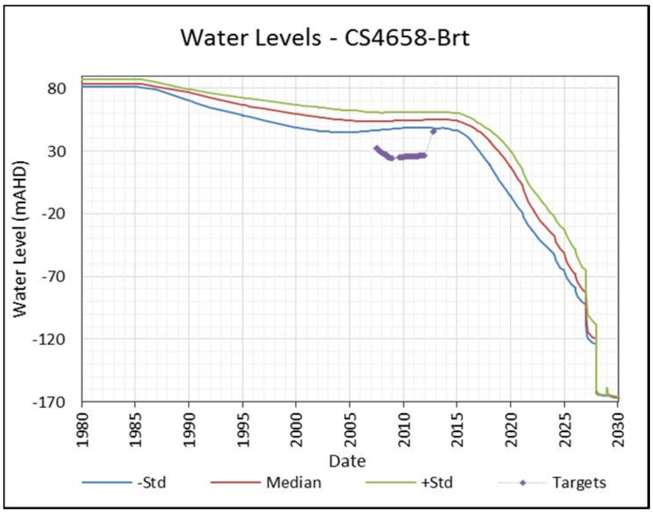
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4658-Brt
Water Level (mAHD)
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-20
-70
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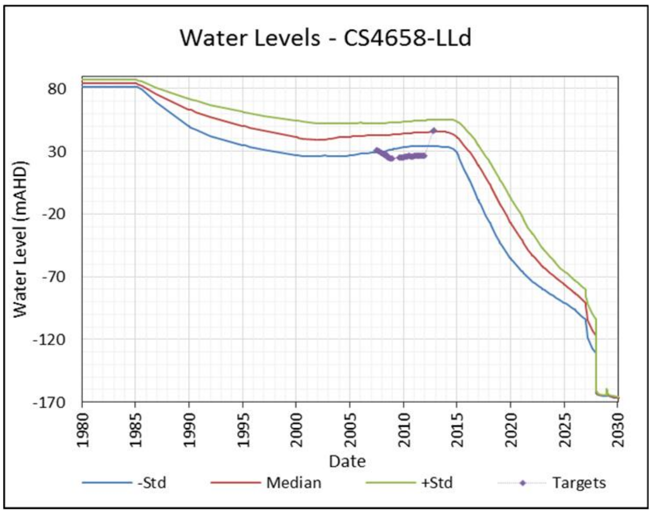
Date
-Std
Median
+Std
Targets


Water Levels - CS4658-LLd
Water Level (mAHD)
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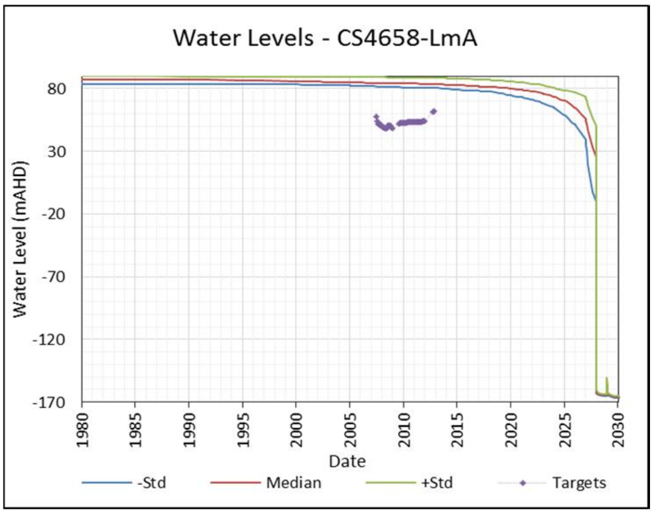
-70
-120
-170
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets


Water Levels - CS4658-LmA
Water Level (mAHD)
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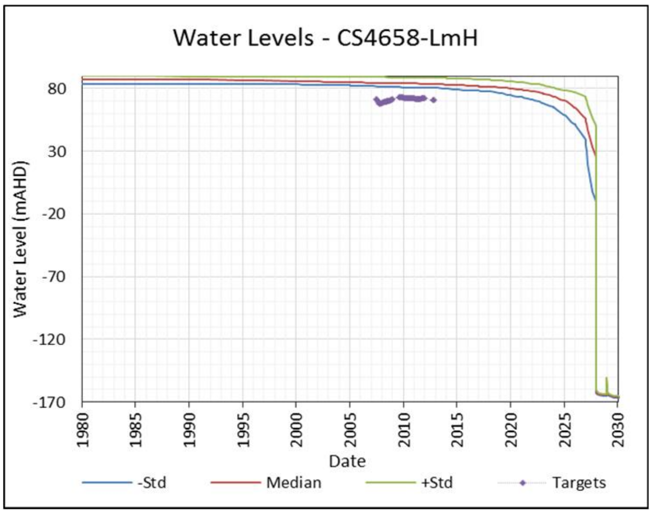
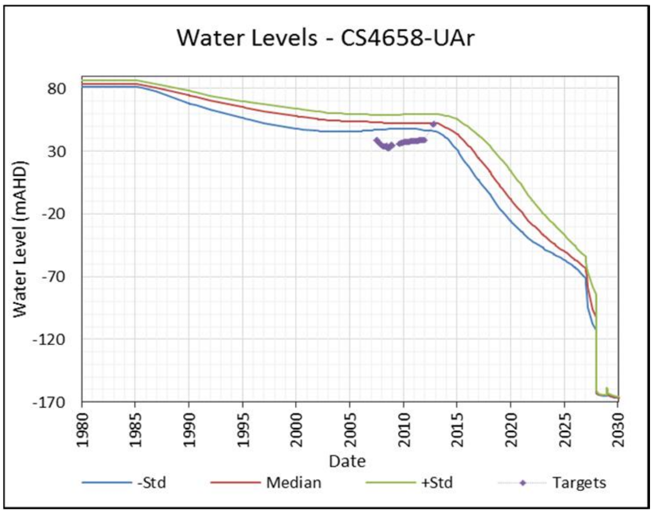
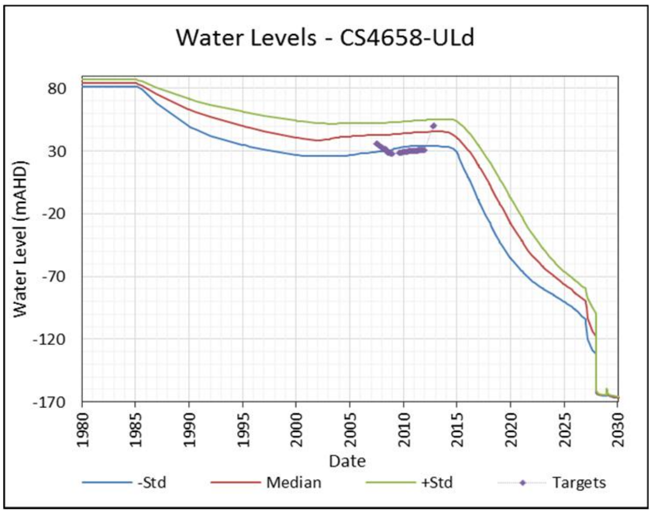
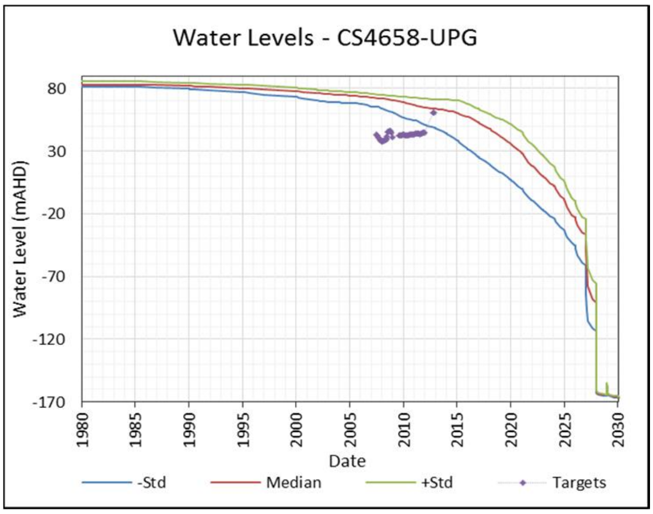
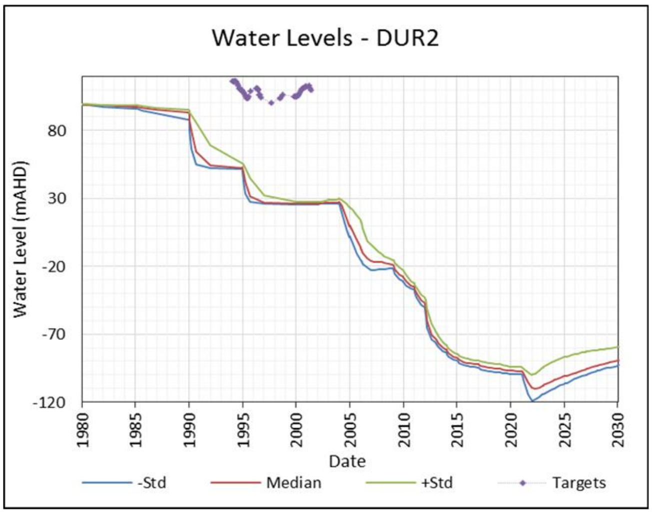
-20
-70
-120
-170
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

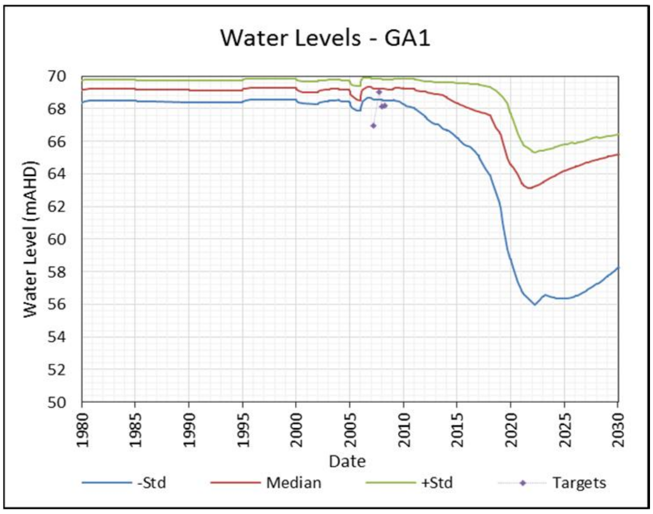

Water Levels - CS4658-LmH
Water Level (mAHD)
80
30
-20
-70
-120
-170
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

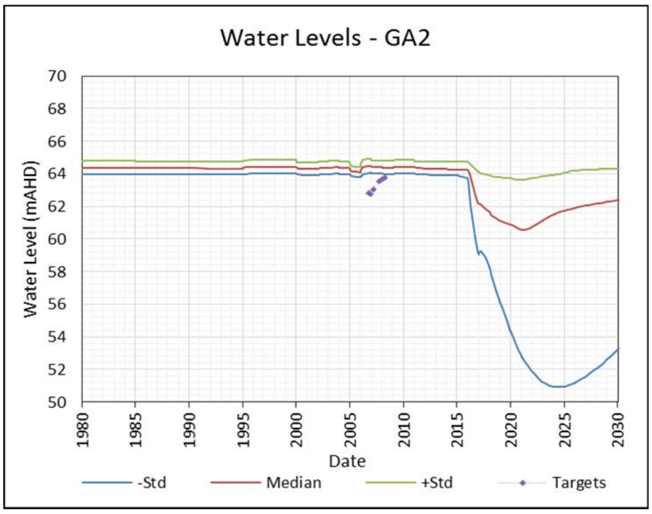

Water Levels - CS4658-UAr
Water Level (mAHD)
80
30
-20
-70
-120
-170
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

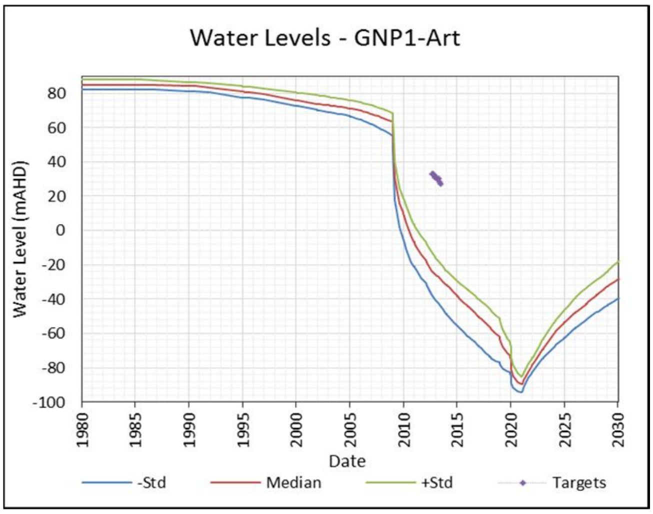

Water Levels - CS4658-ULd
Water Level (mAHD)
80
30
-20
-70
-120
-170
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

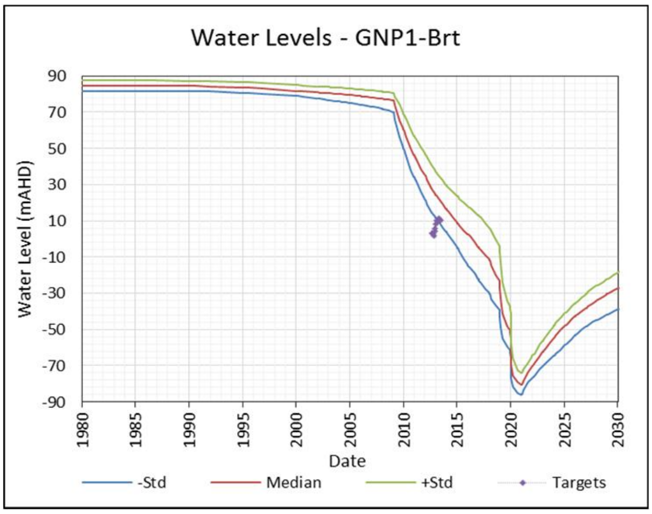

Water Levels - CS4658-UPG
Water Level (mAHD)
80
30
-20
-70
-120
-170
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

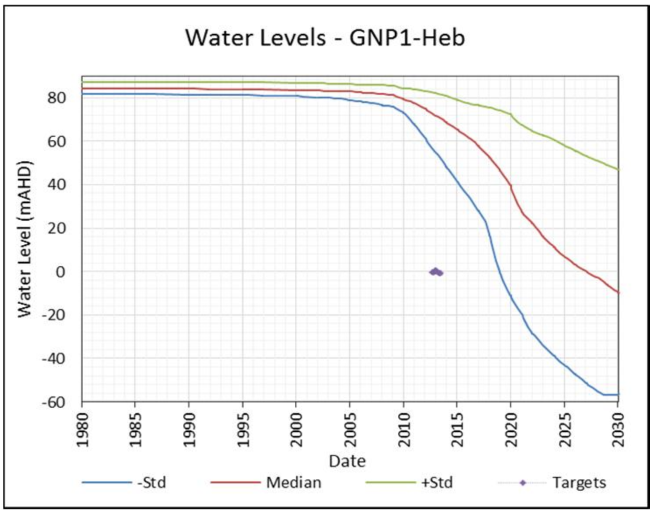

Water Levels - DUR2
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

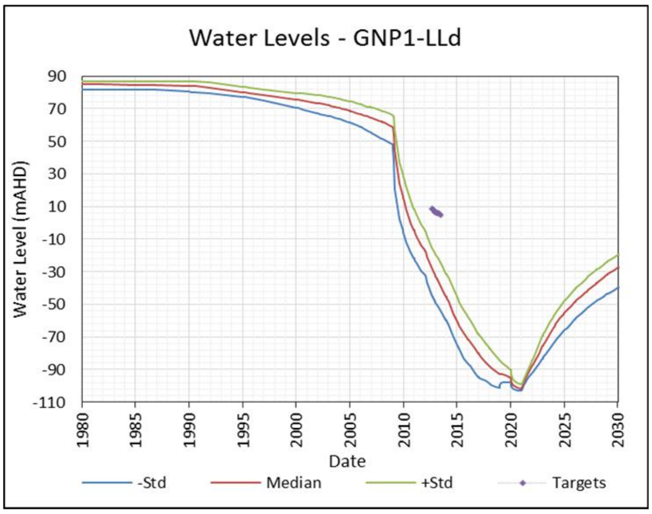

Water Levels - GA1
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

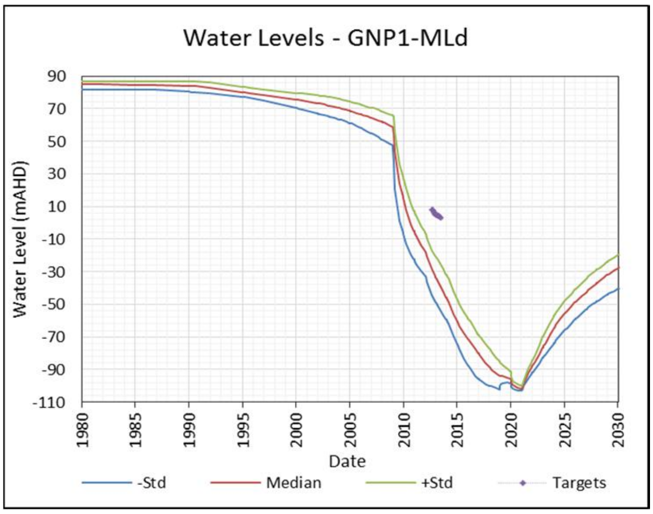

Water Levels - GA2
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

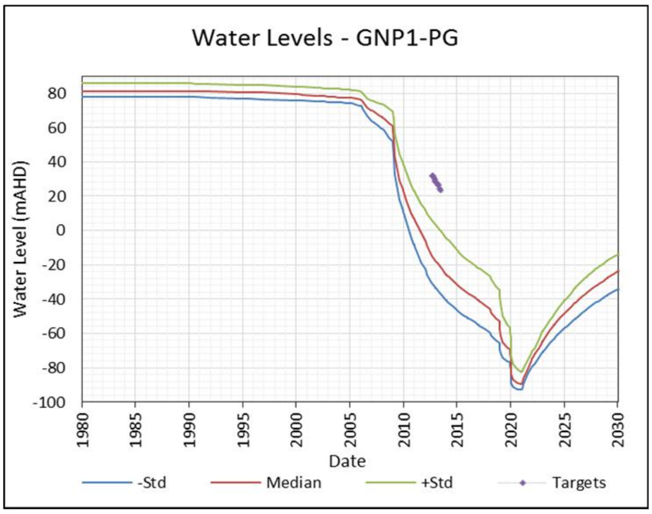

Water Levels - GNP1-Art
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

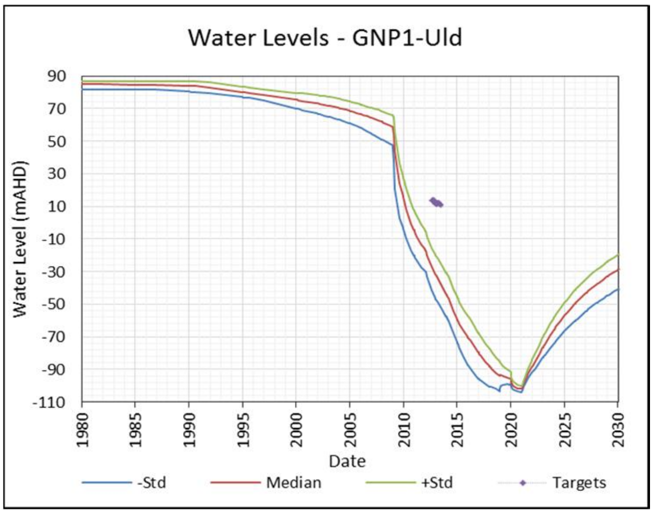

Water Levels - GNP1-Brt
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

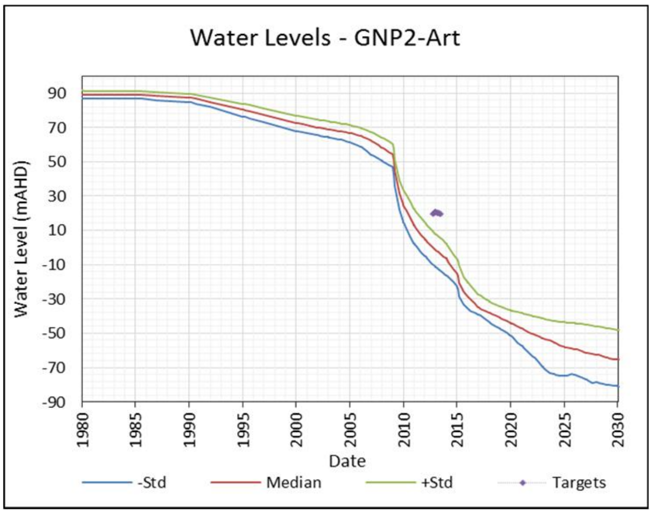

Water Levels - GNP1-Heb
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

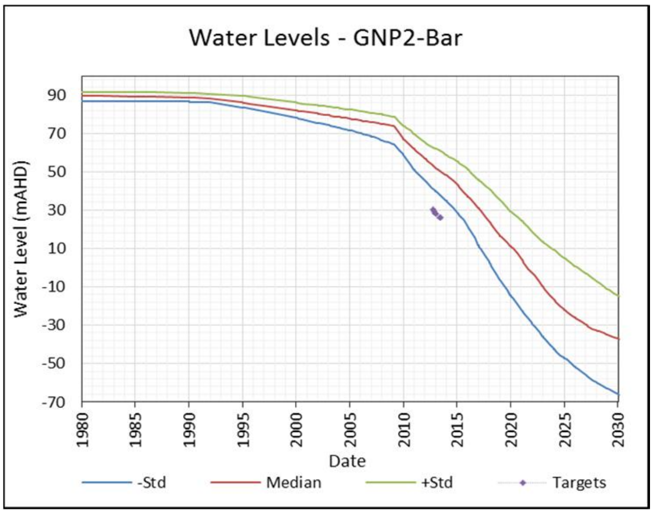

Water Levels - GNP1-LLd
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

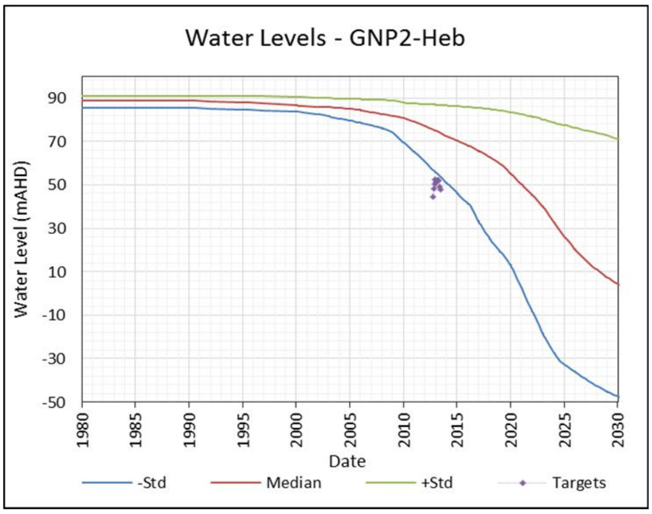

Water Levels - GNP1-MLd
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

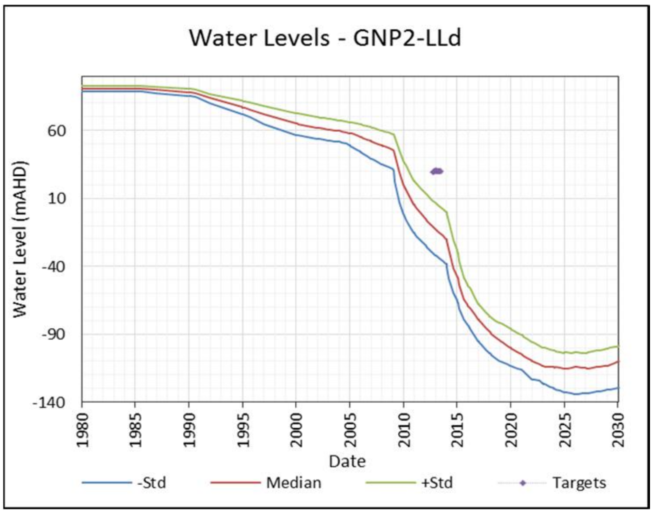

Water Levels - GNP1-PG
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

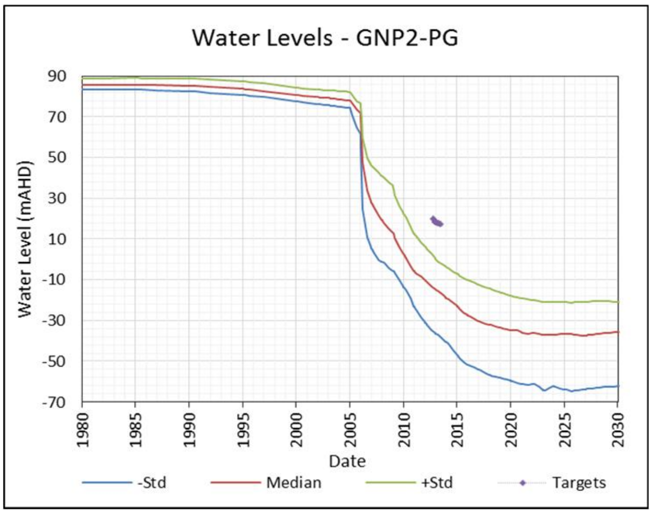

Water Levels - GNP1-Uld
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

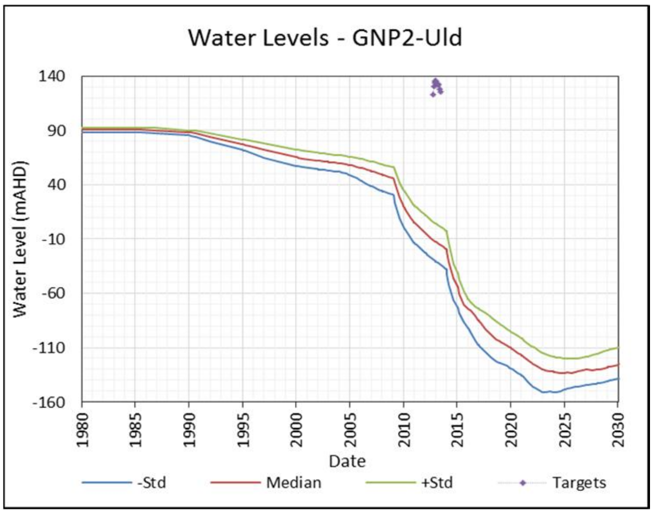

Water Levels - GNP2-Art
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

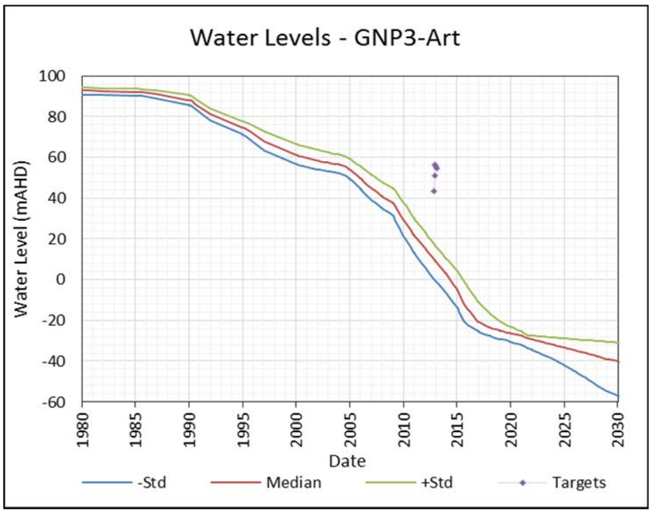

Water Levels - GNP2-Bar
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

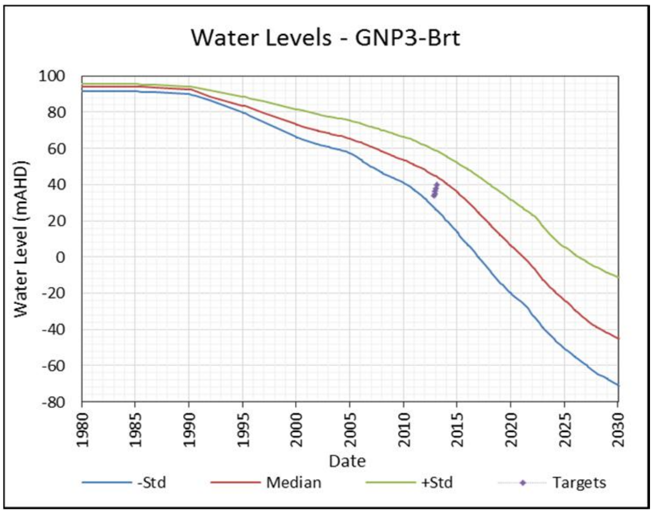

Water Levels - GNP2-Heb
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

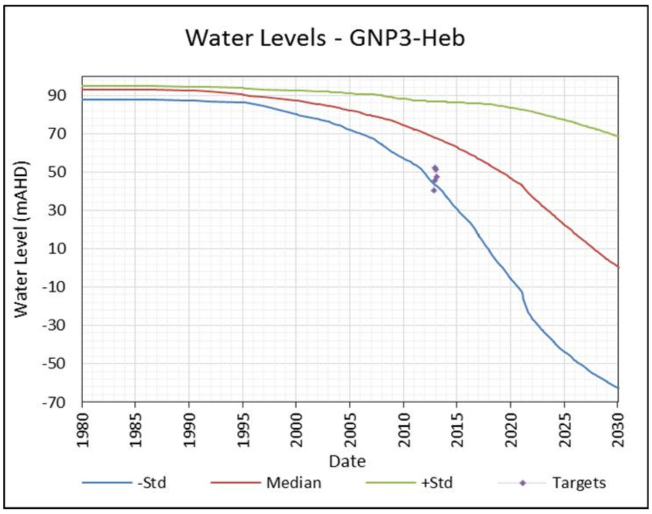

Water Levels - GNP2-LLd
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

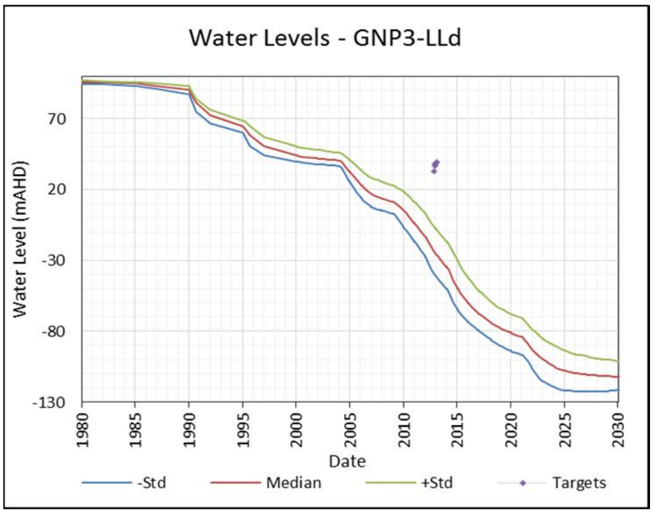

Water Levels - GNP2-PG
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

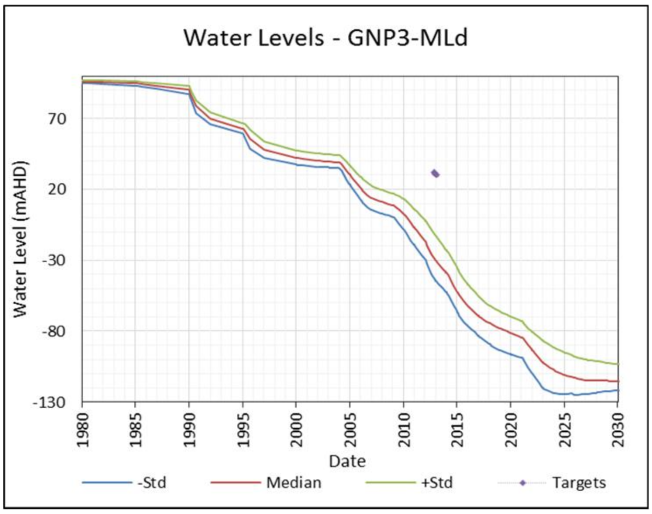

Water Levels - GNP2-Uld
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

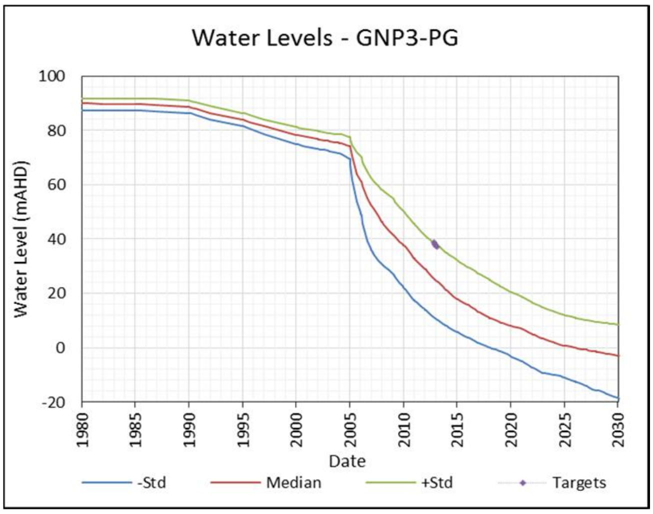

Water Levels - GNP3-Art
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

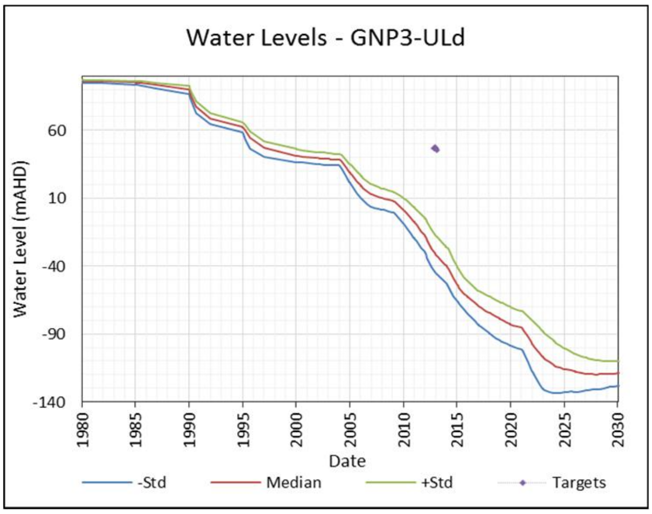

Water Levels - GNP3-Brt
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

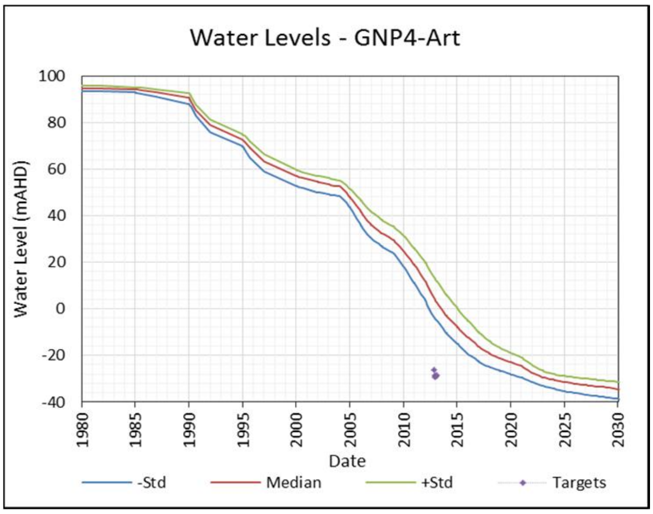

Water Levels - GNP3-Heb
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

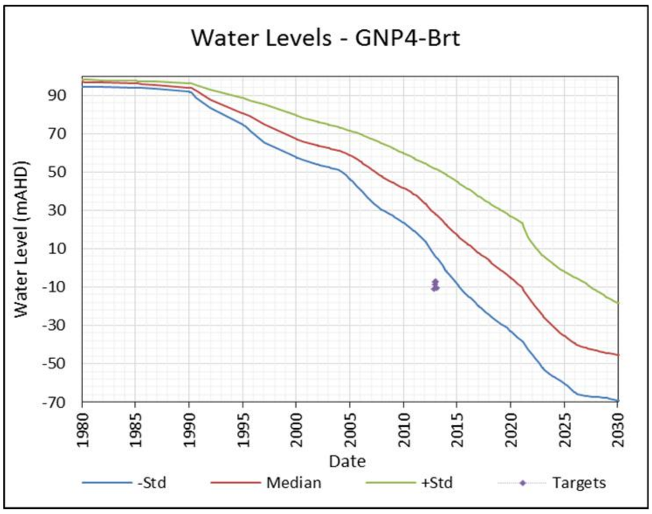

Water Levels - GNP3-LLd
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

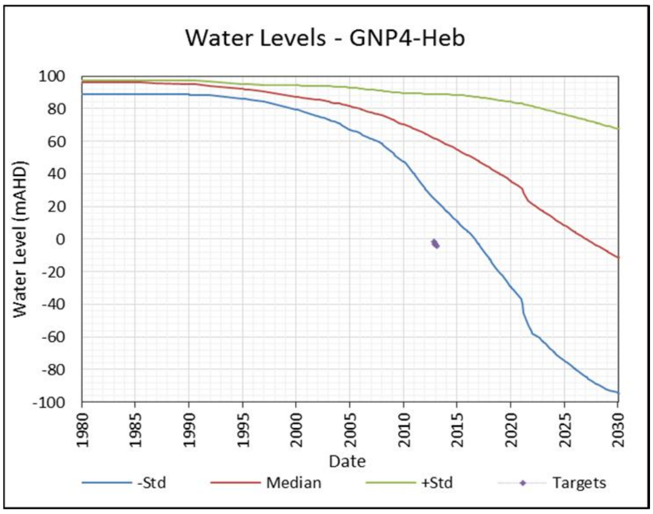

Water Levels - GNP3-MLd
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

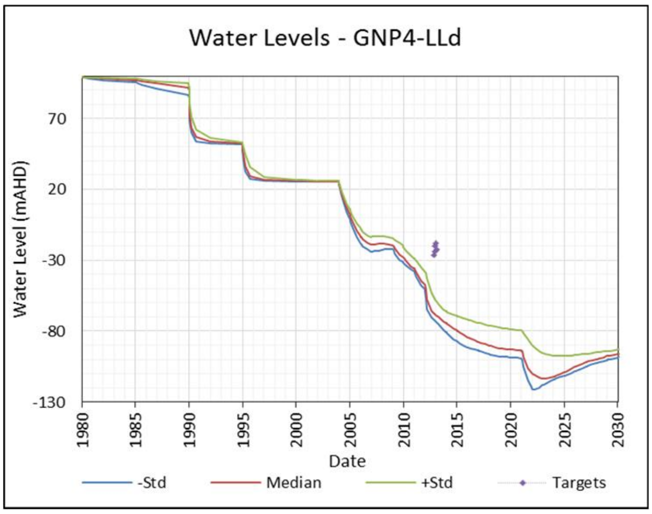

Water Levels - GNP3-PG
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

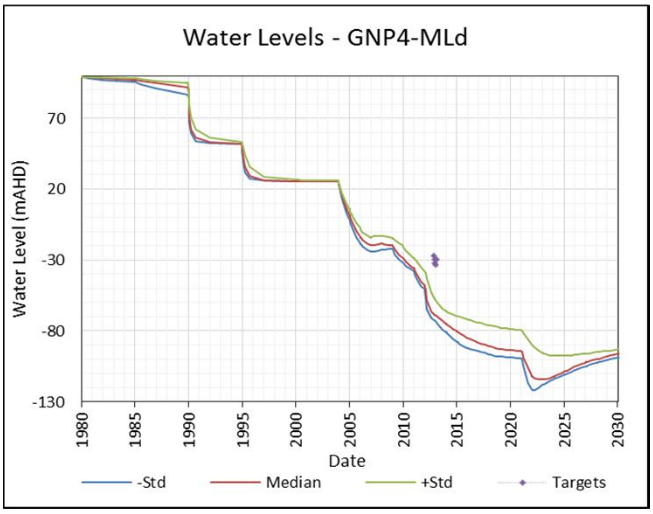

Water Levels - GNP3-ULd
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

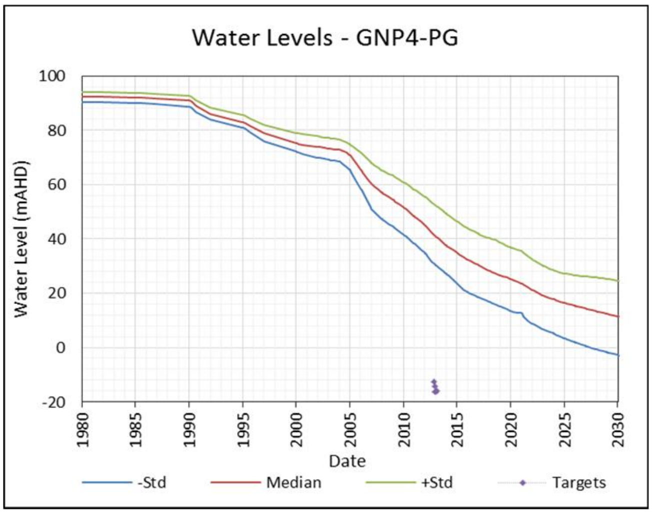

Water Levels - GNP4-Art
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

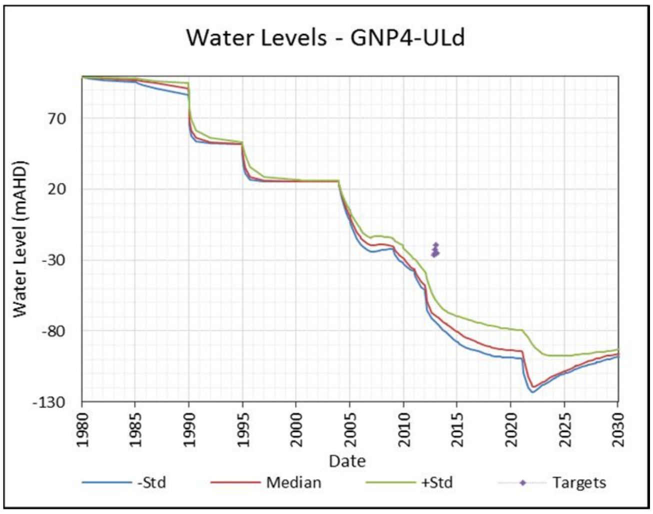

Water Levels - GNP4-Brt
Water Level (mAHD)
90
70
50
30
10
-10
-30
-50
-70
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

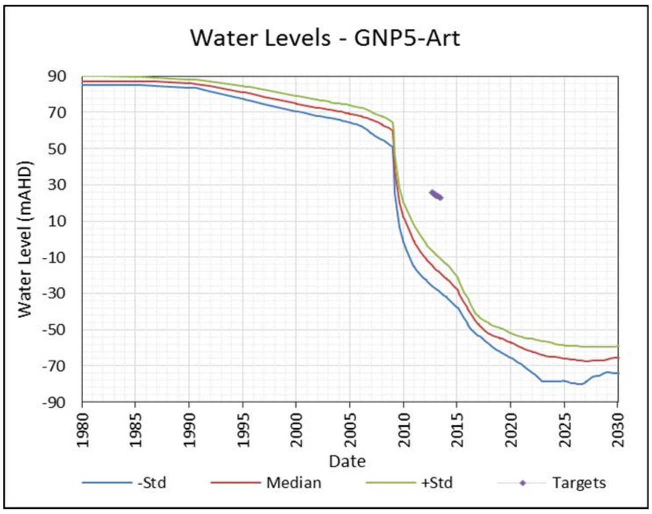

Water Levels - GNP4-Heb
Water Level (mAHD)
100
80
60
40
20
0
-20
-40
-60
-80
-100
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

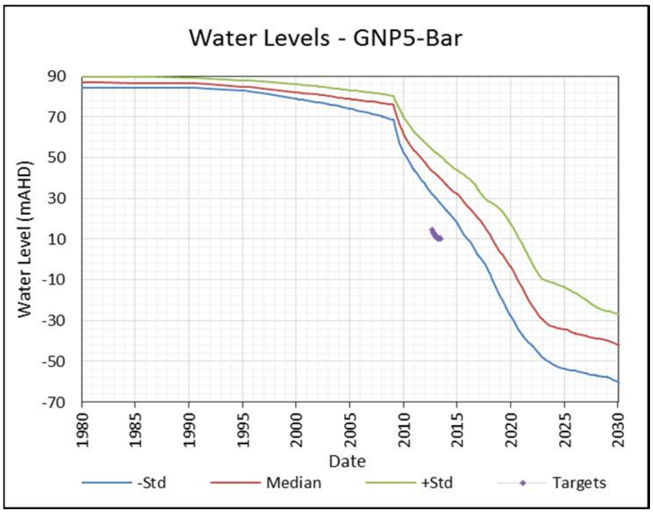

Water Levels - GNP4-LLd
Water Level (mAHD)
70
20
-30
-80
-130
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

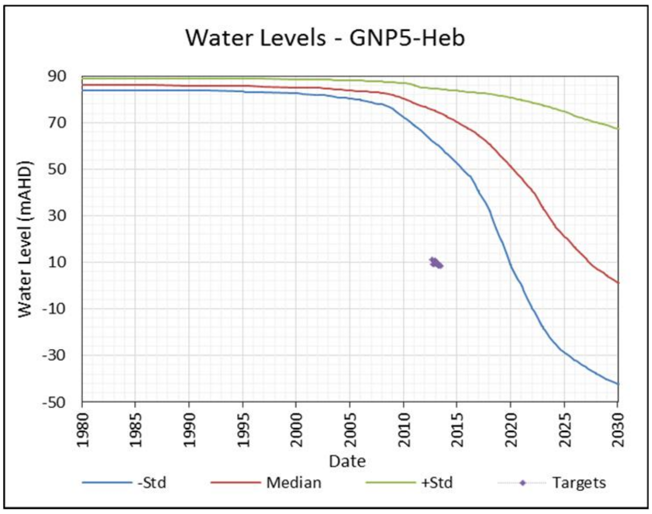

Water Levels - GNP4-MLd
Water Level (mAHD)
70
20
-30
-80
-130
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

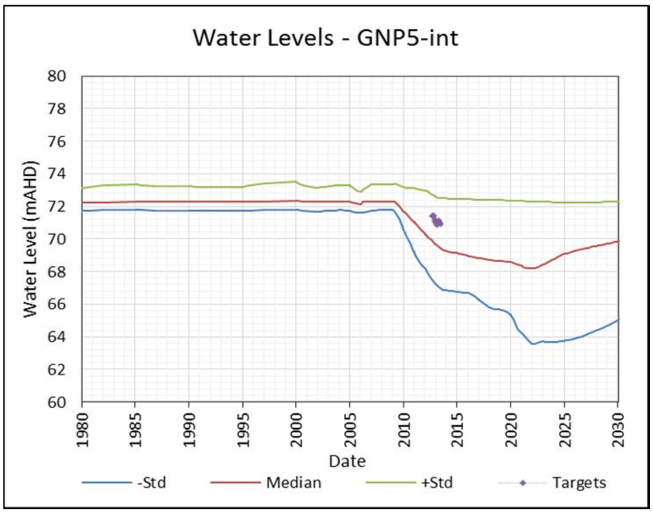

Water Levels - GNP4-PG
Water Level (mAHD)
100
80
60
40
20
0
-20
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

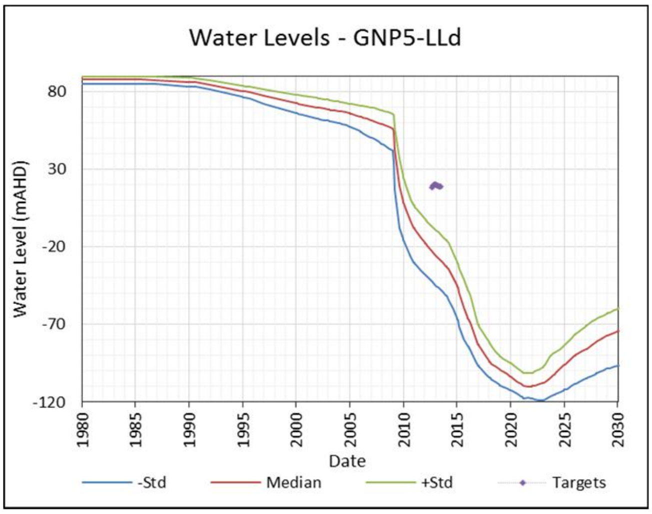

Water Levels - GNP4-ULd
Water Level (mAHD)
70
20
-30
-80
-130
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

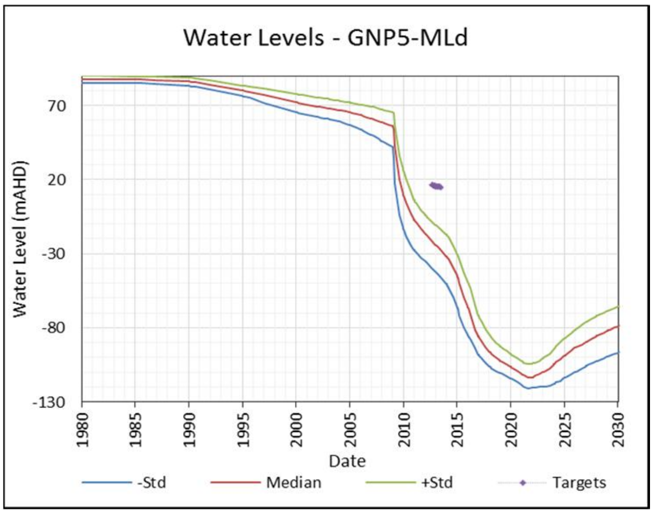

Water Levels - GNP5-Art
Water Level (mAHD)
90
70
50
30
10
-10
-30
-50
-70
-90
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

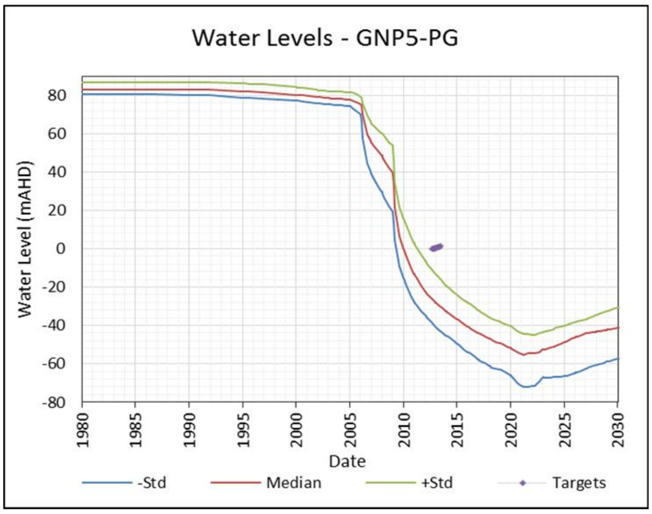

Water Levels - GNP5-Bar
Water Level (mAHD)
90
70
50
30
10
-10
-30
-50
-70
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

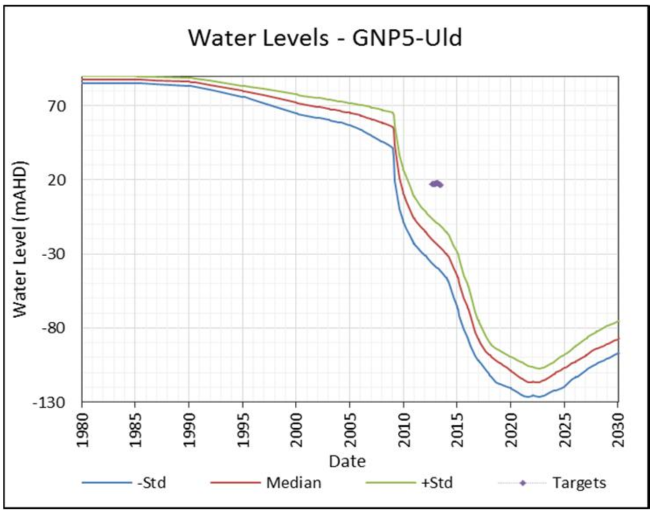

Water Levels - GNP5-Heb
Water Level (mAHD)
90
70
50
30
10
-10
-30
-50
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

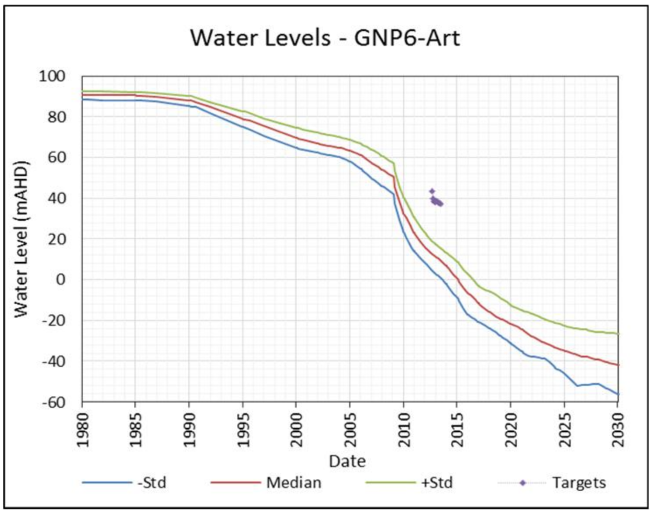

Water Levels - GNP5-int
Water Level (mAHD)
80
78
76
74
72
70
68
66
64
62
60
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

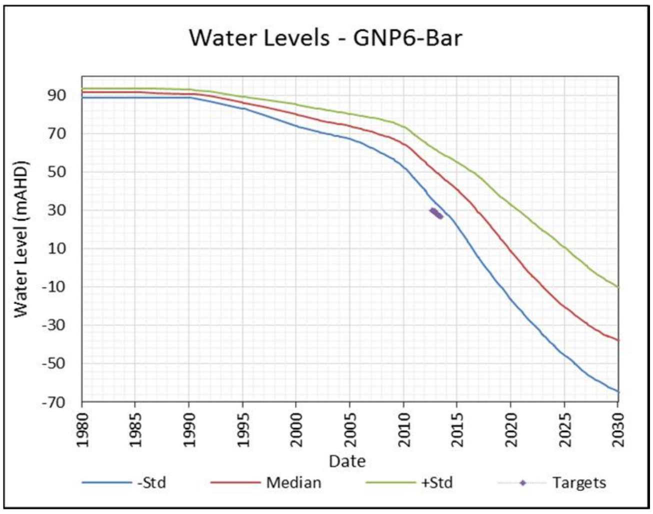

Water Levels - GNP5-LLd
Water Level (mAHD)
80
30
-20
-70
-120
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

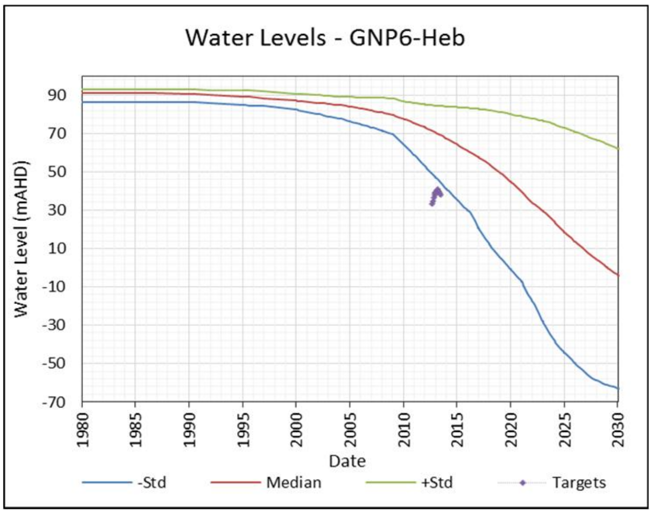

Water Levels - GNP5-MLd
Water Level (mAHD)
70
20
-30
-80
-130
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

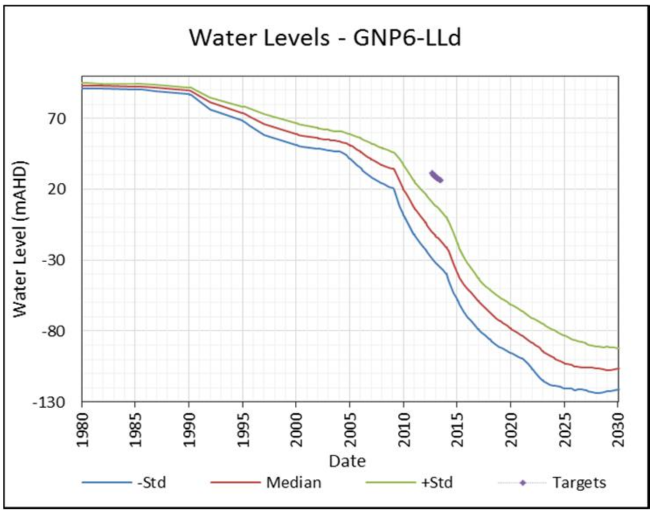

Water Levels - GNP5-PG
Water Level (mAHD)
80
60
40
20
0
-20
-40
-60
-80
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

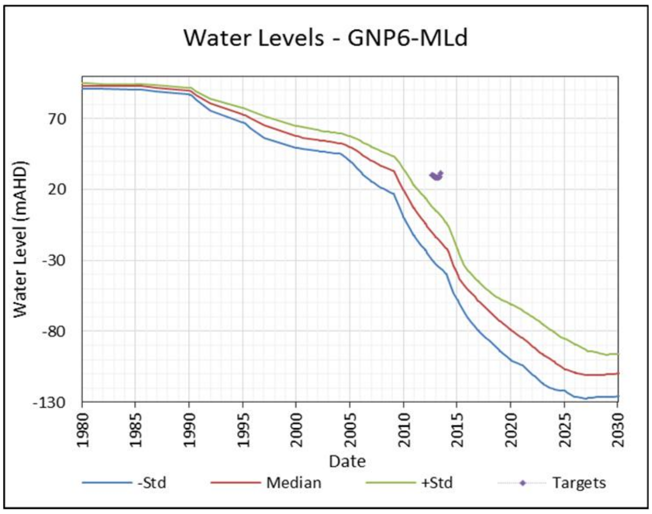

Water Levels - GNP5-Uld
Water Level (mAHD)
70
20
-30
-80
-130
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

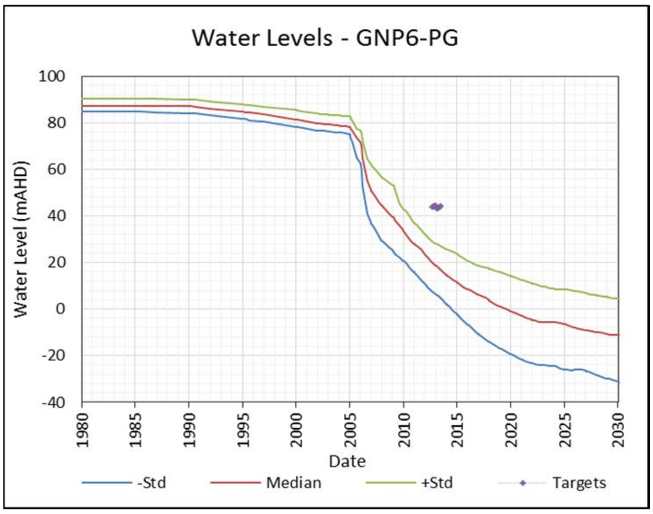

Water Levels - GNP6-Art
Water Level (mAHD)
100
80
60
40
20
0
-20
-40
-60
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

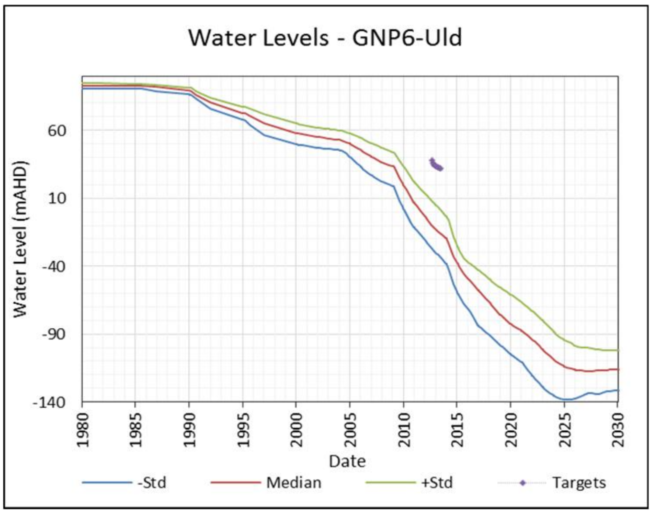

Water Levels - GNP6-Bar
Water Level (mAHD)
90
70
50
30
10
-10
-30
-50
-70
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

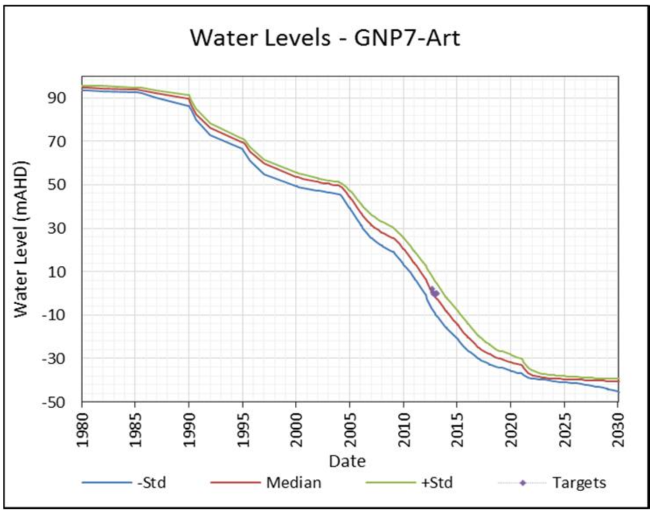

Water Levels - GNP6-Heb
Water Level (mAHD)
90
70
50
30
10
-10
-30
-50
-70
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

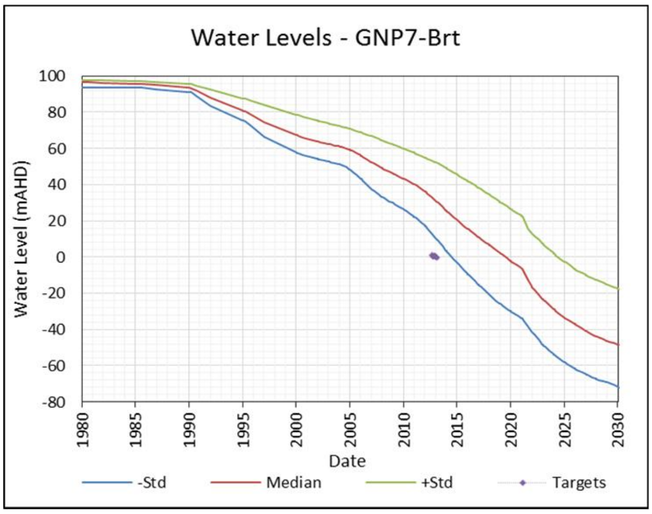

Water Levels - GNP6-LLd
Water Level (mAHD)
70
20
-30
-80
-130
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

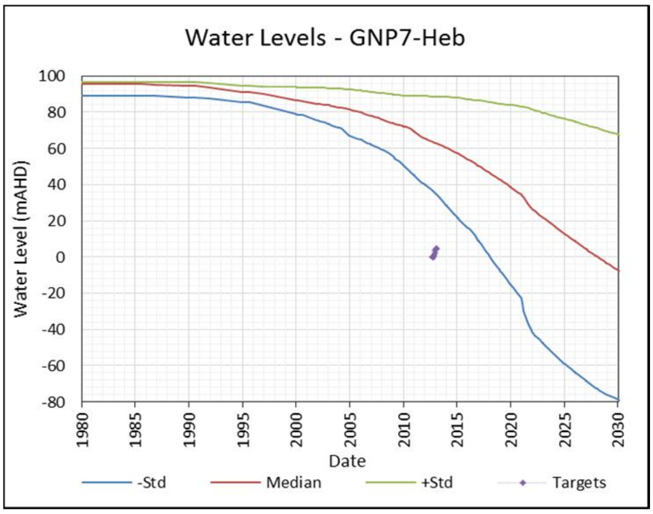

Water Levels - GNP6-MLd
Water Level (mAHD)
70
20
-30
-80
-130
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

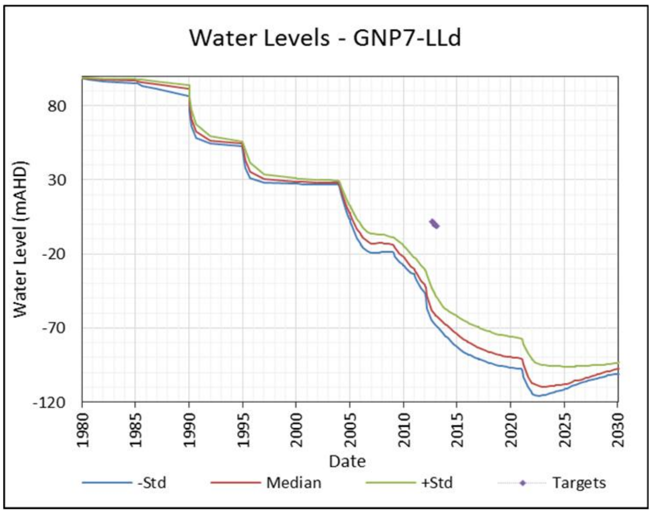

Water Levels - GNP6-PG
Water Level (mAHD)
100
80
60
40
20
0
-20
-40
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

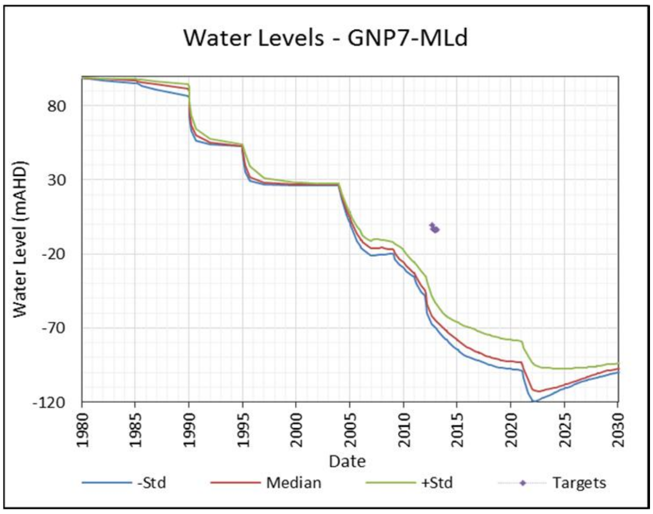

Water Levels - GNP6-Uld
Water Level (mAHD)
60
10
-40
-90
-140
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

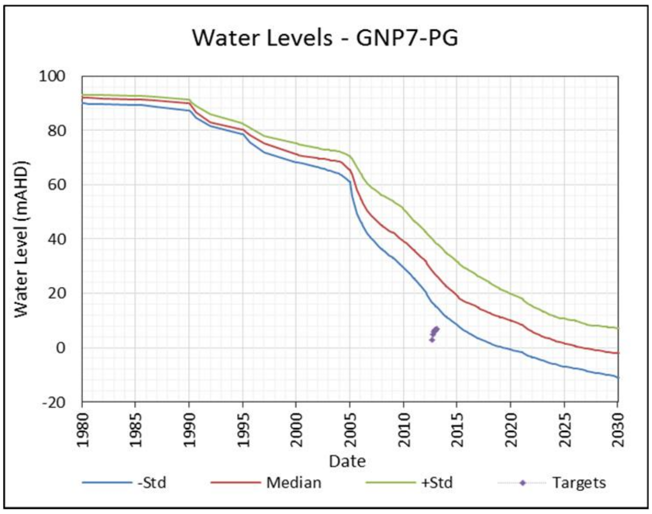

Water Levels - GNP7-Art
Water Level (mAHD)
90
70
50
30
10
-10
-30
-50
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

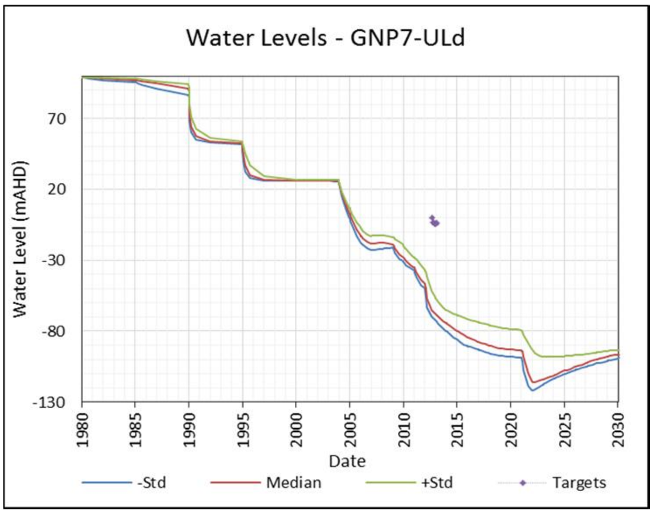

Water Levels - GNP7-Brt
Water Level (mAHD)
100
80
60
40
20
0
-20
-40
-60
-80
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

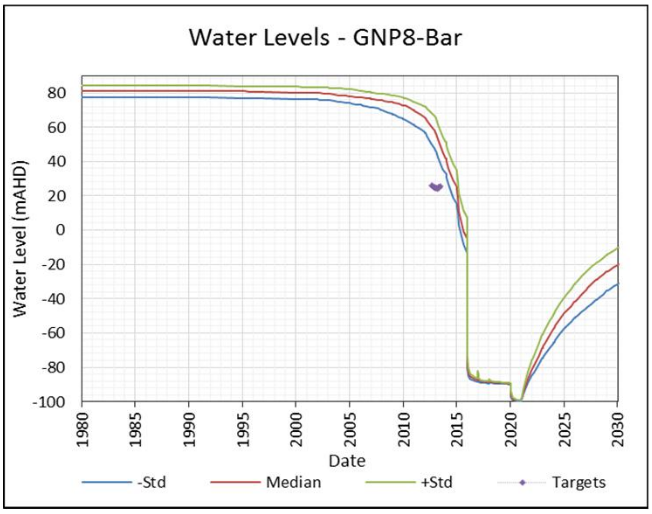

Water Levels - GNP7-Heb
Water Level (mAHD)
100
80
60
40
20
0
-20
-40
-60
-80
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

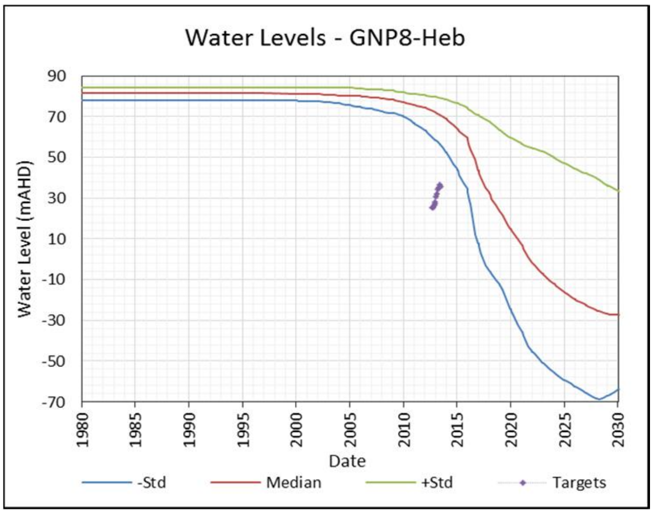

Water Levels - GNP7-LLd
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

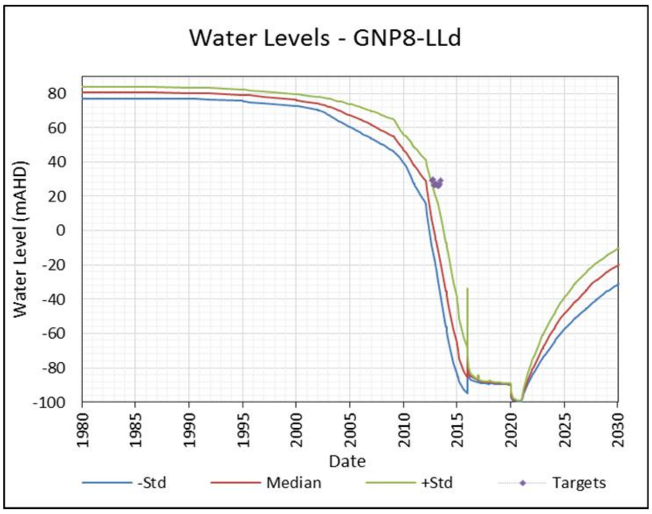

Water Levels - GNP7-MLd
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

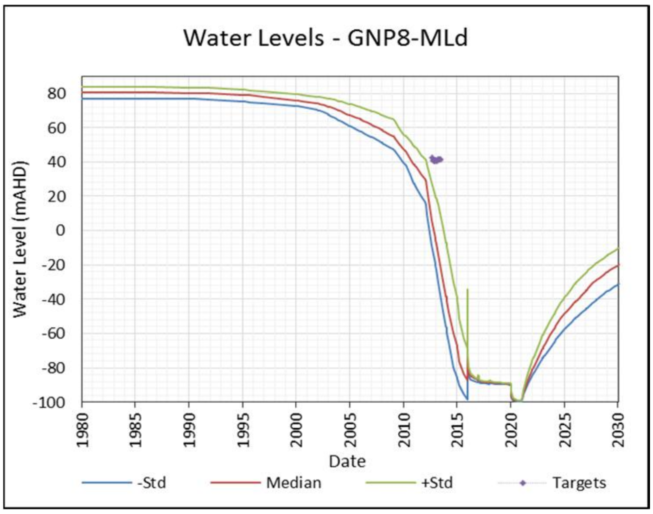

Water Levels - GNP7-PG
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

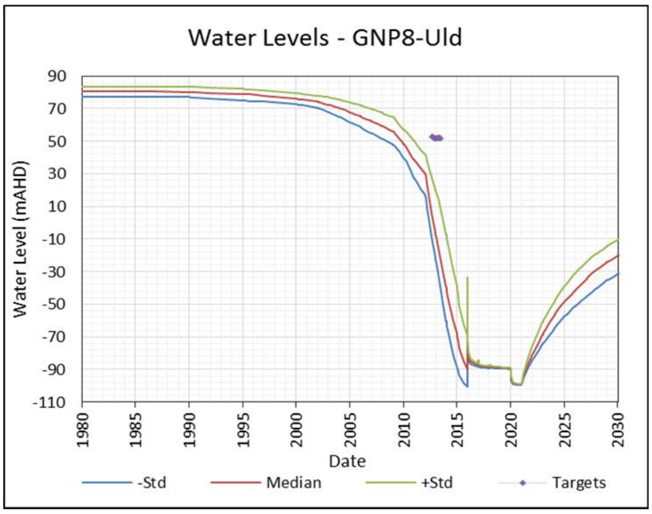

Water Levels - GNP7-ULd
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

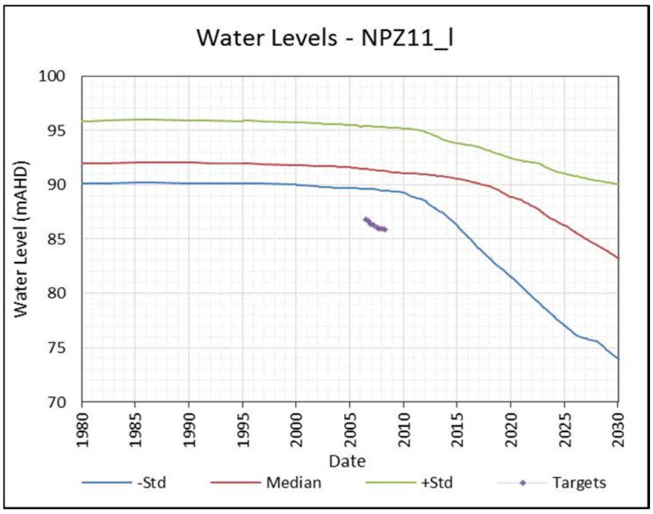

Water Levels - GNP8-Bar
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

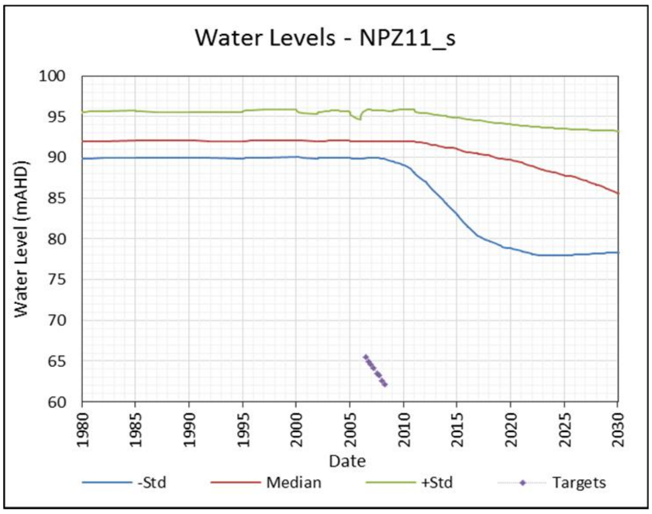

Water Levels - GNP8-Heb
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

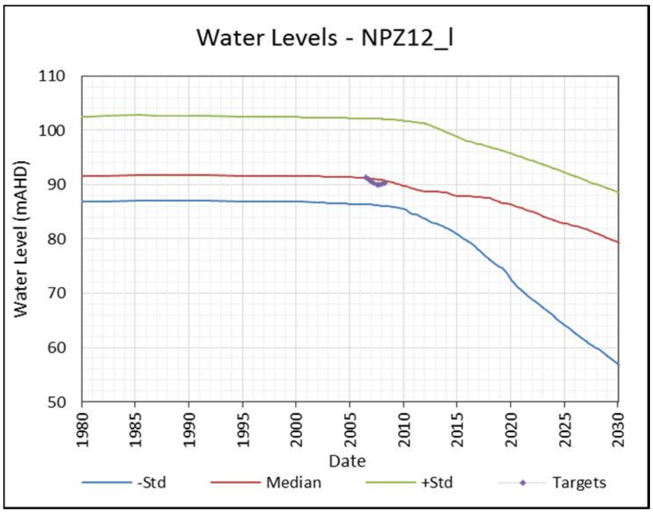

Water Levels - GNP8-LLd
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

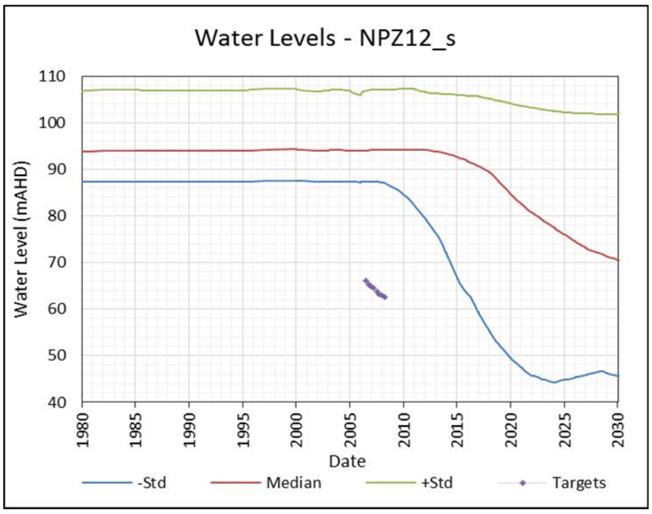

Water Levels - GNP8-MLd
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

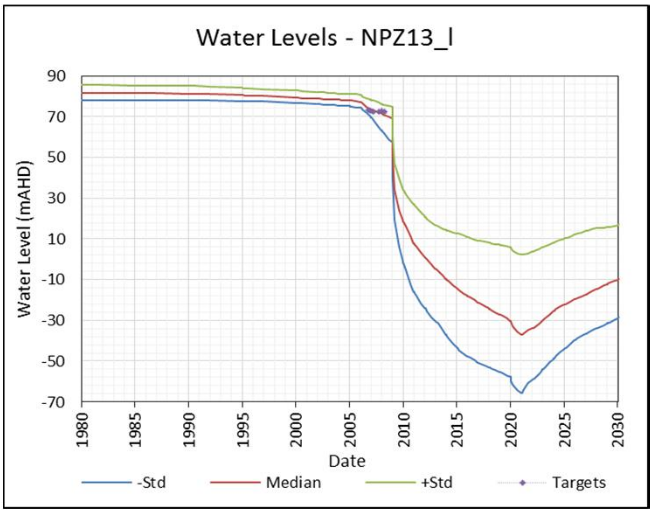

Water Levels - GNP8-Uld
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

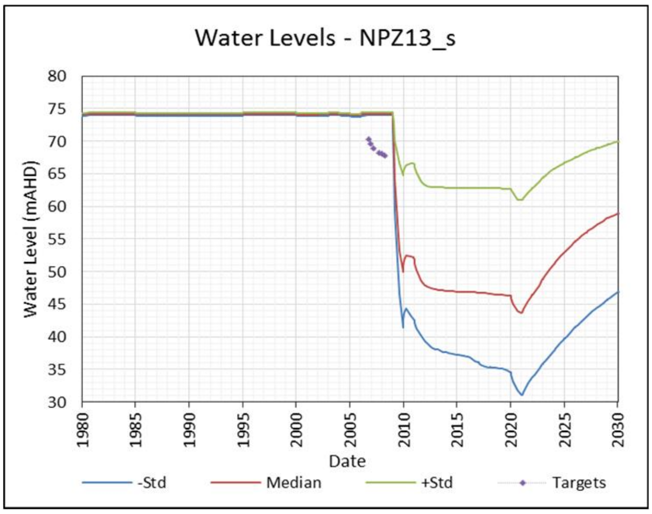

Water Levels - NPZ11_l
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

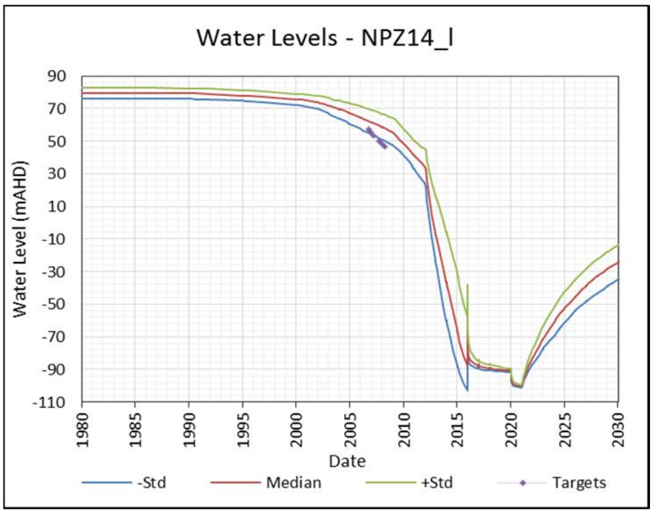

Water Levels - NPZ11_s
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

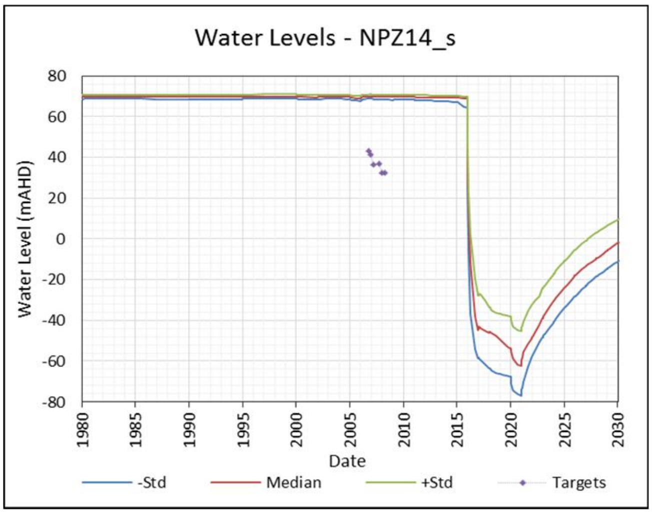

Water Levels - NPZ12_l
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

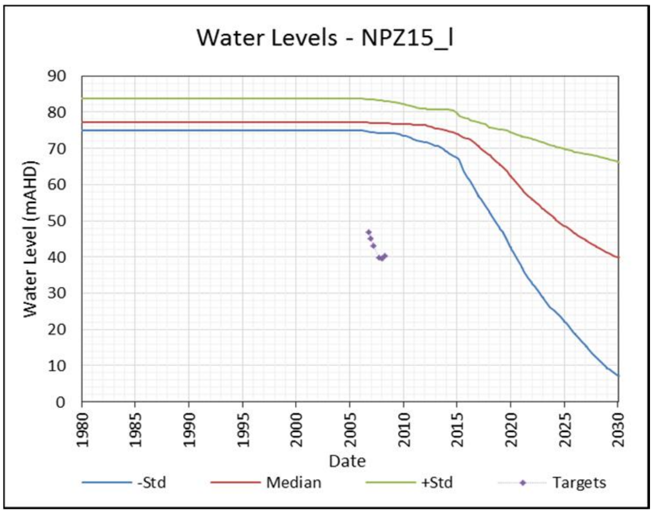

Water Levels - NPZ12_s
110
100
90
80
70
60
50
40
Water Level (mAHD)
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

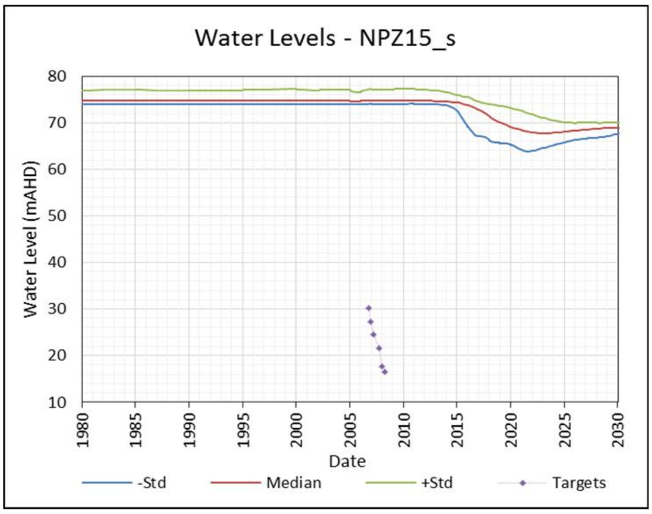

Water Levels - NPZ13_l
90
70
50
30
10
-10
-30
-50
-70
Water Level (mAHD)
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

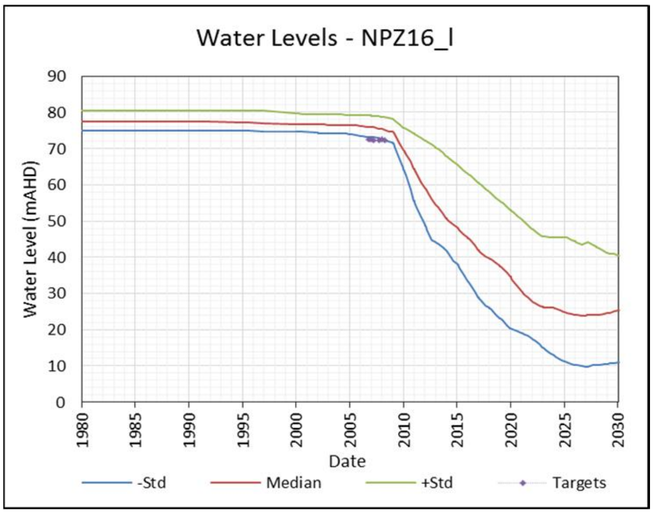

Water Levels - NPZ13_s
80
75
70
65
60
55
50
45
40
35
30
Water Level (mAHD)
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

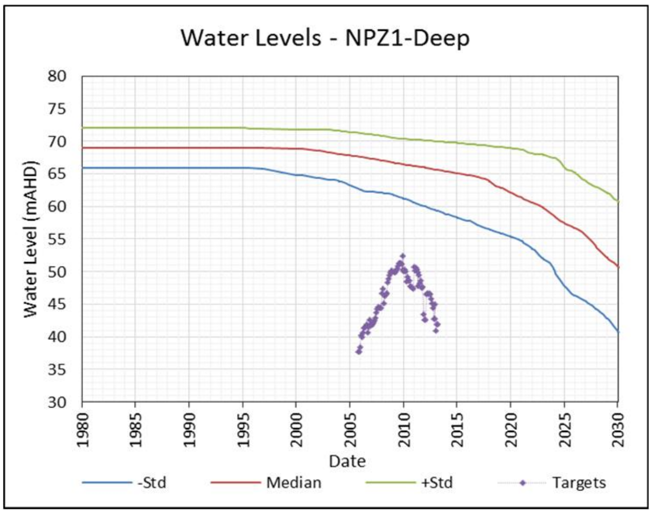

Water Levels - NPZ14_l
90
70
50
30
10
-10
-30
-50
-70
-90
-110
Water Level (mAHD)
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

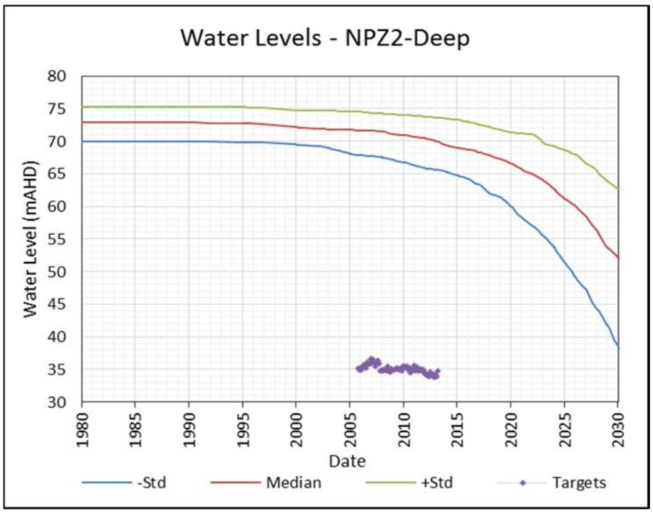

Water Levels - NPZ14_s
80
60
40
20
0
-20
-40
-60
-80
Water Level (mAHD)
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

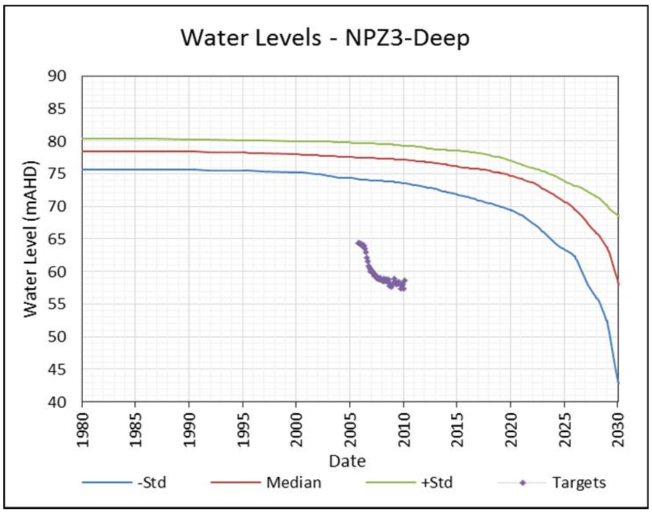

Water Levels - NPZ15_l
90
80
70
60
50
40
30
20
10
0
Water Level (mAHD)
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

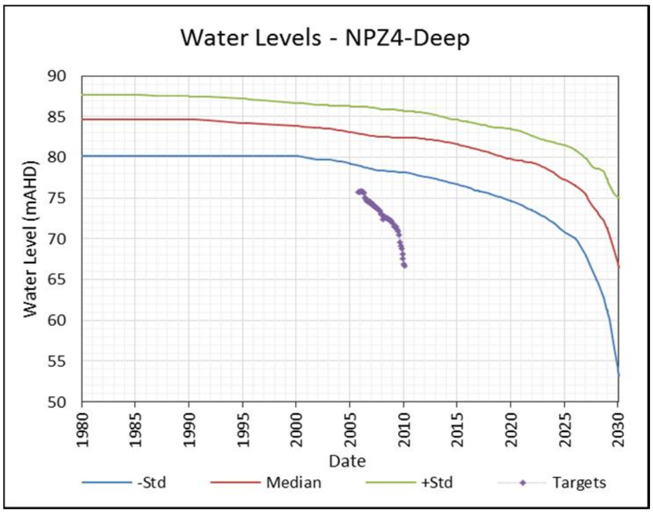

Water Levels - NPZ15_s
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

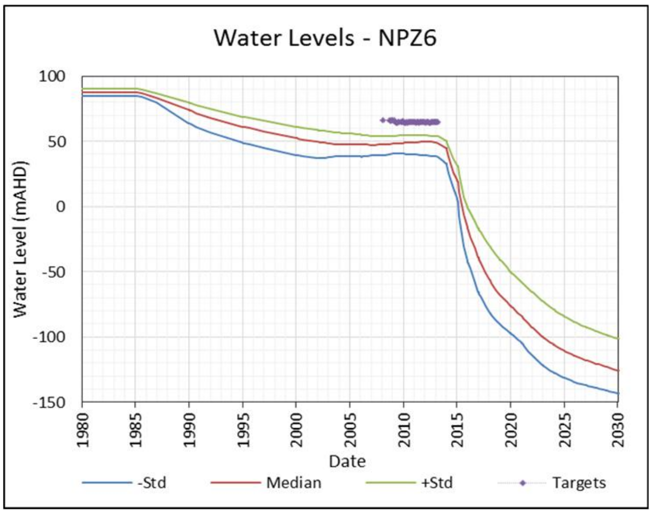

Water Levels - NPZ16_l
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

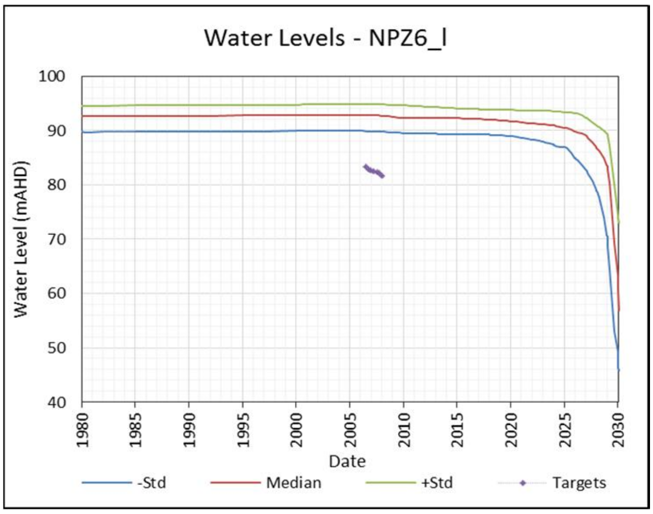

Water Levels - NPZ1-Deep
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

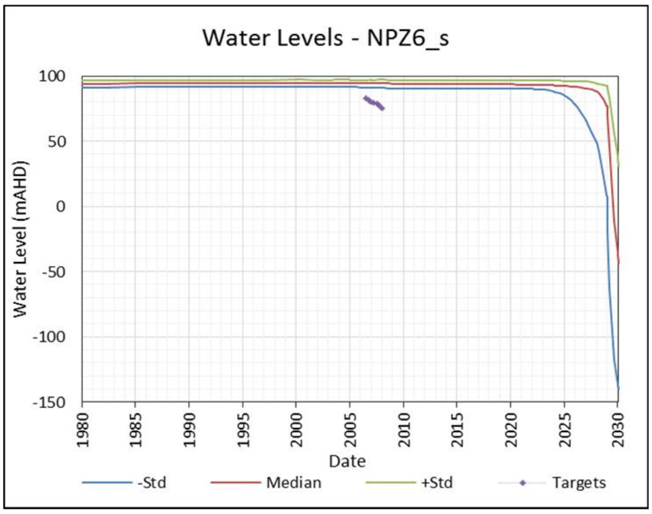

Water Levels - NPZ2-Deep
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

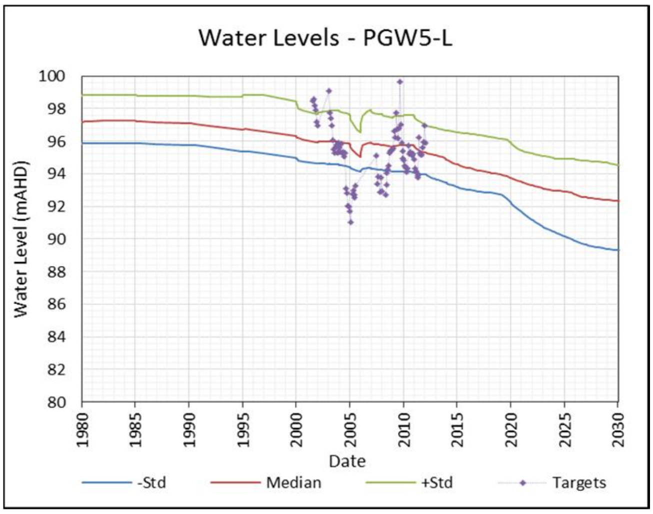

Water Levels - NPZ3-Deep
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

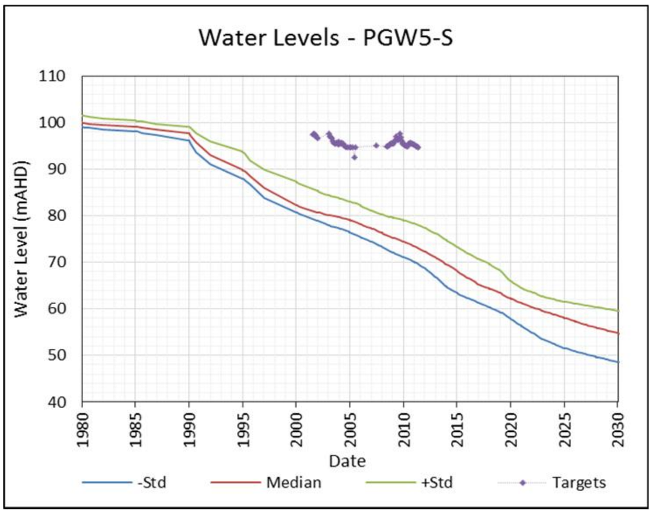

Water Levels - NPZ4-Deep
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

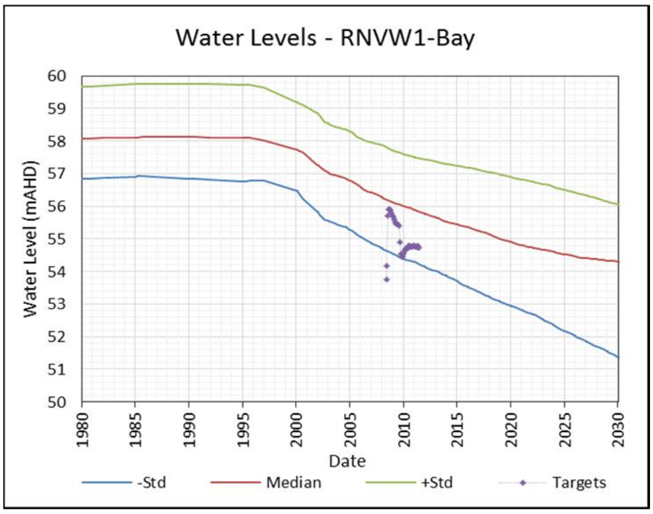

Water Levels - NPZ6
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

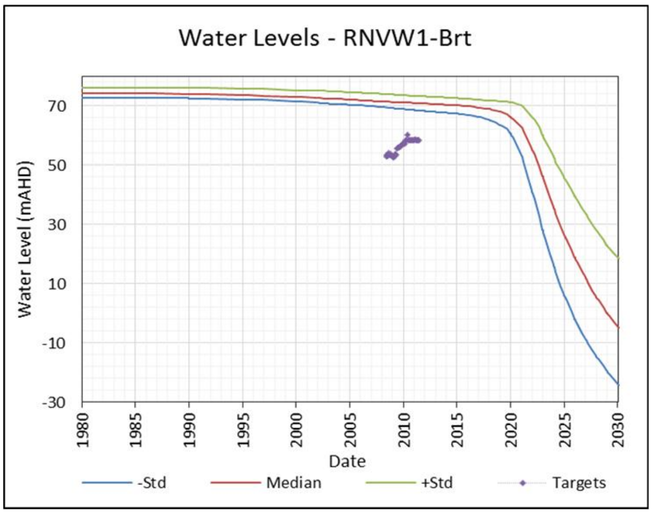

Water Levels - NPZ6_l
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

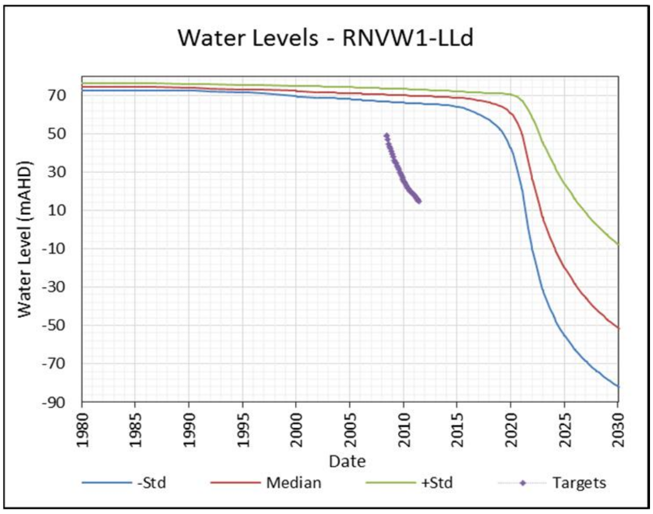

Water Levels - NPZ6_s
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

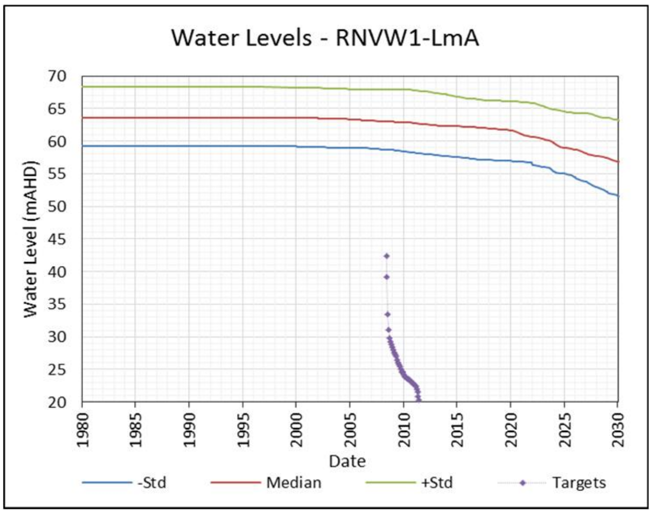

Water Levels - PGW5-L
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

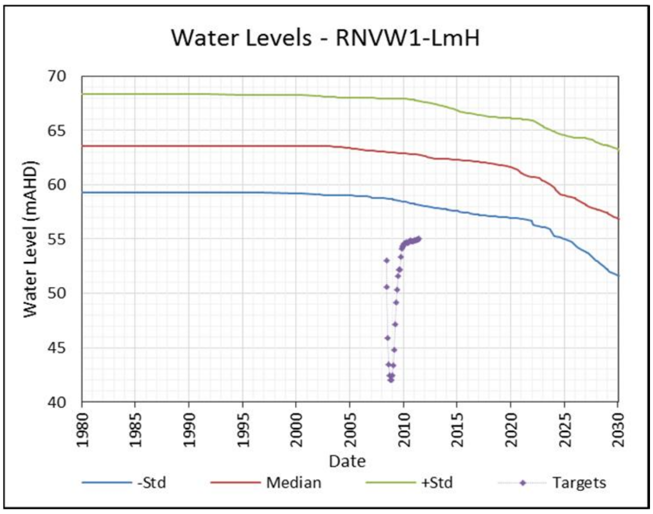

Water Levels - PGW5-S
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

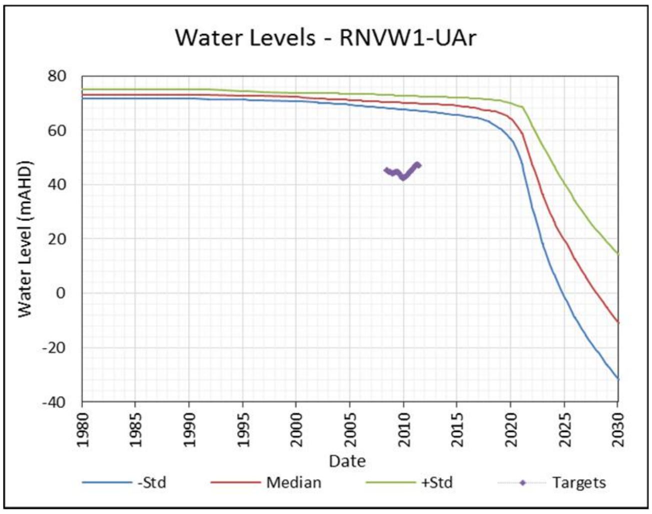

Water Levels - RNVW1-Bay
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

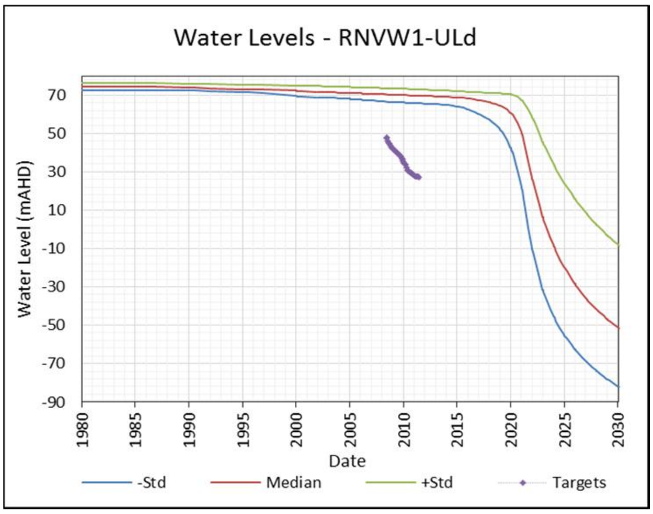

Water Levels - RNVW1-Brt
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

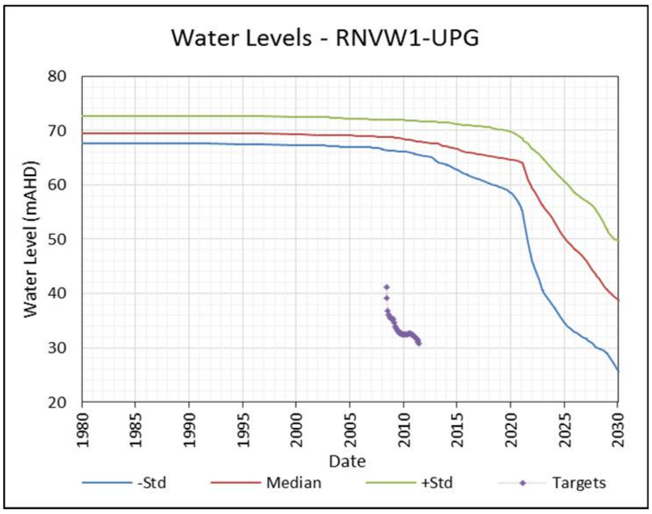

Water Levels - RNVW1-LLd
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

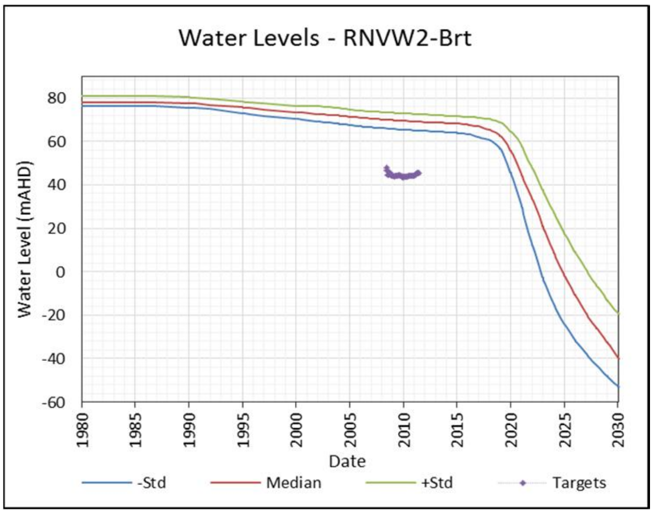

Water Levels - RNVW1-LmA
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

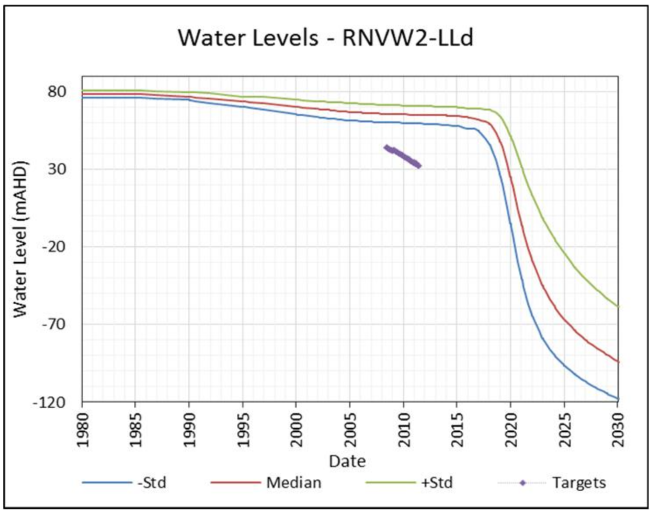

Water Levels - RNVW1-LmH
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

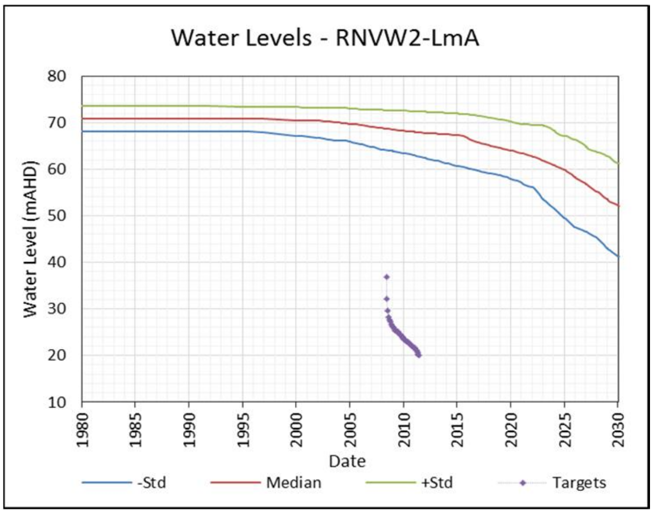

Water Levels - RNVW1-UAr
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

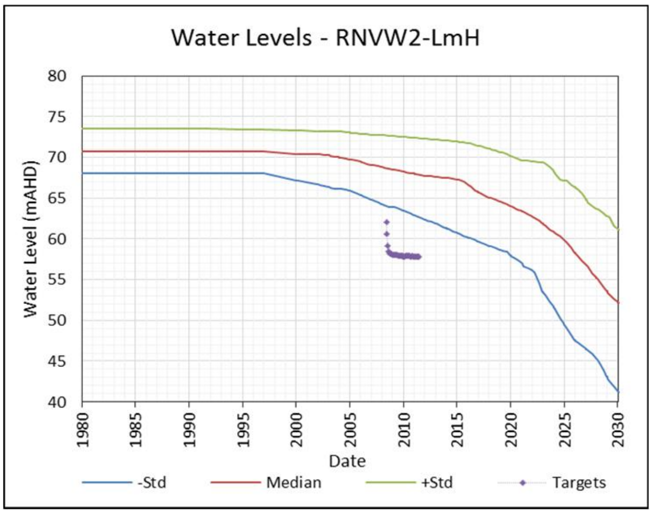

Water Levels - RNVW1-ULd
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

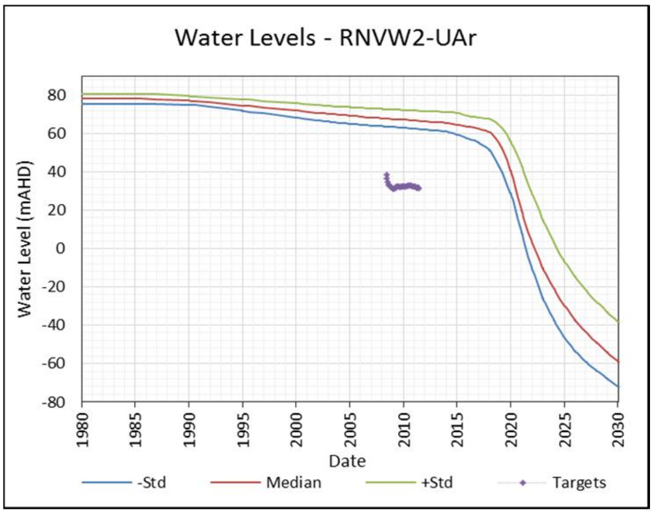

Water Levels - RNVW1-UPG
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

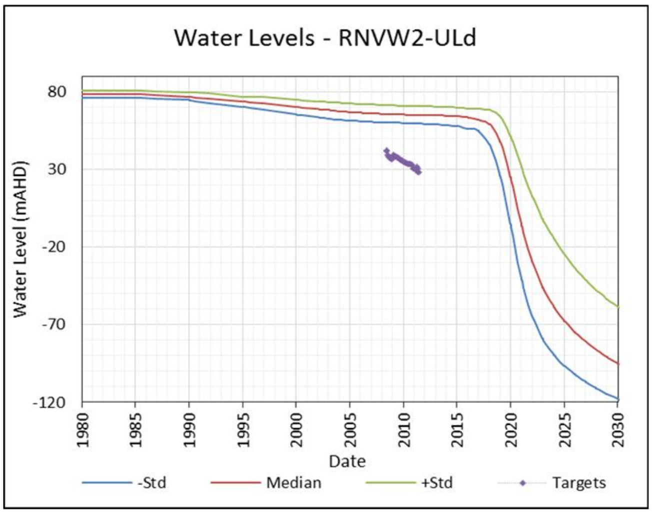

Water Levels - RNVW2-Brt
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

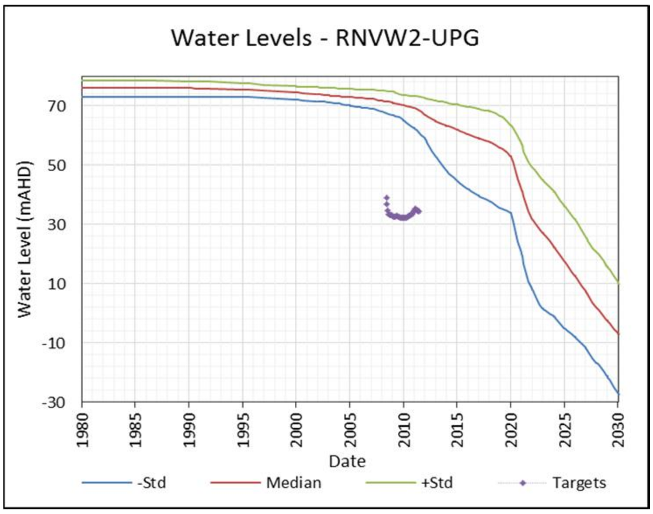

Water Levels - RNVW2-LLd
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

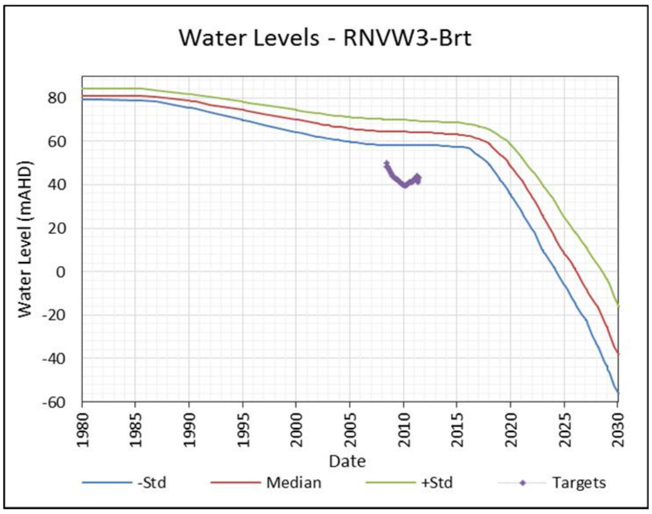

Water Levels - RNVW2-LmA
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

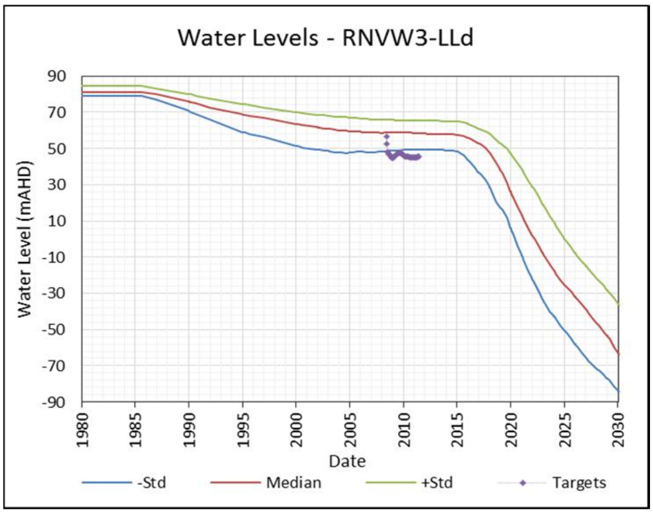

Water Levels - RNVW2-LmH
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

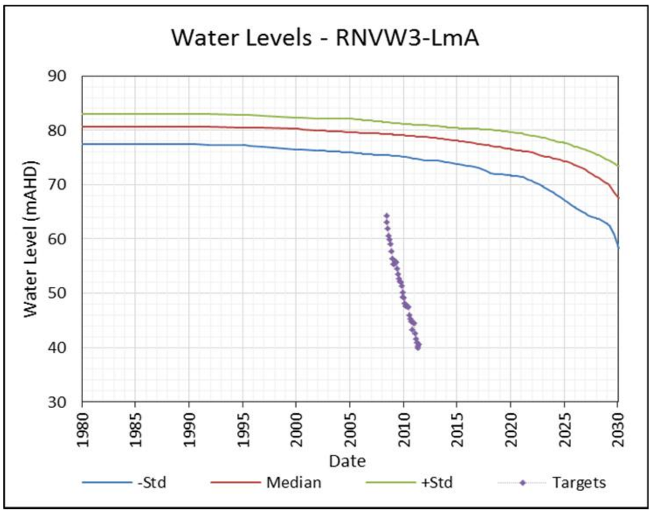

Water Levels - RNVW2-UAr
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

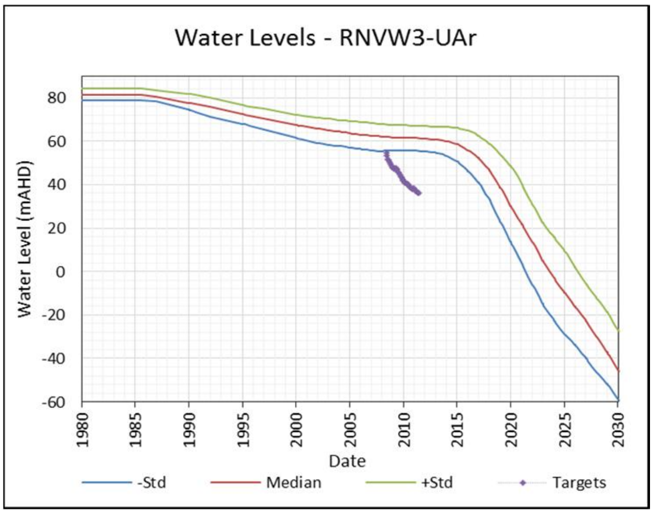

Water Levels - RNVW2-ULd
Water Level (mAHD)
80
30
-20
-70
-120
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

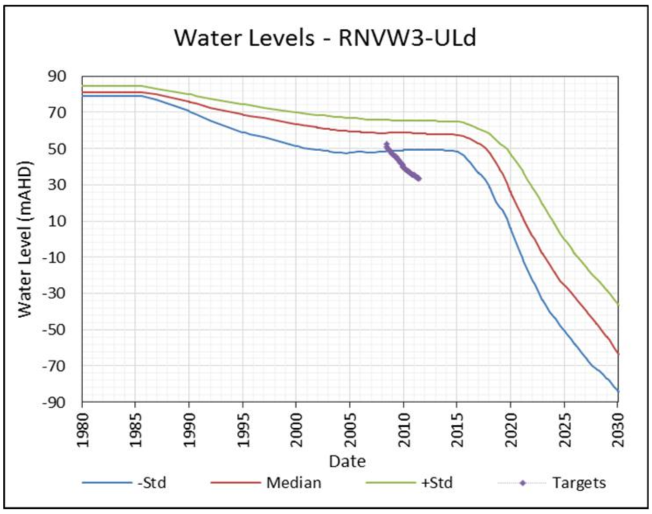

Water Levels - RNVW2-UPG
Water Level (mAHD)
70
50
30
10
-10
-30
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

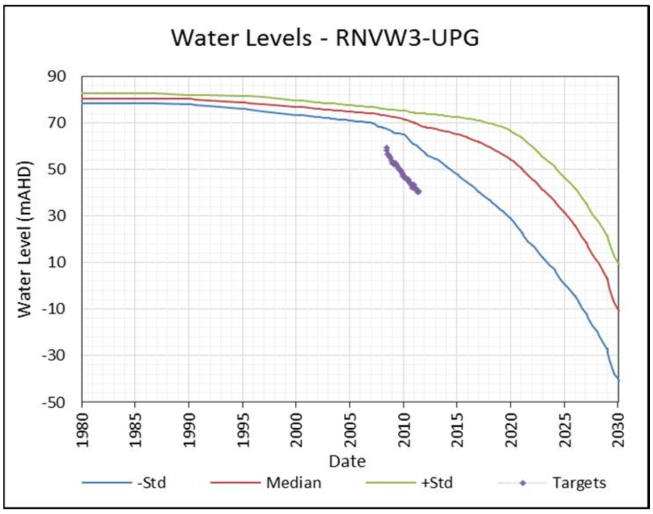

Water Levels - RNVW3-Brt
Water Level (mAHD)
80
60
40
20
0
-20
-40
-60
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

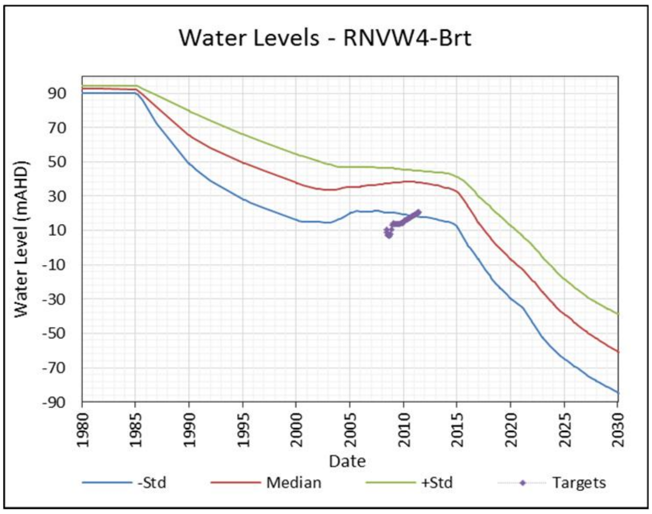

Water Levels - RNVW3-LLd
Water Level (mAHD)
90
70
50
30
10
-10
-30
-50
-70
-90
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

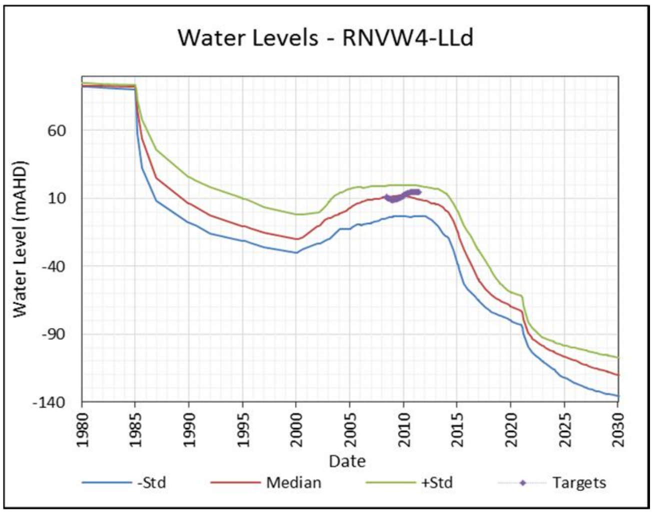

Water Levels - RNVW3-LmA
Water Level (mAHD)
90
80
70
60
50
40
30
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

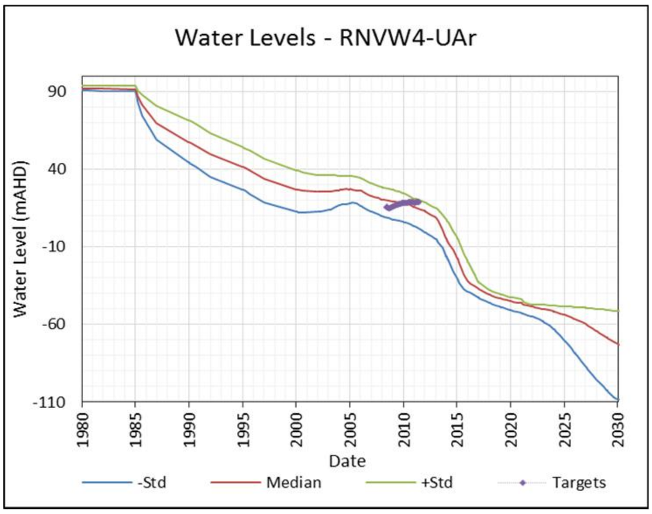

Water Levels - RNVW3-UAr
Water Level (mAHD)
80
60
40
20
0
-20
-40
-60
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030
Date
-Std
Median
+Std
Targets

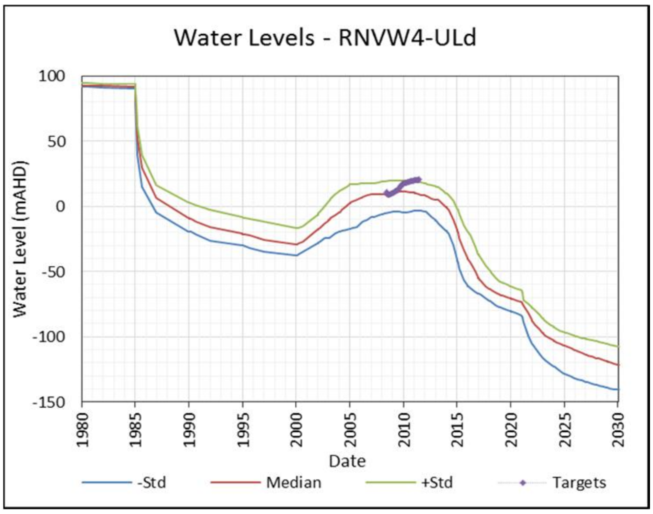

Water Levels - RNVW3-ULd
Water Level (mAHD)
90
70
50
30
10
-10
-30
-50
-70
-90
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

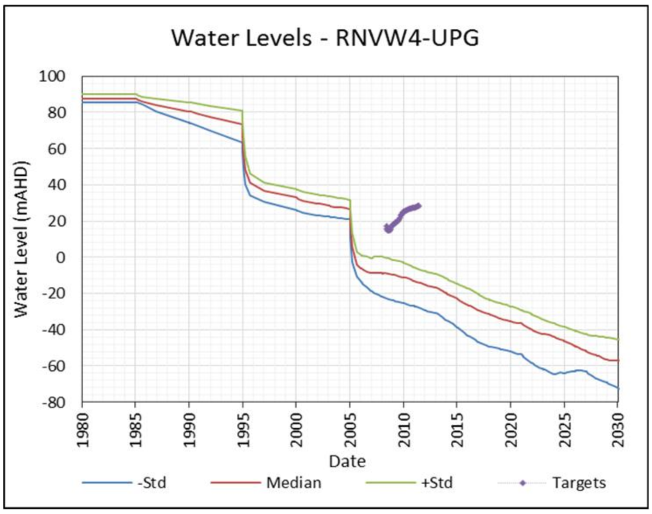

Water Levels - RNVW3-UPG
Water Level (mAHD)
90
70
50
30
10
-10
-30
-50
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

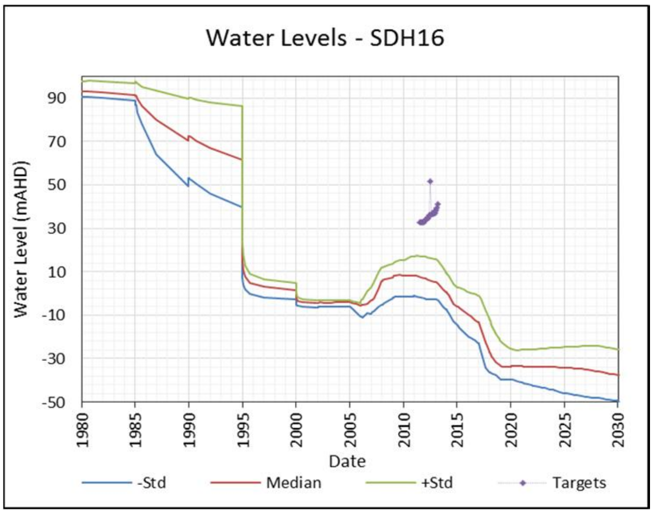

Water Levels - RNVW4-Brt
Water Level (mAHD)
90
70
50
30
10
-10
-30
-50
-70
-90
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

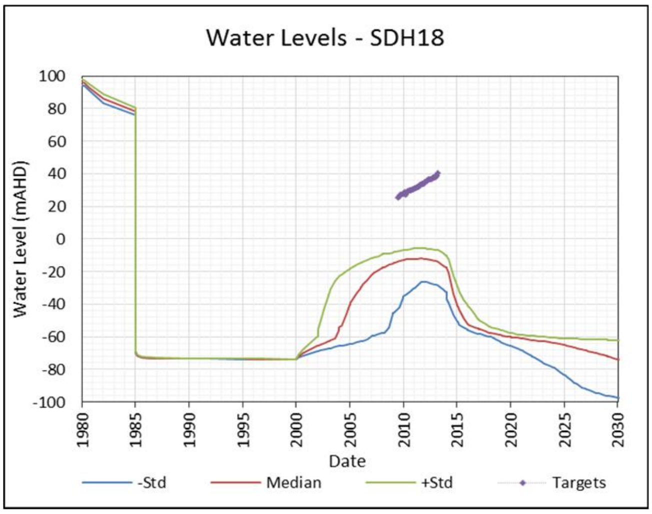

Water Levels - RNVW4-LLd
Water Level (mAHD)
60
10
-40
-90
-140
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

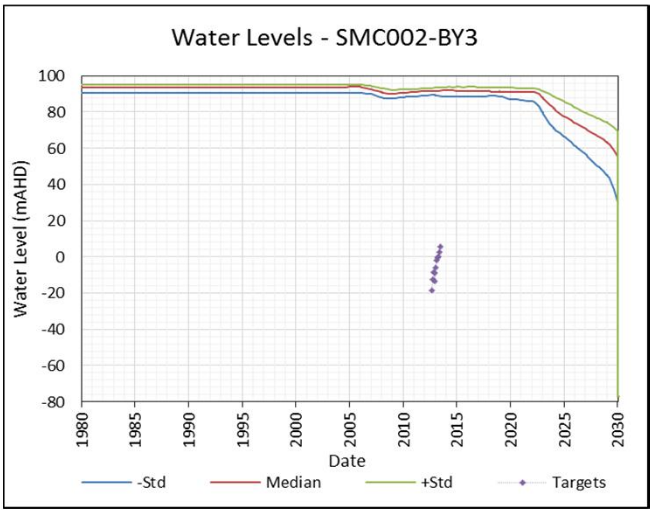

Water Levels - RNVW4-UAr
Water Level (mAHD)
90
40
-10
-60
-110
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

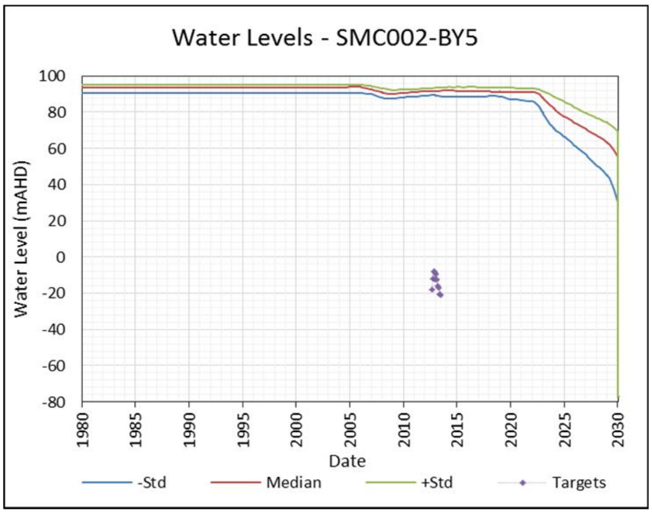

Water Levels - RNVW4-ULd
Water Level (mAHD)
100
50
0
-50
-100
-150
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

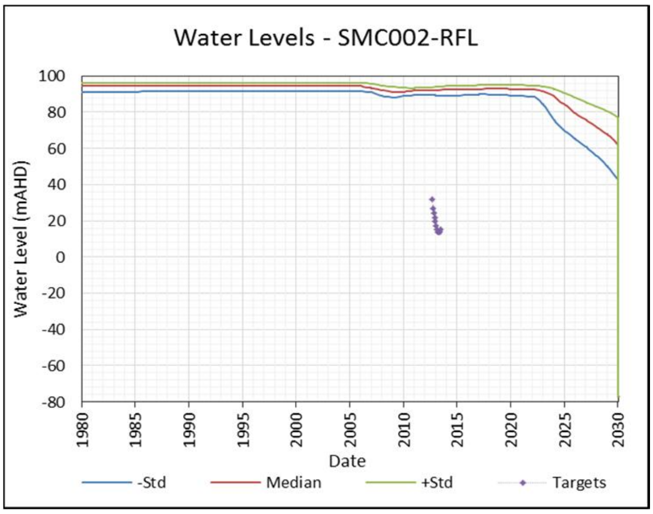

Water Levels - RNVW4-UPG
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

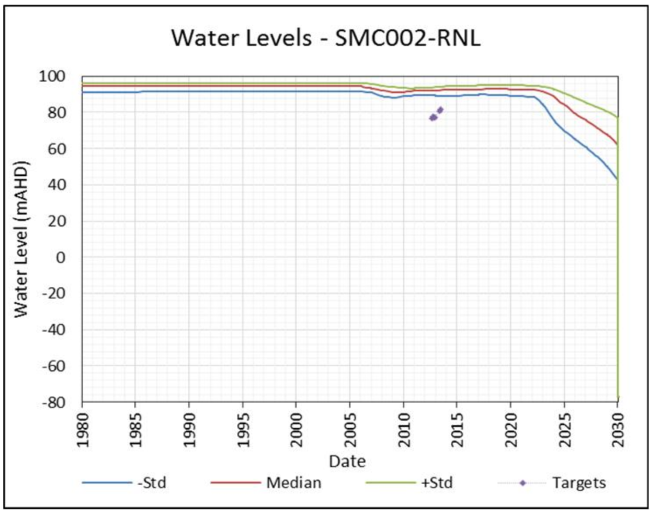

Water Levels - SDH16
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

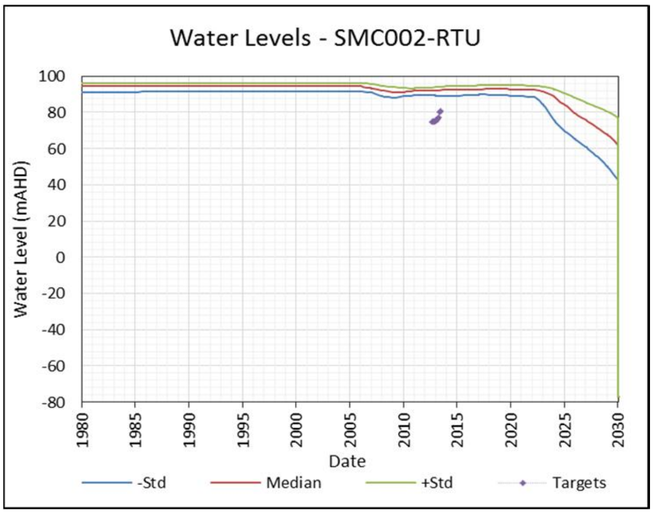

Water Levels - SDH18
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

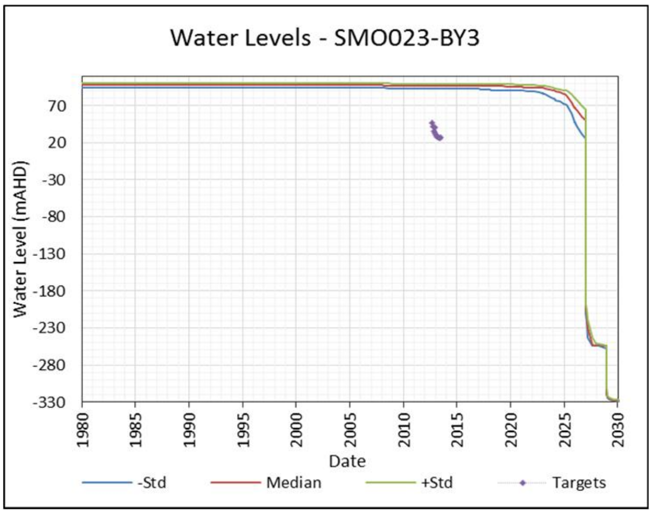

Water Levels - SMC002-BY3
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

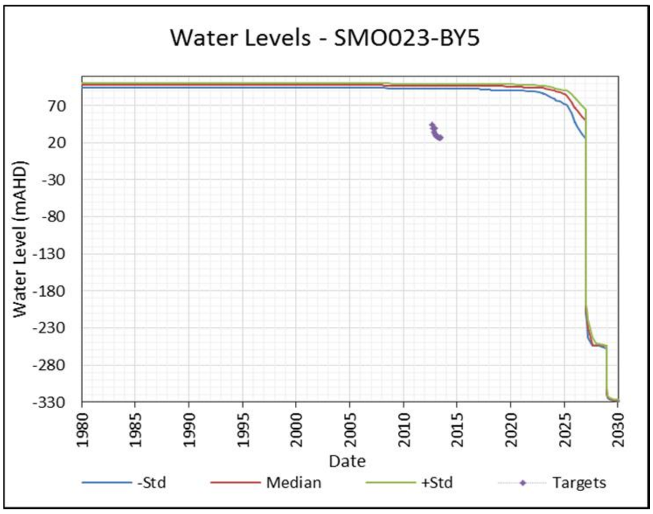

Water Levels - SMC002-BY5
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

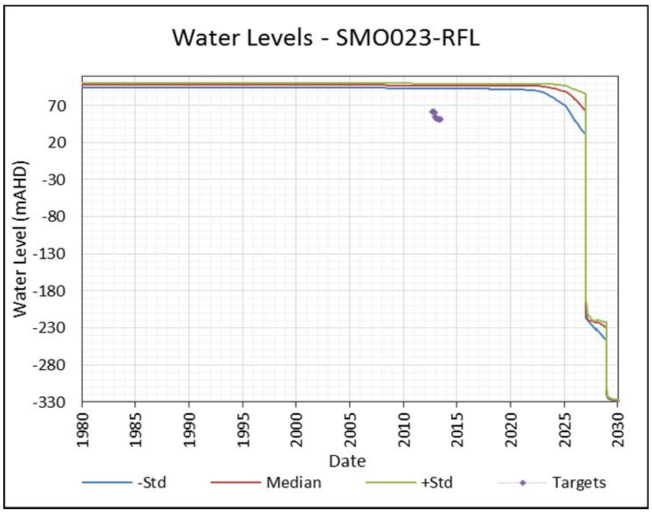

Water Levels - SMC002-RFL
Water Level (mAHD)
Date
-Std
Median
+Std
Targets

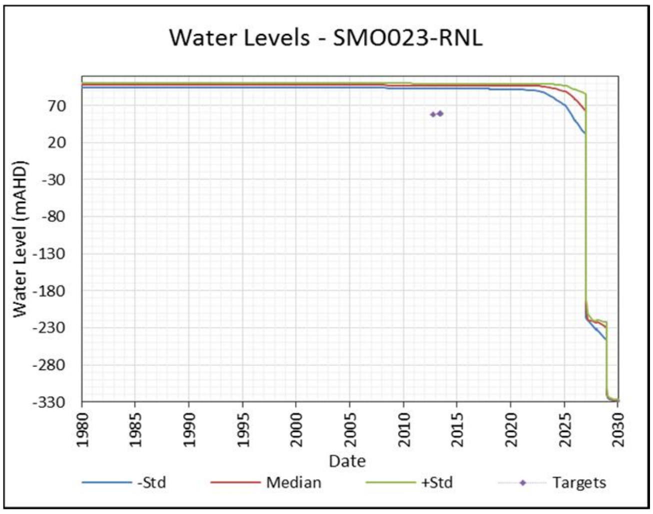

Water Levels - SMC002-RNL
Water Level (mAHD)
100
80
60
40
20
0
-20
-40
-60
-80
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

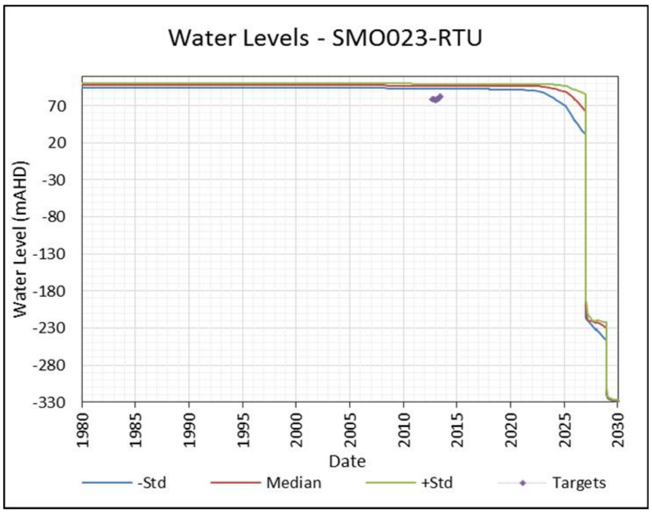

Water Levels - SMC002-RTU
Water Level (mAHD)
100
80
60
40
20
0
-20
-40
-60
-80
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

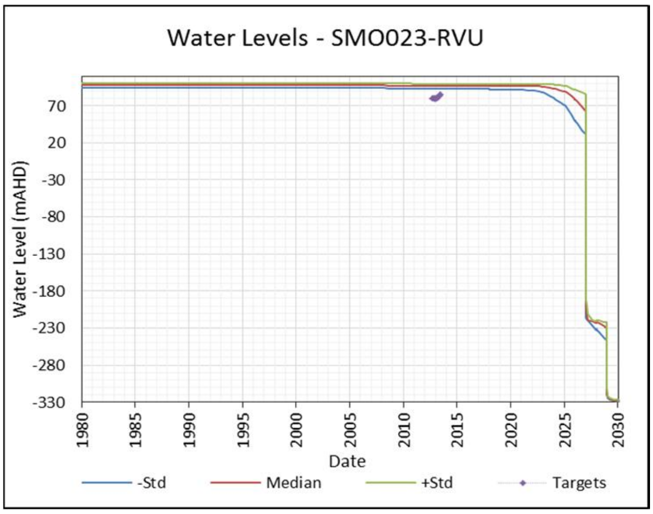

Water Levels - SMO023-BY3
Water Level (mAHD)
70
20
-30
-80
-130
-180
-230
-280
-330
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

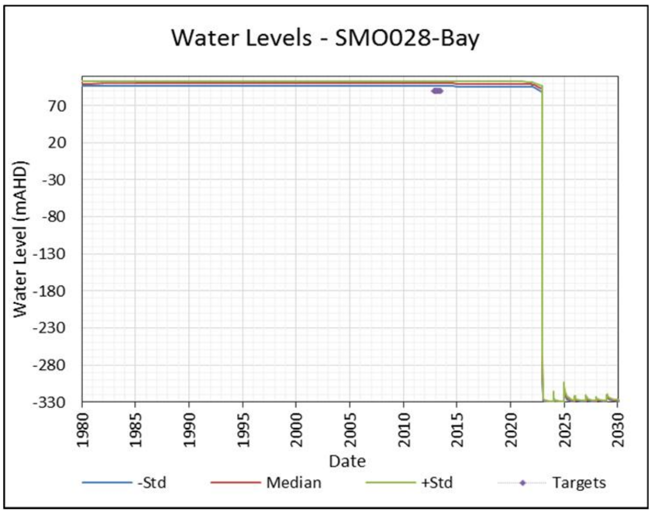

Water Levels - SMO023-BY5
Water Level (mAHD)
70
20
-30
-80
-130
-180
-230
-280
-330
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

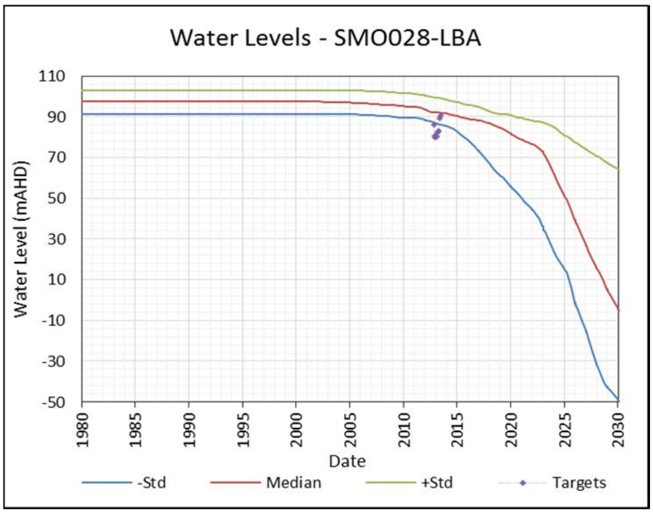

Water Levels - SMO023-RFL
Water Level (mAHD)
70
20
-30
-80
-130
-180
-230
-280
-330
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

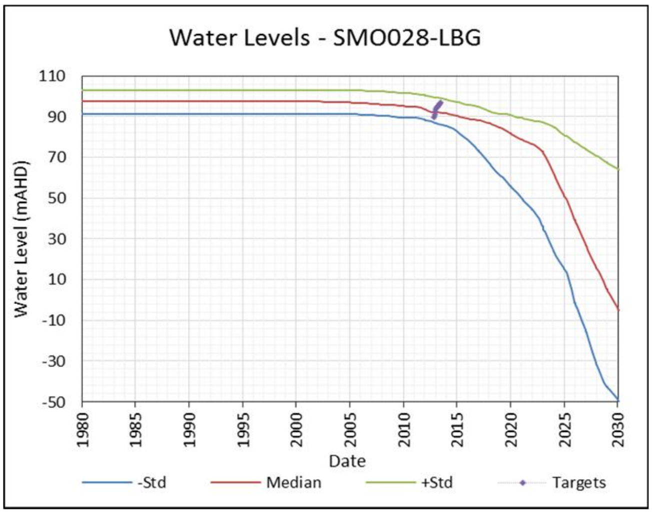

Water Levels - SMO023-RNL
Water Level (mAHD)
70
20
-30
-80
-130
-180
-230
-280
-330
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

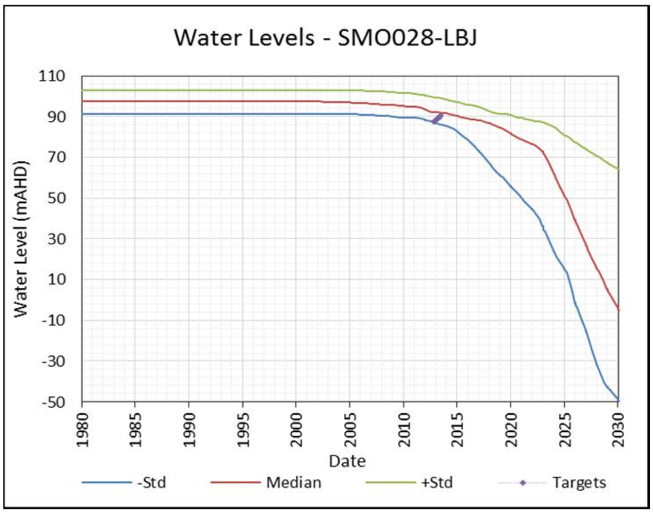

Water Levels - SMO023-RTU
Water Level (mAHD)
70
20
-30
-80
-130
-180
-230
-280
-330
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

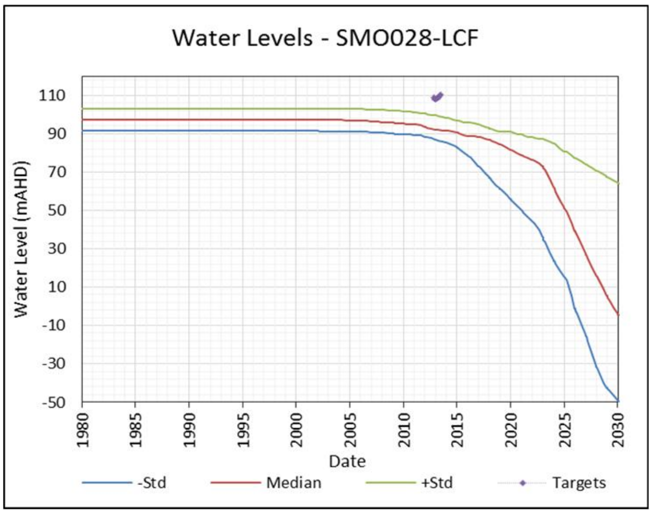

Water Levels - SMO023-RVU
Water Level (mAHD)
70
20
-30
-80
-130
-180
-230
-280
-330
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets

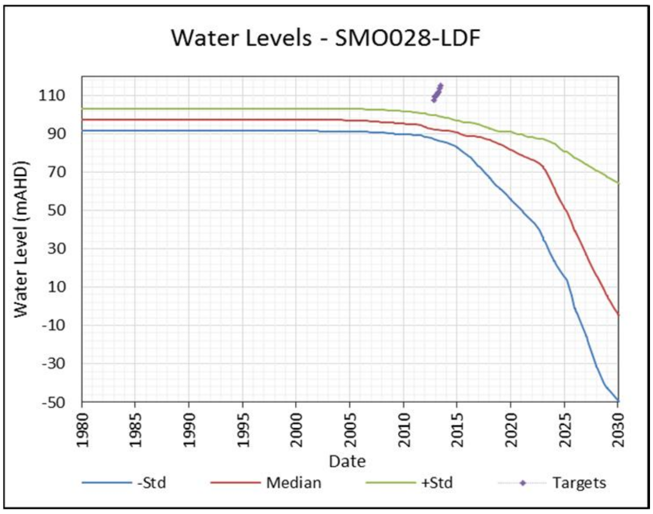

Water Levels - SMO028-Bay
Water Level (mAHD)
70
20
-30
-80
-130
-180
-230
-280
-330
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - SMO028-LBA
Water Level (mAHD)
110
90
70
50
30
10
-10
-30
-50
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - SMO028-LBG
Water Level (mAHD)
110
90
70
50
30
10
-10
-30
-50
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - SMO028-LBJ
Water Level (mAHD)
110
90
70
50
30
10
-10
-30
-50
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - SMO028-LCF
Water Level (mAHD)
110
90
70
50
30
10
-10
-30
-50
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets


Water Levels - SMO028-LDF
Water Level (mAHD)
110
90
70
50
30
10
-10
-30
-50
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Date
-Std
Median
+Std
Targets