APPENDIX H GROUNDWATER IMPACT ASSESSMENT

Angus Place Amended Project

Centennial Angus Place Pty Ltd

Groundwater Impact Assessment

IA161511-RPT-0006 | Rev0

31 October 2019

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Document history and status

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Angus Place Amended Project

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Jacobs Group (Australia) Pty Limited
ABN 37 001 024 095
Level 7, 177 Pacific Highway
North Sydney NSW 2060 Australia
PO Box 632 North Sydney
NSW 2059 Australia
T +61 2 9928 2100
F +61 2 9928 2444
www.jacobs.com

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Centennial Angus Place Pty Limited (Centennial) operates the Angus Place Colliery and propose to recommence longwall mining operations with the proposed LW1001 to LW1015 longwalls.

In April 2014 a State significant development application and the supporting Environmental Impact Statement for the Angus Place Mine Extension Project was submitted to the then NSW Department of Planning and Infrastructure. In response to a prolonged downturn in international coal markets, Centennial made the decision in March 2015 to move Angus Place Colliery to care and maintenance following the completion of secondary extraction within Longwall 900W. At this time, the assessment of the Angus Place Mine Extension Project was placed on hold and the Project did not progress to determination.

A revised mine plan is proposed for the Project. An Amended Project Report assessing the impacts of the revised mine plan will be submitted for SSD 5602. This surface water impact assessment has been prepared to support the Amended Project Report.

The life of mine will be extended to 2053. Dewatering of the mine will occur throughout the mine life, in conjunction with neighbouring Springvale Mine, and will continue to be transferred to the Springvale Water Treatment Project until 2053. Post mining no dewatering will occur and both Angus Place and Springvale underground mining areas will be flooded.

From 2020, there will be no discharge of mine water (treated or raw) from the project and all mine water not used on site will be transferred to the Springvale Water Treatment Project. Site water management at the Angus Place Pit Top will remain unchanged.

The revised mine plan has potential to impact a number of Temperate Highland Peat Swamps on Sandstone, which are listed as an Endangered Ecological Community under the EPBC Act due to their restricted distribution and their vulnerability to ongoing threats. Two swamps (Tri Star Swamp and Twin Gully Swamp) lie within the 26.5 degree angle of draw of longwall subsidence and will be directly undermined. A further five swamps lie within, or are in close proximity to, an extended 600m study area from the proposed longwalls.

Extensive baseline monitoring of swamp water levels and groundwater levels and quality have been undertaken for the Project including data for neighbouring Springvale Mine.

A detailed numerical groundwater model has been built on the MODFLOW USG platform for the purposes of assessing mine dewatering requirements and informing a groundwater impact assessment for the Project, as has a swamp water balance model. The swamp water balance model is a combined GoldSIM/Australian Water Balance Model and incorporates outputs from seepage faces and baseflow contribution generated from the groundwater model.

Groundwater drawdown and propagation within the Lithgow Seam are attenuated rapidly upgradient, to the east and south, but extends towards the east and northeast, where the Lithgow Seam remains hydraulically confined. The 1m drawdown contour extends approximately 17 km to the east. Drawdown in overlying layers, beneath the Mount York Claystone, is of similar extent and magnitude; however, above the Mount York Claystone, drawdown is limited to the immediate mining area, largely due to the Bankswall Sandstone being truncated and isolated from the east by the deeply incised Carne Creek valley.

No significant impacts are predicted to other groundwater users; however, Temperate Highland Peat Swamps on Sandstone exist above the proposed mining area and are listed as matters of national environmental significance under the EPBC Act and are registered as high priority groundwater dependent ecosystems under the relevant water sharing plan. Drawdowns resulting from mine dewatering and subsidence are predicted to impact on the Temperate Highland Peat Swamps on Sandstone. Corresponding reductions to surface flow are also anticipated and are discussed in the Surface Water Impact Assessment.

Given the predicted impacts to a high priority groundwater dependant ecosystem, the project does not meet the Level 1 Minimal Impacts Considerations of the NSW Aquifer Interference Policy. However, it is the intention of Centennial to offset the predicted impacts via the environmental offset facility of the EPBC Act.

Mine dewatering take has been partitioned between the applicable groundwater and surface water sources, including allowance for incidental surface water take through baseflow reduction (surface water licencing requirements are addressed in the Surface Water Impact Assessment). The maximum predicted take from each of the applicable water sources, and therefore the volume of share components for each of the water sources required to be held during mining are summarised below. It is noted that, in general, the maximum takes are predicted at the end of mining or in the immediate post mining period.

For the Sydney Basin Coxs River Groundwater Source, water take increases steadily through the mining with a maximum take predicted in the year following completion of mining at 1,213 ML in 2039/2040.

For the Sydney Basin Richmond Groundwater Source, water take is relatively consistent throughout mining with a maximum of 6,505 ML in 2037/2038. Groundwater take then declines through the post mining period.

Important note about your report

The purpose of this report is to present the findings of a groundwater impact assessment investigation carried out by Jacobs for Centennial Angus Place Pty Limited (the Client) in connection with the Angus Place Amended Project environmental impact statement. This report was produced in accordance with, and is limited to the scope of, services set out in the contract between Jacobs and the Client.

The findings presented in this report are professional opinions based solely on information and data provided or made available by the Client or otherwise available in the public domain documentation made available by the Client and its contractors.

Jacobs has relied on and presumed that documentation made available by the Client and its contractors is accurate and representative of the environmental conditions within the Project Application Area. 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, or if site conditions change, then it is possible that the conclusions as expressed in this report may not be relevant.

Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession and by reference to applicable guidelines and practice at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

This report has been prepared on behalf of and for the exclusive use of the Client, and is subject to, and issued in accordance with, the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of any use of, or reliance upon this report by any third party.

1. Introduction

1.1 Background

Centennial Angus Place Pty Limited (Centennial) operates the Angus Place Colliery under State significant consent MP06_0021.The key components of this consent are:

- extraction of up to 4 Mtpa of run of mine (ROM) coal from longwalls within the 900 Panel Area;
- employment of 300 full time equivalent (FTE) workforce;
- transfer of up to 13.4 ML/year of mine inflows from the existing workings (700 and 800 Panel Areas) water storage areas to the Springvale Water Treatment Project (SSD 7592);
- transfer of up to 4 Mtpa of run-of-mine (ROM) coal to the Western Coal Services Project (SSD 5579); and
- utilisation of the existing infrastructure at the Angus Place Colliery pit top and Newnes Plateau.

The development consent will expire in August 2024 and a new consent is required to ensure Angus Place Colliery is operational beyond this date.

1.1.1 Angus Place Mine Extension Project

A State significant development application (SSD 5602) and the supporting Environmental Impact Statement (EIS) for the Angus Place Mine Extension Project (APMEP) was submitted to the then NSW Department of Planning and Infrastructure (DP&I) in April 2014. The APMEP sought to extend the life of the Angus Place Colliery and to extend the life of mine workings into the new extension area (1000 Panel Area) to the east of the existing workings. The APMEP also sought to continue to utilise existing infrastructure approved under SSD 06_0021 as modified, and to construct and operate additional surface infrastructure on the Newnes Plateau to support the underground mining operations.

The exhibition period for the EIS commenced on 12 April 2014 and ended on 26 May 2014. A Response to Submissions (RTS) report was lodged with the then Department of Planning and Environment (now Department of Planning and Infrastructure (DP&I)) on 1 October 2014 to respond to submissions received during the public exhibition period. A supplementary RTS was lodged with DP&I in December 2014 to responses to additional government agency submissions on the initial RTS. The EIS and associated RTS reports are available on the Department’s Major Project website.

In response to a prolonged downturn in international coal markets, Centennial made the decision in March 2015 to move Angus Place Colliery to care and maintenance following the completion of secondary extraction within Longwall 900W. At this time, the assessment of the APMEP was placed on hold.

1.1.2 EPBC Referral

Due to the potential for the APMEP to impact on matters of national environmental significance (MNES) under the Environment Protection and Biodiversity Conservation Act 1999 (the EPBC Act), an EPBC referral (EPBC 2013/6889) was submitted to the then Department of Sustainability, Environment, Water, Population and Communities (now Department of Planning, Industry and Environment) on the 20 May 2013.

The APMEP was subsequently declared a controlled action on 7th July 2013, and supplementary Director General’s Requirements (DGRs) were issued on 30th August 2013.

The APMEP will be assessed by accredited assessment under the Environment Planning and Assessment Act, 1979 (EP&A Act).

1.1.3 Secretary’s Environmental Assessment Requirements

All mining projects in NSW must be assessed under the EP&A Act. The APMEP is classified as a State Significant Development (SSD) in accordance with the State Environmental Planning Policy (State and

Regional Development) 2011. An EIS must be prepared in response to requirements set out by the Secretary of the DPI&E. These requirements are known as the Secretary's Environmental Assessment Requirements (SEARs) and were formerly known as DGRs.

The 2014 EIS for the APMEP was prepared in accordance with the DGRs issued on 6 November 2012 by the then DP&I, and Supplementary DGRs issued on 30 August 2013 in relation to referral EPBC 2013/6889.

The DGRs (SEARs) for the APMEP remain valid. A summary of the DGRs relating to groundwater are provided in Table 2.3 of Section 2.3.

1.1.4 Project Review

Since the submission of the APMEP EIS, and subsequent RTS documents, a review of the APMEP has been completed to take into consideration the current monitoring information obtained from the adjacent Springvale Mine in relation to observed swamp impacts as well as recent changes in operational requirements.

This review has resulted in proposed changes to the APMEP to that presented in the EIS.

Three major changes have occurred in relation to the current approved operations at the Angus Place Colliery:

- Angus Place MOD 4 was approved to allow three gate roads to be developed in the 1000 Panel Area.
- Angus Place MOD 5 was approved that has altered the mine water management at the mine, a consequence of which is that from 2020 all mine inflows from the existing workings will be transferred to the Springvale Water Treatment Project (SSD 7592).
- Springvale Water Treatment Project (SSD 7592) has been developed to address condition 12 under schedule 4 of Springvale Mine's consent SSD 5594.

1.1.5 IESC Comments on the Angus Place Mine Extension Project

The APMEP EIS received a series of comments from the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mine Development (IESC) on the groundwater model prepared at that time (IESC, 2014). That model was the COSFLOW model developed by the CSIRO (2013) and the Groundwater Impact Assessment was prepared by RPS (2014a).

Comments received from the IESC were as follows:

- Relevant data and information:
  - Requirement to characterise existing surface water, groundwater and ecological conditions for the majority of Temperate Highland Peat Swamps on Sandstone (THPSS) (IESC01).
  - Seasonal surface water flow and an assessment, or estimation, of the baseflow component of the Coxs River (IESC02).
- Application of appropriate methods:
  - Inclusion of all swamps in the groundwater model (IESC03).
  - Finer scaled, site specific models, informed by a conceptualisation of the hydrology and hydrogeology, would be needed to have confidence in the predictions of groundwater impacts to individual swamps (IESC04).
  - Water quality impact estimations for the Coxs River need to consider the increased discharge volumes to Coxs River resulting from reduced demand from the Wallerawang Power Station (IESC05).
- Reasonable values and parameters in calculation:
  - Confidence in groundwater model predictions is limited by a lack of site-specific hydrogeological data and lineament groundwater flow behaviour (IESC06).

A response to the comments received from the IESC was provided in RPS (2014b). As well, the issues raised were taken into consideration during the development of the new groundwater and swamp water balance models (JBS&G, 2019a,b).

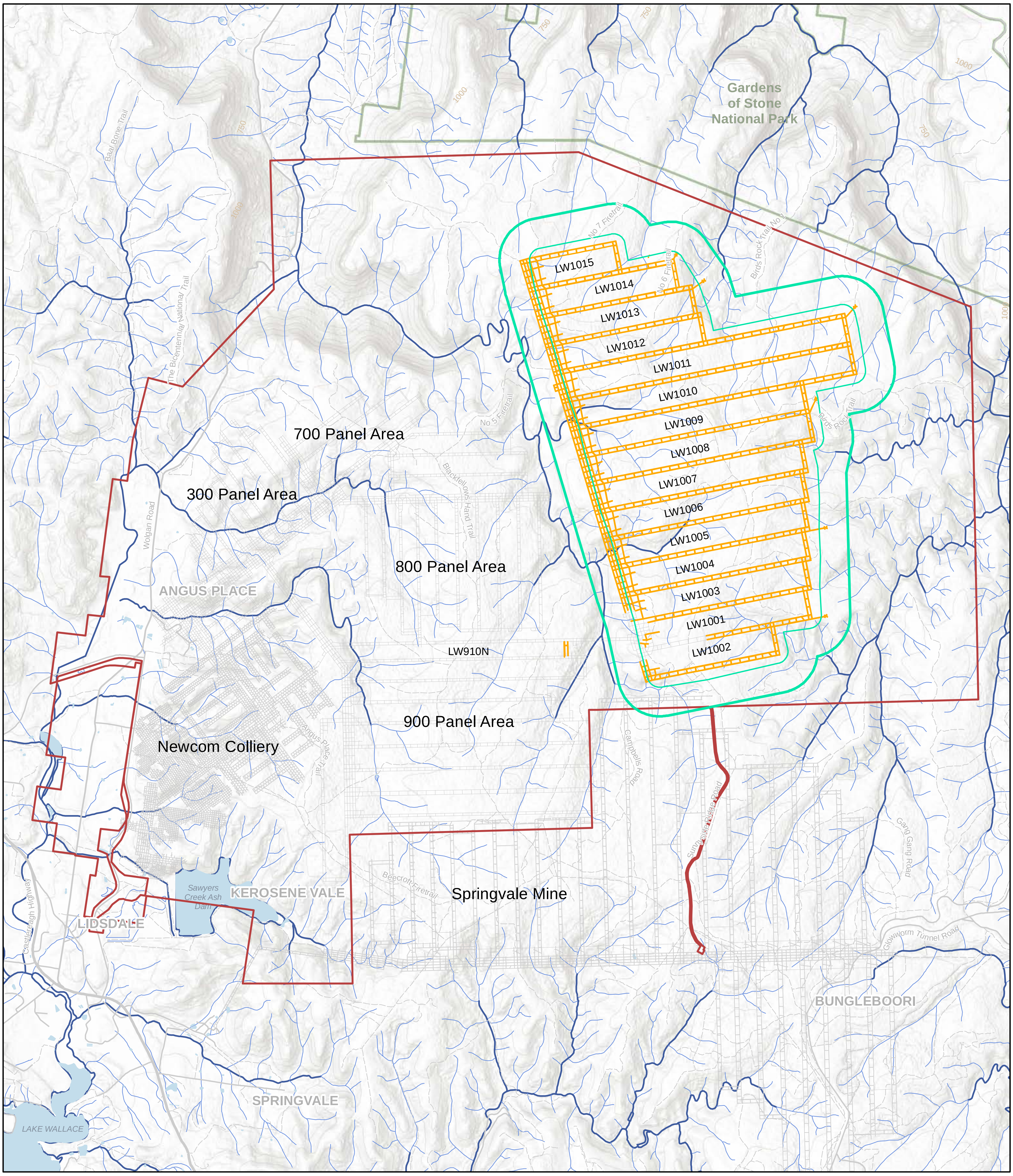
An updated response to matters raised by the IESC is provided in Section 5.7.

1.2 Amended Project Overview

The APMEP, as amended will, in general, include all currently approved operations, facilities and infrastructure of the Angus Place Colliery, except as otherwise indicated below:

- Extend the life of the mine to 31 December 2053;
- Increase in Project Application Area from 10,460ha to 10,551ha;
- Increase in full time equivalent (FTE) personnel from 300 to 450;
- Increase the extraction up to 4.5 million tonnes per annum (Mtpa) of run of mine (ROM) coal from the Lithgow Seam underlying the Project Application Area;
- Continued development of new roadways to enable access to the proposed 1000 panel longwall mining area;
- Extraction of existing approved longwall 910N;
- Development and extraction of 15 longwalls (LW1001-1015) with void widths of 360m;
- Development of underground roadway connections between the Angus Place Colliery underground mine workings and the Springvale Mine underground mine workings;
- Transfer up to 4.5 Mtpa of run-of-mine (ROM) coal to the Angus Place pit top for processing and handling before being transported off site in accordance with the Western Coal Services Project development consent (SSD 5579);
- Transfer up to 4.5 Mtpa of ROM coal by underground conveyor to the Springvale Mine pit top via proposed new underground connection roadways for handling and processing in accordance with the Springvale Mine Extension Project development consent (SSD 5594);
- Enlargement of the ROM coal stockpile at the Angus Place Colliery pit top from 90,000 t to 110,000 t capacity;
- Construction of the approved but not yet constructed 4.5 m shaft at the Angus Place Ventilation Facility (APC-VS2) on the Newnes Plateau;
- Installation and operation of the ventilation fan at the Angus Place Ventilation Facility (APC-VS2) on the Newnes Plateau;
- Construction and operation of one additional downcast shaft and mine services boreholes within the proposed Angus Place Ventilation Facility (APC-VS3) on the Newnes Plateau to support mining in the 1000 panel area;
- Construction and operation of additional dewatering facilities and associated infrastructure on the Newnes Plateau to support mining in the 1000 panel area to facilitate the transfer of mine water into the Springvale Water Treatment Project;
- Transfer of mine inflows from the existing and proposed workings at Angus Place Colliery to the Springvale Water Treatment Project (SSD 7972) for treatment and beneficial reuse at the Mount Piper Power Station;
- Operation of the Angus Place Colliery 930 Bore and associated infrastructure for raw mine water transfer from the surface infrastructure back to the underground mining area when required; and
- Connection to the Lithgow City Council main sewer line prior to the commencement of longwall extraction (subject to a separate development application through Lithgow City Council). A pipeline system is proposed to be constructed along the Wallerawang Haul Road (similar to the Angus Place Pipeline alignment) to connect to Lithgow City Council's Duncan Street Pump station.

Figure 1.1: Angus Place Amended Project Overview



Infrastructure
- Proposed Workings
- Existing Workings

Project Area
- Project Area

APE Study Areas
- 26.5 degree AoD
- 600m Study Area

Contours
- 50 Metre

Hydrology
- Water Areas
- Stream Order 1 - 2
- Stream Order 3 - 6

Tenures
- National Parks

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Angus Place Amended Project

Data Sources - Centennial Angus Place Pty Ltd: Project Area, Infrastructure (2019); NSW Government Public Data: Roads, Hydrology, Placenames; Geosciences Australia (ELVIS): 50m Contours; Office of Environment and Heritage NSW: Tenures; ESRI ArcGIS Image Service: World Elevation Terrain, World Topographic Map

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1.3 Existing Water Management and Proposed Changes

1.3.1 Existing Water Management

The key points in relation to the existing mine water management at Angus Place Colliery with respect to groundwater are described below. Additional water management measures at the Angus Place Colliery pit top are discussed in the Surface Water Impact Assessment (Jacobs, 2019).

- Mine inflows from the existing workings are managed as follows.
  - Mine water is treated in a temporary water treatment plant (reverse osmosis) located at the Angus Place Colliery pit top, and up to 10 ML/day of the treated water is discharged via Angus Place LDP001 to Kangaroo Creek (Coxs River catchment). This discharge will cease from 2020, and mine inflows will be transferred to the Springvale Water Treatment Project via the Angus Place Pipeline, currently under construction.
  - Mine inflows (untreated) are transferred to the Springvale Delta Water Transfer Scheme (SDWTS) via the dewatering bore facility 940 Bore, located on Newnes Plateau, above the mining area. The SDWTS also manages Springvale Mine's mine inflow contributions. Mine water transferred to the SDWTS was previously discharged to Sawyers Swamp Creek (Coxs River catchment) via Springvale Mine's LDP009. This discharge ceased as of 30 June 2019, and mine inflows are now transferred to, and are managed by, the Springvale Water Treatment Project.
- The pit top surface water management system manages clean and dirty water separation, as well managing grey water and sewage from the administration and bath house buildings.

1.4 Proposed Changes to Water Management

From 2020, all mine inflows from existing workings will be transferred to the Springvale Water Treatment Project, as discussed above.

Changes to water management infrastructure, with respect to groundwater, required to support the Amended Project are detailed below.

1.4.1 Newnes Plateau Infrastructure

Mine inflows, comprising groundwater intercepted during mining are required to be managed to ensure a safe work environment underground. New dewatering facilities will require to be constructed on the Newnes Plateau, which will dewater the existing and proposed workings. Additional infrastructure, such as associated trenched pipelines and booster pump stations and power kiosks, will also be required. Pipelines will follow existing access tracks, albeit widened for installation of the pipeline and power cables. The pipelines from the Angus Place dewatering facilities will connect to the existing Springvale Water Treatment Project pipeline.

It is noted that no infrastructure will be sited in the vicinity of any waterway and pipelines will not be trenched through any waterway.

1.4.2 Study Areas

In addition to the greater Project Application Area, for the purposes of assessing subsidence related impacts, two refined study areas relating to the location of the proposed longwalls are defined.

MSEC (2019) have defined the Study Area as the surface area that could be affected by the extraction of the proposed LW1001 to LW1015. Two areas have been considered in this report, these being the Study Area based on the 26.5° angle of draw of longwall subsidence, and a Study Area based on a 600m offset from the proposed longwalls.

The Study Area based on the 26.5° angle of draw represents the minimum extent for the assessments of the conventional ground movements (i.e. vertical subsidence and its associated effects). However, it is noted that low level conventional ground movements can extend beyond the 26.5° angle of draw.

The Study Area based on the 600m offset boundary represents the minimum extent of the assessments of the valley related effects. This distance is based on the recommendations from the Southern Coalfield Inquiry (DPIE, 2008) for the risk management zones.

The Study Areas are presented on Figure 1.1 and other figures as relevant. Further discussion regarding the development of the Study Areas is provided in MSEC (2019).

2. Relevant Legislation, Policy and Guidelines

Commonwealth and State legislation, policies and guidelines relevant to groundwater management are outlined below.

2.1 Commonwealth Legislation and Policies

2.1.1 Environment Protection and Biodiversity Conservation Act 1999

The EPBC Act prescribes the Commonwealth Government's role in environmental assessment, biodiversity conservation and the management of protected areas and species, population and communities and heritage items.

Approval from the Commonwealth Minister for the Environment is required for:

- An action which has, would have, or is likely to have a significant impact on 'Matters of National Environmental Significance' (MNES) such as wetlands, ecological communities, or water resources.
  - An action by the Commonwealth or a Commonwealth agency which has, would have, or is likely to have a significant impact on the environment
- An action on Commonwealth land which has, would have, or is likely to have a significant impact on the environment
- An action which has, would have, or is likely to have a significant impact on the environment of Commonwealth land, no matter where it is to be carried out.
- Of most relevance to the APMEP, MNES include the Temperate Highland Peat Swamps on Sandstone (THPSS) which are federally listed Endangered Ecological Communities under the EPBC Act, and occur within the Project Application Area.
- Water resources in relation to coal seam gas and large coal mining developments are also considered as MNES.

Impacts on MNES are assessed through a referral process to the Commonwealth Department of the Environment and Energy, and the EPBC Act Significant Impact Guidelines. If the Commonwealth Minister for the Environment determines that a project is likely to have a significant impact on a MNES, then the project becomes a controlled action and approval of the Commonwealth Minister for the Environment would be required.

2.1.1.1 Significant Impact Guidelines: Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources 2013

The Significant Impact Guidelines include general criteria for whether there is a real or "not remote" chance or possibility that an action will have a significant impact on water resources, which may directly or indirectly result in changes to the hydrology of a water resource, or the water quality of a water resource, that is of sufficient scale or intensity as to reduce the current or future utility of the water resource for third party users, including environmental and other public benefit outcomes, or to create a material risk of such reduction in utility occurring.

Under the Significant Impact Guidelines, the value of the water resource needs to be confirmed such that impacts from actions can be evaluated on their significance. Key factors for determining the value of a water resource is its utility for all third-party users, including environmental and other public benefit outcomes. Outcomes relevant to the Project include:

- Provisioning services (e.g. use by other industries and use as drinking water).
- Cultural services (e.g. recreation and tourism, science and education).
- Supporting services (e.g. maintenance of ecosystem function).

If there is evidence, based on data, modelling and stakeholder engagement, that the action would not materially affect the availability and quality of water for all third-party users, then that would reduce3 the likelihood of the action having a significant impact.

2.1.2 National Water Quality Management Strategy

The National Water Quality Management Strategy (NWQMS) is the adopted national framework to protecting and improving water quality in Australia. The main policy objective of the NWQMS is to achieve sustainable use of the nation's water resources, protecting and enhancing their quality, while maintaining economic and social development. The framework consists of a number of guideline documents, of which certain documents relate to protection of surface water resources and others relate to the protection of groundwater resources.

The framework refers to other NWQMS guidelines documents for specific water quality objective values. Where the resource requiring protection is a surface water resource with a component of groundwater discharge, the water quality objectives should be applied at the point of discharge. Other NWQMS guideline documents containing specific water quality objectives guideline values that are relevant to the project include:

- Guidelines for Managing Risks in Recreational Water (National Health and Medical Research Council (NHMRC) 2008)
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000)
- Australian Drinking Water Guidelines (NHMRC/NRMMC, 2011).

Where these specific water quality objectives are identified, the groundwater component of the water source should meet the guideline values. For the APMEP, this means that the current uses of groundwater or surface water must not be degraded as a result of the construction or operation of the APMEP.

2.2 State Legislation and Policies

2.2.1 Water Management Act 2000

Water resources in NSW are administered under the Water Act 1912 and the Water Management Act 2000 by the NSW Department of Industry – Water (DoI Water), in the NSW Department of Planning, Industry and Environment. The Water Management Act 2000 governs the issue of water access licences and approvals for water sources (rivers, lakes, estuaries and groundwater) in New South Wales where Water Sharing Plans have started. The Water Sharing Plans relevant to the APMEP have started and the area is therefore governed under the Water Management Act 2000.

Part 2 of the Water Management Act 2000 establishes access licences for the take of water within a particular water management area. The Water Management (General) Regulation 2011 is the primary regulation instrument under the Water Management Act 2000. In general, the Water Management Act 2000 requires:

- a water access licence to take water
- a water supply works approval to construct a work
- a water use approval to use the water.

2.2.1.1 Water Sharing Plans

Water Sharing Plans (WSPs) establish rules for sharing water between the environmental needs of the river or aquifer and water users, and between different types of water use such as town supply, rural domestic supply, stock watering, industry and irrigation. There are Water Sharing Plans for regulated and unregulated river catchments and groundwater sources in water management areas.

For groundwater the APMEP proposed longwalls reside in the Sydney Basin Richmond Groundwater Source of the Greater Metropolitan Region Groundwater Sources 2011 and the Angus Place Colliery pit top resides in the Sydney Basin Coxs River Groundwater Source of the Greater Metropolitan Region Groundwater Sources 2011. The boundaries of these, and adjoining groundwater sources are shown on Figure 2.1.

For surface water, the APMEP lies on the boundary of the Upper Nepean and Upstream Warragamba Water Source (Wywandy Management Zone) (southwest) and the Hawkesbury and Lower Nepean Rivers Water Source (Colo River Management Zone) (northeast) of the Water Sharing Plan for Greater Metropolitan Region Unregulated River Water Sources 2011 (NSW). Surface water source boundaries are provided in the Surface Water Impact Assessment.

2.2.1.2 NSW Aquifer Interference Policy

The NSW Aquifer Interference Policy (AIP) (NSW Office of Water, 2012) presents the requirements of the assessment of aquifer interference activities administered by the WMA 2000.

Key components to the AIP are:

- All water taken must be properly accounted for within the extraction limits set by the relevant Water Sharing Plan. A water licence is required whether water is taken either incidentally or by consumptive use. The AIP also requires consideration of the continued take of groundwater or connected surface waters following cessation of an aquifer interference activity.
- In addition to licencing requirements, the WMA 2000 includes the concept of ensuring “no more than minimal harm”, and the AIP establishes a number of minimal impact considerations relating to water level, water pressure, and water quality. Minimal impact considerations are assigned according to the aquifer category and whether the aquifer is “highly productive” or “less productive”.
- The AIP also requires planning for contingency or mitigating measures in the event that actual impacts are greater than predicted, including making sure there is sufficient monitoring in place.

Sydney Basin Richmond Groundwater Source of the Greater Metropolitan Region Groundwater Sources 2011 is considered to be a highly productive aquifer based on the AIP criteria (NSW Office of Water, 2012) of:

- has total dissolved solids of less than 1,500 mg/L; and
- contains water supply works that can yield water at a rate greater than 5 L/s.

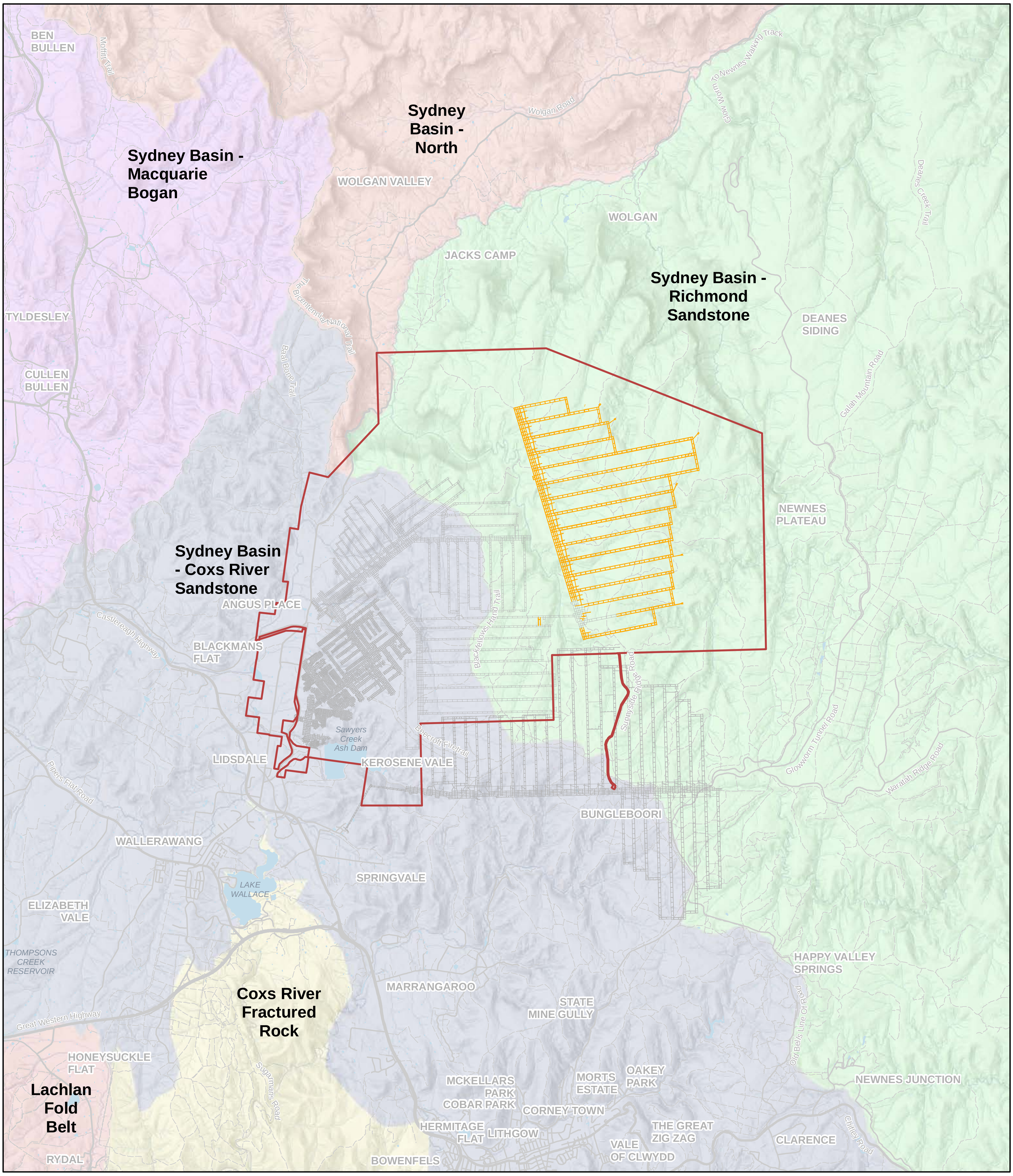
The lithologies of the Sydney Basin within the Project Application area are also mapped as Highly Productive Groundwater – Porous Rock (DPI Water, 2013).

Thresholds for key minimal impact considerations have been developed for the highly productive and less productive groundwater sources, these thresholds deal with water table and groundwater pressure drawdown as well as groundwater and surface water quality changes.

Key minimal impact considerations for the highly productive porous rock aquifers are provided in Table 2.1.

The minimum impact considerations for water quality refer to the beneficial use category of the groundwater source. Beneficial use categories are outlined in the NSW Groundwater Quality Protection Policy (refer Section 2.2.2 below). The NSW Government provides a checklist for assessment under the AIP that is provided in Appendix H. Assessment of the APMEP against the AIP Minimal Impacts Considerations is provided in Section 5.7.

Figure 2.1: Groundwater Sources



Water Sharing Plan Groundwater Sources

- Coxs River Fractured Rock
- Lachlan Fold Belt
- Sydney Basin - Coxs River Sandstone
- Sydney Basin - Richmond Sandstone
- Sydney Basin - North
- Sydney Basin - Macquarie Bogan

Infrastructure

- Proposed Workings
- Existing Workings

Project Area

- Project Area

Roads

- Primary Road
- Arterial Road
- Sub-Arterial Road
- Local Road
- Track-Vehicular

Hydrology

- Water Areas

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Data Sources - Centennial Angus Place Pty Ltd: Project Area, Infrastructure (2019); NSW Government Public Data: Roads, Hydrology, Placenames; Geosciences Australia (ELVIS): 50m Contours; Department of Primary Industries: Water Sharing Plan; Office of Environment and Heritage NSW: Tenures; ESRI ArcGIS Image Service: World Elevation Terrain, World Topographic Map

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Table 2.1: Level 1 Minimum Impact Considerations – Highly Productive Groundwater Sources

Water Source	Water Table	Water Pressure	Water Quality
Porous Rock Water Sources	1. Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m from any (a) high priority GDE, or (b) high priority culturally significant site, listed in the schedule of the relevant water sharing plan. A maximum of a 2m decline cumulatively at any water supply work. 2. If more than 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m from any: (a) high priority GDE; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan then appropriate studies (including the hydrogeology, ecological condition and cultural function) will be required to demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or culturally significant site. If more than 2m decline cumulatively at any water supply work then make good provisions should apply.	1. A cumulative pressure head decline of not more than a 2m decline, at any water supply work. 2. If the predicted pressure head decline is greater than requirement 1. above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long-term viability of the affected water supply works unless make good provisions apply.	1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity. 2. If condition 1 is not met then appropriate studies will be required to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.

2.2.2 NSW Groundwater Quality Protection Policy

The NSW Groundwater Quality Protection Policy (DLWC, 1998) objectives are:

- All groundwater systems should be managed such that their most sensitive identified beneficial use (or environmental value) is maintained.
- Town water supplies should be afforded special protection against contamination.
- Groundwater pollution should be prevented so that future remediation is not required.
- For new developments, the scale and scope of work required to demonstrate adequate groundwater protection shall be commensurate with the risk the development poses to a groundwater system and the value of the groundwater resource.
- A groundwater pumper shall bear the responsibility for environmental damage or degradation caused by using groundwaters that are incompatible with soil, vegetation or receiving waters.
- Groundwater Dependent Ecosystems (GDEs) will be afforded protection.
- Groundwater quality protection should be integrated with the management of groundwater quantity.
- The cumulative impacts of developments on groundwater quality should be recognised by all those who manage, use, or impact on the resource.
- Where possible and practical, environmentally degraded areas should be rehabilitated, and their ecosystem support functions restored.

The following beneficial uses, or environmental values, are adopted by the NSW Groundwater Quality Protection Policy:

- ecosystem protection
- recreation and aesthetics
- raw water for drinking water supply
- agricultural water
- industrial water.

Specific water quality characteristics are determined on a case-by-case basis with due consideration of existing site conditions and uses within each beneficial class.

2.2.3 Protection of the Environment Operations Act 1997

The Protection of the Environment Operations Act 1997 (POEO Act) is administered by the NSW Environment Protection Authority (NSW EPA). The objectives of the POEO Act are to protect, restore and enhance the quality of the environment.

The POEO Act regulates and requires licensing for environmental protection, including for waste generation and disposal and for water, air, land and noise pollution. Relevant features of the POEO Act include:

- protection of the environment policies (PEPs)
- integrated environment protection licensing
- regulation of scheduled and non-scheduled activities.

Under the POEO Act, an Environment Protection Licence (EPL) is required for premises at which a 'scheduled activity' is conducted. Schedule 1 of the POEO Act lists activities that are scheduled activities for the purpose of the act.

Centennial holds an EPL for mining for coal and associated works at the Angus Place Colliery (EPL 467). The EPL covers the mining operation, surface facilities and overland conveyors at Angus Place Colliery. The provisions of EPL 467 prescribe water quality and volumetric discharge limits of various surface water pollutants to designated Licensed Discharge Points (LDPs). The location of LDPs under EPL 467 (latest revision, 9 April 2019), and details of limits to quality and volumetric discharge are summarised in Table 2.2.

Table 2.2: Summary of Licensed Discharge Points - EPL467

Discharge Point	Location and function	Volumetric Limit (kL/d)	Oil and Grease (mg/L)	pH	TSS (mg/L) / Turbidity (NTU)	Electrical Conductivity (µS/cm)
LDP001	Discharge of mine water make and runoff into Kangaroo Creek through wetlands.	10,000	10	6.5 – 9.0	30 / 40	350
LDP002[1]	Discharge of surface water from the Angus Place Colliery surface facilities into the Coxs River through settling ponds.	N/A	10	6.5 – 9.0	30 / 40	N/A
LDP003	Discharge from the Kerosene Vale sediment dam west of the Haul Road	N/A	10	6.5 – 8.5	30 / 40	
LDP005	Discharge of treated sewage effluent from Angus Place Colliery via a spray irrigation network to a designated utilisation area. (Irrigation area (2.5-3 ha) located adjacent to aeration ponds)	N/A	N/A	N/A		N/A

Notes – 1. Clause L2.5 of EPL 467 notes that L2.4 conditions do not apply to LDP002 (and LPD003) when discharge occurs from those LDPs within 5 days of a rainfall event exceeding 44mm over any consecutive 5 day period.

In addition to the physio-chemical parameters outlined on Table 2.1, discharge at LDP001 is also subject to the following pollutant concentration limits:

- Aluminium (0.45mg/L)
- Arsenic (0.024mg/L)
- Boron (0.37mg/L)
- Copper (0.007mg/L)
- Fluoride (1.8mg/L)
- Iron (0.4mg/L)
- Manganese (1.7mg/L)
- Nickel (0.047mg/L)
- Zin (0.05mg/L)

2.2.4 State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011

The State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011 (NSW) is an environmental planning instrument under the Environmental Planning and Assessment Act 1979 (NSW).

Surface water catchments within the Upper Nepean and Upstream Warragamba Water Source, of which Kangaroo Creek and the Coxs River are tributaries, are declared by the State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011 (NSW) to be within the Sydney Drinking Water Catchment.

Part 2, Clause 10 of the State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011 (NSW) requires that:

10 Development consent cannot be granted unless neutral or beneficial effect on water quality

(1) A consent authority must not grant consent to the carrying out of development under Part 4 of the Act on land in the Sydney drinking water catchment unless it is satisfied that the carrying out of the proposed development would have a neutral or beneficial effect on water quality.

(2) For the purposes of determining whether the carrying out of the proposed development on land in the Sydney drinking water catchment would have a neutral or beneficial effect on water quality, the consent authority must, if the proposed development is one to which the NorBE Tool applies, undertake an assessment using that Tool.

Following an amendment to the State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011 (NSW), Part 2, Clause 11A now requires that:

11A   Neutral or beneficial effect on water quality—continuing development

(1) This clause applies for the purposes of determining under this Policy whether the carrying out of continuing development on land in the Sydney drinking water catchment would have a neutral or beneficial effect on water quality.

(2) Continuing development is any development (such as mining) for which development consent was limited to the carrying out of the development for a particular time or to a particular area or intensity, but which was likely to be the subject of future applications for consent for its extension or expansion.

(3) If:

(a) development consent was granted for continuing development ("the existing development consent"), and

(b) a development application is made for consent to extend or expand the carrying out of the development ("the proposed development"), and

(c) the development application is made before the authority conferred by the existing development consent expires or is exhausted, the carrying out of the proposed development will have a neutral or beneficial effect on water quality if it will have the same or a lesser adverse impact on water quality when compared to the adverse impact that the continuing development would have if it were extended or expanded under similar conditions as the existing development consent.

(4) Subclause (3) extends to an existing development consent that is to be surrendered if consent is granted on the determination of the development application.

(5) In this clause, a reference to an existing development consent includes a reference to a project approved under Part 3A of the Act before its repeal (or granted after its repeal pursuant to Schedule 6A to the Act).

2.3 Summary of Requirements

A summary of the APMEP DGRs (SEARs) and other requirements, and where they are addressed in this report is provided in Table 2.3.

Table 2.3: Summary of Requirements

DGRs Specific to Groundwater (Issued on 6 November 2012)	Report
Detailed assessment of the key issues and any other significant issues identified in this risk assessment, which includes a description of the existing environment, using sufficient baseline data	Summary of risk assessment presented in Hydrogeological Model Report, Appendix H
An assessment of the potential impacts of all stages of the development, including any cumulative impacts, taking into consideration relevant guidelines, policies, plans and statutes	Section 5.2 Section 5.9
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	Potential impacts to swamps and direct vegetation clearing for infrastructure will be offset the environmental offset

DGRs Specific to Groundwater (Issued on 6 November 2012)	Report
	facility of the EPBC Act. Refer to Biodiversity Assessment, RPS (2019).
Detailed assessment of potential impacts on the quality and quantity of existing surface water and ground water resources in accordance with the NSW Aquifer Interference Policy, including: • impacts on affected licensed water users and basic landholder rights. • impacts on riparian, ecological, geo-morphological and hydrological values of watercourses, including groundwater dependent ecosystems and environmental flows. • whether the development can operate to achieve a neutral or beneficial effect on water quality in the drinking water catchment, consistent with the provisions of State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011.	Impacts to other groundwater users – Section 5.4.4 Impacts to GDEs – Section 5.4.5 Impacts to baseflow – Section 5.4.6 Other impacts to watercourses assessed in the Surface Water Impact Assessment Neutral or beneficial effect – Section 5.7
Identification of any licensing requirements, including existing or future Environment Protection Licences (EPLs) or Pollution Reduction Programs (PRPs), and approvals under the Water Act 1912 and/or Water Management Act 2000	Water access licence requirements – Section 6
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).	Addressed in Surface Water Impact Assessment
A description of the measures proposed to ensure the development can operate in accordance with the requirements of any relevant WSP or water source embargo.	Section 6
A detailed description of the proposed water management system water monitoring regime, beneficial water re-use program and all other proposed measures to mitigate groundwater impacts	Groundwater monitoring – Section 4 and Section 7 Surface water monitoring and water re-use address in Surface Water Impact Assessment
Supplementary DGRs Specific to Groundwater (Issued on 30 August 2013)	
An assessment of all relevant impacts on water resources and water related values, including: detailed information addressing the Independent Expert Scientific Committee Information Guidelines for Proposals Relating to the Development of Coal Seam Gas and Large Coal Mines where there is a Significant Impact on Water Resources. detailed information addressing the department's Water Resources Terms of Reference, currently in preparation.	Water Balance: – Refer to Surface Water Impact Assessment Impact Assessment including Risk Assessment: – Section 5 and Appendix G Management and Monitoring: – Section 7
IESC Comments on the APMEP EIS (Issued 25 August 2014)	
Relevant data and information: Requirement to characterise existing surface water, groundwater and ecological conditions for the majority of Temperate Highland Peat Swamps on Sandstone (THPSS) (IESC01). Seasonal surface water flow and an assessment, or estimation, of the baseflow component of the Coxs River (IESC02).	Section 5.7 Existing groundwater conditions Section 4 and Section 5.1. Existing surface water and ecological conditions are discussed under the relevant impact assessments. Surface flow and baseflows in the Coxs River are discussed in the Surface Water Impact Assessment.
Application of appropriate methods: Inclusion of all swamps in the groundwater model (IESC03). Finer scaled, site specific models, informed by a conceptualisation of the hydrology and hydrogeology, would be needed to have confidence in the predictions of groundwater impacts to individual swamps (IESC04).	Section 5.7 and Appendix G. Coxs River water quality is no longer an issue with the implementation of the Springvale water Treatment Project.

DGRs Specific to Groundwater (Issued on 6 November 2012)	Report
Water quality impact estimations for the Coxs River need to consider the increased discharge volumes to Coxs River resulting from reduced demand from the Wallerawang Power Station (IESC05).	
Reasonable values and parameters in calculation: Confidence in groundwater model predictions is limited by a lack of site-specific hydrogeological data and lineament groundwater flow behaviour (IESC06).	Section 5.7 and Appendix G.
State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011	
Neutral or Beneficial Impact	Section 5.8
NSW Aquifer Interference Policy	
NSW AIP Checklist	Section 5.9 and Appendix H

3. Existing Environment

3.1 Climate

The Newnes State Forest is described as a warm temperate climate with an annual rainfall of 1,091mm (Lithgow (Newnes State Forest); Bureau of Meteorology (BoM) Station No. 63062). Summers are mild with average temperatures of 23.5˚C and winters are cold with average minimum temperatures of -1.0˚C. Rainfall and temperature are highest in summer and lowest during winter.

Angus Place Colliery pit top facilities are located on the footslopes below the Newnes Plateau, about 150m lower in elevation. Climatological characteristics at the Angus Place Colliery pit top are different to that encountered on the Newnes Plateau, with average annual rainfall at the pit top of 758mm (Lidsdale (Maddox Lane); BoM Station No. 63132).

3.1.1 Rainfall

BoM Station No. 63062 (Newnes Forest Centre) located on the Newnes Plateau has rainfall data records from 1938 to 1999. Centennial also operate a weather station on the Newnes Plateau (SVNEWPFR) with data from 1998 to present. A compilation of data from these two stations are provided on Figure 3.1.

Rainfall at the Angus Place Colliery pit top is provided by BoM Station No. 63132 (Maddox Lane) in Lidsdale. The Maddox Lane gauge has data from 1959 to present. Data is presented along with Plateau data and key rainfall statistics on Table 3.1.

Mean annual rainfall on the Newnes Plateau at Newnes Forrest Centre is typically of the order of 44% higher than that at Lidsdale. Average annual rainfall at Newnes Prison Farm is also lower than that for Newnes Forrest Centre, reflecting the predominantly below average rainfall of the past 18 years.

Table 3.1: Average Monthly Rainfall Statistics

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
BoM Station No. 63132 (Maddox Lane)													
Mean	85.8	75.9	66.6	42.4	47.9	50.3	50.0	63.2	53.0	68.0	72.4	73.9	758.3
Lowest	8.0	5.6	3.8	1.0	2.6	2.6	2.7	1.8	3.4	2.4	7.6	0.0	329.8
Median	76.7	68.2	51.4	31.6	40.6	39.8	42.6	50.0	49.9	71.4	62.5	66.1	761.8
Highest	213.6	270.4	270.4	202.6	131.2	228.3	214.0	363.8	123.0	228.4	164.7	217.0	1260.3
BoM Station No. 63062 (Newnes Forest Centre)													
Mean	121.0	114.1	102.9	79.9	81.3	83.0	68.3	83.5	67.9	91.5	89.0	90.4	1091.9
Lowest	18.8	5.6	5.1	6.2	11.0	0.0	2.0	4.6	0.0	6.4	4.7	2.6	495.5
Median	132.9	90.8	78.7	60.0	63.2	62.8	53.9	67.2	64.3	80.8	78.6	67.1	1136.8
Highest	280.8	338.6	519.4	299.1	286.9	320.0	240.7	412.4	207.2	267.2	209.3	303.2	1889.1
Centennial Newnes Prison Farm													
Mean	93.7	119.6	105.3	54.5	41.1	79.2	49.9	52.7	54.5	83.6	100.4	84.2	924.6
Lowest	19.5	15.2	29.5	10.0	13.0	9.0	8.5	13.5	0.4	8.0	31.5	37.5	595.5
Median	79.3	99.5	89.5	49.3	35.4	54.1	39.0	46.6	52.0	77.9	80.8	75.6	979.9
Highest	196.8	285.0	244.5	206.4	94.0	255.5	114.5	108.5	137.6	272.5	196.0	207.0	1286.0

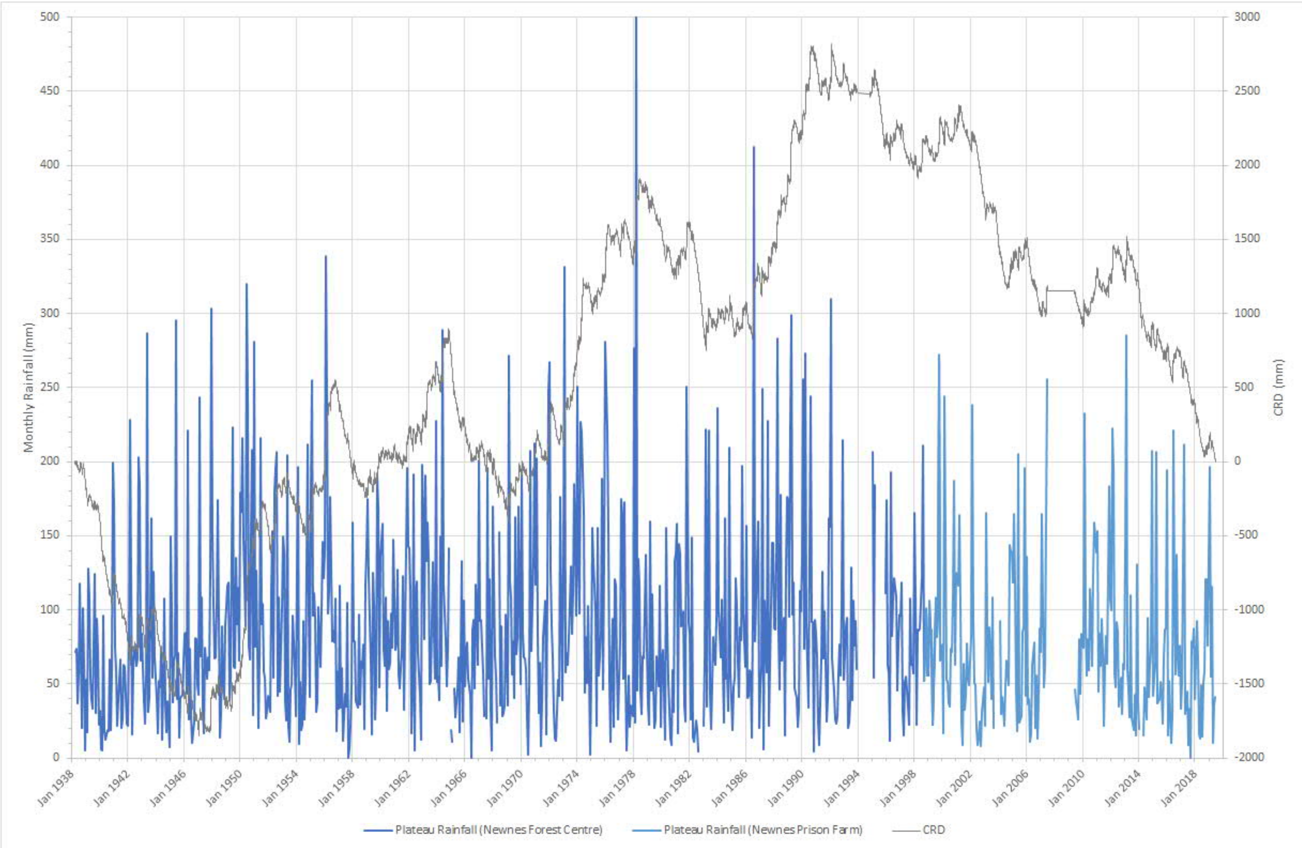


Figure 3.1: Newnes Plateau Rainfall (1938 to 2019)

Figure 3.1 also presents the cumulative deviation of rainfall trends from the long-term average rainfall (CRD) for the combined Newnes Forrest Centre and Newnes Prison Farm rainfall record. From the CRD trend it is apparent that from 1947 through to 1990, there was a long period of predominantly above average rainfall (upwards trending plot), following which rainfall has been predominantly below average (downwards trending plot). Shorter term cycles of above and below average rainfall are over printed on the longer-term trends.

As well reduced average rainfalls, rainfall intensities are also shown to be decreasing:

- In the 43 years of data to 1990, there were 43 occasions when monthly rainfall totals met or exceeded 200mm (average once per year) and 23 occasions when monthly rainfall totals met or exceeded 250mm (average 0.53 times per year).
- In the 28 years of data from 1990, there were 19 occasions when monthly rainfall totals met or exceeded 200mm (average 0.68 times per year) and three occasions when monthly rainfall totals met or exceeded 250mm (average 0.11 times per year).

3.1.1.1 Evaporation

Daily Pan A evaporation has been recorded at the Bathurst Agricultural Station (BoM Station 63005) from 1966 to 2018. The average monthly evaporation rate is presented in Table 3.2. The annual average daily Pan A evaporation rate is 3.7mm/day. The Bathurst Agricultural Station is the closest monitoring station to Angus Place and is approximately 60km to the west. Mean monthly rainfall for Bathurst is also provided on Table 3.2 for comparison, with average annual rainfall approximately 120 mm lower than Lidsdale.

Table 3.2: Evaporation - BoM Station 63005 (Bathurst Agricultural Station)

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Monthly Rainfall (mm)	68.4	57.7	52.1	41.4	41.1	44.2	48.3	49.4	46.9	59.0	61.2	66.2	636.8
Mean Daily Evaporation (mm)	6.8	5.8	4.5	2.9	1.7	1.1	1.2	1.9	2.8	4.1	5.3	6.5	3.7

3.1.2 SILO Climate Data

Supporting studies for this Groundwater Impact Assessment (JBS&G, 2019a, JBS&G, 2019b) incorporate the use of the Scientific Information for Land Owners (SILO) climate data. SILO is a database of Australian climate data from 1889 to the present, hosted by the Queensland Department of Environment and Science (DES).

Data can be acquired for individual weather stations (station point datasets are available at approximately 8,000 station locations around Australia), or as point or grid data sets.

- Station point datasets are a time series of data at weather station locations, consisting of weather station records which have been supplemented by interpolated estimates when observed data are missing.
- Point datasets are temporal datasets at a single grid location. They provide a time-series of data (usually daily time-step) at either a single grid cell or a single station. Point datasets at grid locations consist entirely of interpolated data.
- Gridded datasets are spatial datasets for a given date. SILO grids cover all of Australia with resolution 0.05° longitude by 0.05° latitude (approximately 5 km × 5 km).

Rainfall and evapotranspiration data for the region was obtained from the SILO climatic dataset for use in the numerical groundwater model (JBS&G, 2019a) and the swamp water balance model (JBS&G, 2019b). Point data was obtained for SILO grid point Latitude -33.40 and Longitude 150.20, and the gridded dataset (0.05 degrees, equivalent to 5km x 5km cells) was also used in the Swamp Water Balance Model and Hydrogeological Model.

3.2 Drainage and Catchments

The Project application area is located in the catchments of the Coxs River and Wolgan River.

The Angus Place Colliery pit top is located in the Coxs River Valley. Kangaroo Creek drains off the Newnes Plateau and joins the Coxs River in the vicinity of the pit top.

Proposed longwalls, LW1001 to LW1015, of the Amended Project are located beneath the catchment of the Wolgan River. The longwalls are bounded by the Wolgan River to the west and Carne Creek to the east. In the vicinity of the Amended Project the Wolgan River flows generally to the north and then to the northeast in the Wolgan Valley. Carne Creek also drains in a generally northwards direction, flowing to the Wolgan Valley and its confluence with the Wolgan River. Numerous drainages on the plateau contribute to the Wolgan River and Carne Creek, including the drainages of Tri Star Swamp and Twin Gully Swamp, located above the proposed longwalls, that drain to the west to the Wolgan River.

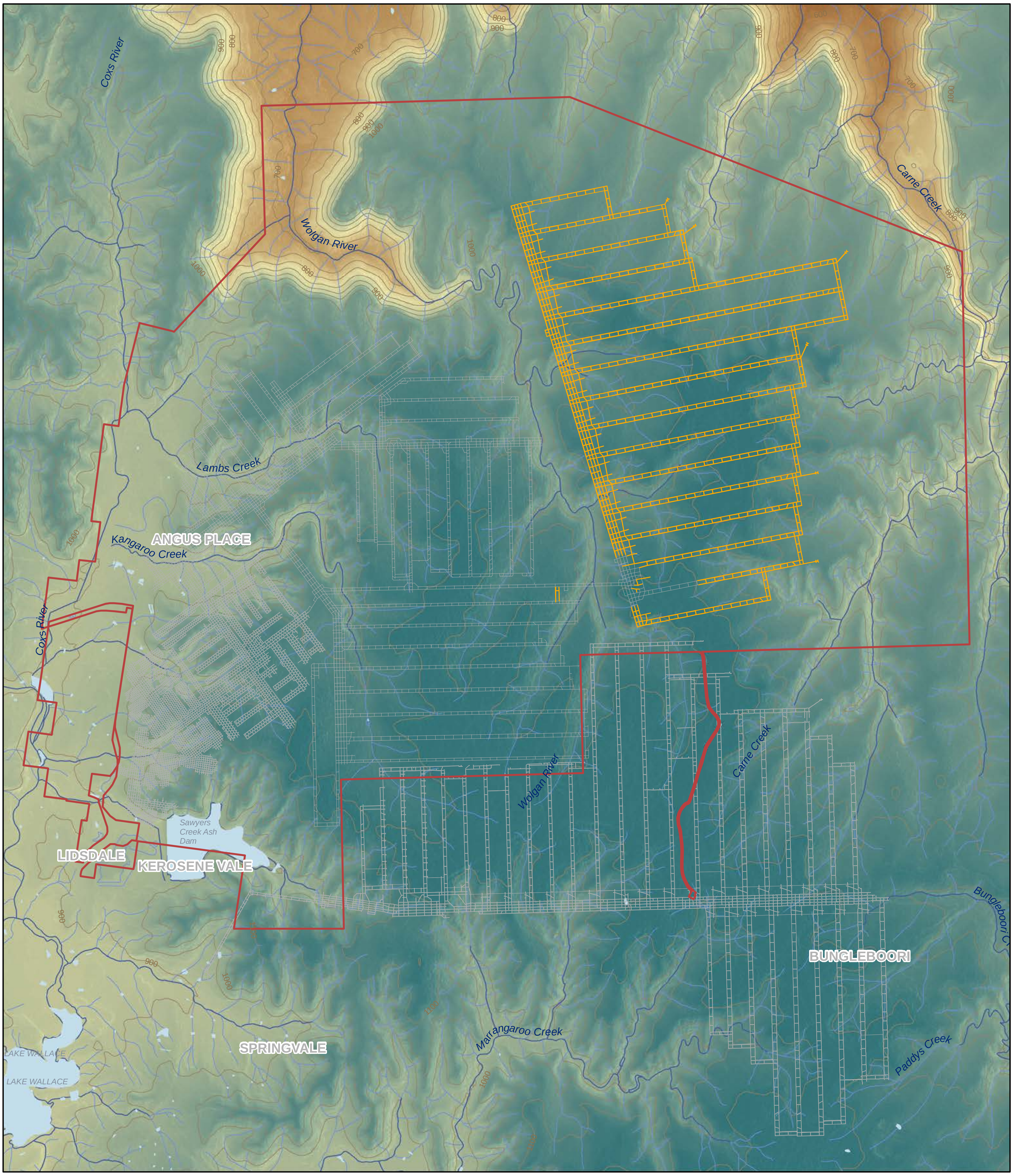
Catchment areas above the proposed longwalls typically comprise open eucalypt woodland on the ridges and valley flanks, with dry rocky heath along exposed ridges and cliff lines. Valley floors in the upper catchment area comprise a combination of open woodland and wet heath and sedge shrubs swamps (refer Section 3.5.1).

The Coxs River Valley is largely cleared and modified with the predominant land use being dryland grazing.

Topography and drainages are presented on Figure 3.2. Drainages off the plateau are often deeply incised in their lower reaches, incorporating numerous cliff lines and pagodas bordering the valley flanks. In the upper catchment areas drainage lines are typically poorly defined to non-existent with overland sheet flow being the typical mode of discharge during high rainfall events.

The Angus Place Colliery pit top sits at an elevation of approximately 915 mAHD in the Coxs River Valley. Ridgeline elevations of the Newnes Plateau above the proposed longwalls are at elevation of the order of 1100 to 1160 mAHD, with valleys incised down to approximately 1000 mAHD above the proposed longwalls.

Figure 3.2: Topography and Drainage



Infrastructure
- Proposed Workings
- Existing Workings

Project Area
- Project Area

Contours [mAHD]
- 50 m interval

Hydrology
- Water Areas
- Stream Order 1 - 2
- Stream Order 3 - 6

Elevation [mAHD]
High : 1150
Low : 500

Jacobs does not warrant that this document is definitive nor free of errors and does not accept liability for any loss caused or arising from reliance upon information provided herein.

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Kilometres

JACOBS

Data Sources - Centennial Angus Place Pty Ltd: Project Area, Infrastructure (2019); NSW Government Public Data: Roads, Hydrology, Placenames; Geosciences Australia (ELVIS): Elevation, 50m Contours; Office of Environment and Heritage NSW: Tenures; ESRI ArcGIS Image Service: World Elevation Terrain, World Topographic Map

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3.3 Geology

3.3.1 Regional Setting

The APMEP and the existing operations at Springvale and Angus Place Collieries extract coal from the Lithgow Seam of the Permian age Illawarra Coal Measures of the Sydney Basin. The Lithgow Seam is up to 400m below the surface of the Newnes Plateau and outcrops/sub-crops in areas of the Coxs River Valley and the Wolgan Valley.

The Illawarra Coal Measures are unconformably overlain by the lithologies of the Triassic Narrabeen Group and are unconformably underlain by the lithologies of the early Permian Shoalhaven Group (Yoo et al, 2001). West of the coal bearing Permian strata, the older sediments, meta-sediments and granitic bodies of the underlying Silurian and Devonian age rocks of the Lachlan Fold Belt dominate the surface geology. These older strata also extend beneath the Sydney Basin lithologies.

The regional geological setting of the Western Coalfields is provided on Figure 3.3, with stratigraphy in the vicinity of the Project is summarised on Figure 3.4 and in Table 3.3. Figure 3.4 also provides indicative heights of the various units above the roof of the Lithgow seam. Further discussion on key formations is provided in Section 3.3.2.

The Lithgow seam at Angus Place Colliery is the lowermost economic seam and is only tens of metres to 100 metres above the older basement strata. In other parts of the Sydney basin it is typical for the Permian coal bearing strata to be separated from the basement strata by many hundreds of metres. The total thickness of the Illawarra Coal Measures increases towards the east, from approximately 120m in the Lithgow area to a maximum thickness of 520m in the northern part of the Southern Coalfield, (Palaris 2013c). The highest stratigraphic units present at Angus Place Colliery are those of the Narrabeen Group.

3.3.2 Key Lithological Units

Key units underlying the project area as detailed in Palaris (2013a) are described below in descending order (youngest to oldest) and are shown schematically on Figure 3.4.

Burralow Formation (Narrabeen Group)

The Burralow Formation consists of medium to coarse-grained sandstones inter-bedded with fine-grained sandstone/siltstone/claystone units, the latter of which can be several metres thick. The base of the Burralow Formation is defined as the first significant fine-grained unit above the Banks Wall Sandstone.

Within the Burralow Formation a number of continuous fine-grained units have been identified that act as aquitards, limiting the vertical infiltration of groundwater and resulting in a sequence of perched aquifers. These low permeability units are designated YS1 to YS6 (McHugh 2013). The study by McHugh (2013 and 2016) of the upper stratigraphy of Angus Place Colliery indicates that there is a lithographic and topographic link between the outcrop of the low permeability units within the Burralow Formation and the location of THPSS.

Banks Wall Sandstone (Narrabeen Group)

The Banks Wall Sandstone consists predominantly of sandstone which is generally medium to coarse grained. It is continuous in nature and the average thickness across the Angus Place Project Application Area is approximately 90m. The base of the Banks Wall sandstone is defined by the presence of the first significant claystone band of the Mount York Claystone (MYC).

Table 3.3: Angus Place Stratigraphy

Age	Group	Sub-Group	Formation / Seam	Dominant Lithologies	Hydrostratigraphy / Aquifer Unit[1]
Triassic	Narrabeen Group	Grose Subgroup	Burralow Formation	Quartz sandstones, shales and red-brown claystones.	Aquifer - AQ5 / AQ6 Aquitards – YS Plies including SP4
			Bankswall Sandstone	Predominantly quartzose sandstone, abundant ironstone bands, occasional conglomerates and numerous claystone lenses several metres thick.	Aquifer – AQ4
			Mt York Claystone	Red-brown claystone	Aquitard – SP3
			Burra-Moko Head Sandstone	Quartzose to quartz-lithic sandstone	Aquifer – AQ3
			Caley Formation	Claystone, shale, quartz-lithic sandstone	
Permian	Illawarra Coal Measures	Wallerawang Subgroup	Farmers Creek Formation	Claystone, carbonaceous claystone, mudstone, tuffaceous shale, coal (Katoomba Seam).	
			Gap Sandstone	Lithic, medium-grained sandstone.	Aquitard – SP2 Aquifer – AQ2
		Charbon Subgroup	State Mine Creek Formation	Claystone, mudstone, siltstone; thin coal. (Middle River Seam)	
			Watts Sandstone	Medium- to coarse-grained sandstone.	
			Denman Formation	Dark grey striped sandstone-siltstone laminate, bioturbated.	Aquitard – SP1
			Glen Davis Formation	Coal, carbonaceous claystone, claystone and siltstone and sandstone.	Aquifer – AQ1
			Newnes Formation	Fine- to medium-grained, lithic sandstone, with interbedded siltstone and claystone	
			Irondale Coal	Coal, mainly bright, claystone, black carbonaceous and also buff	
			Long Swamp Formation	Bioturbated claystone and siltstone, tuff, sandstone and thin discontinuous coal layers	
		Cullen Bullen subgroup	Lidsdale Coal	Predominantly dull coal, thin claystone, carbonaceous and tuffaceous claystone and siltstone.	
			Blackmans Flat Formation	Quartz sandstone, pebbly, coarse-grained.	
			Lithgow Coal	Dull coal with minor bright layers; a few thin carbonaceous or tuffaceous claystone layers in the upper half.	
			Marangaroo Formation	Fluvial, pebbly sandstone to cobble conglomerate	
		Nile subgroup	Gundangaroo Formation	Thin coal seams, carbonaceous shale, fossil wood horizons, grey shale.	Aquitard – SP0

Age	Group	Sub-Group	Formation / Seam	Dominant Lithologies	Hydrostratigraphy / Aquifer Unit[1]
			Coorongooba Creek Sandstone	Thin coal seams, carbonaceous shale, fossil wood horizons, grey shale.	
			Mount Marsden Claystone	Thin massive limestones, dolomite, claystone, siltstone; few pebble horizons.	
	Shoalhaven Group		Berry Siltstone	Sandy grey mudstone.	
			Snapper Point Formation	White to yellow quartzose, fine to very coarse-grained sandstone, siltstone, pebbly sandstone, conglomerate. Fossiliferous locally.	

Note: [1] – refer Section 3.4.1 and Section 5.1.2 for correlation with groundwater model layers.

Mount York Claystone (Narrabeen Group)

This unit is a sequence of inter-bedded claystone and sandstone. The average thickness of the unit is 22m at Angus Place Colliery. Typically, the MYC comprises two or three discreet claystone bands, up to 4m thick separated by sandstone / siltstone bands up to 8m thick. The top of the unit is generally 100m to 120m above the Katoomba Seam. The MYC is generally difficult to differentiate from drill hole cuttings, but geophysical gamma logging can be used to identify the unit more accurately. The top of the unit is identified as the first significant claystone band below the Banks Wall Sandstone. The base of the MYC is less distinct as additional thick claystone bands occur within the underlying Burra-Moko Head Sandstone. The MYC is shown to be continuous across the Project Application Area where it has been identified in over 100 cored and geophysically logged drill holes (Palaris, 2013a).

Burra-Moko Head Sandstone (Narrabeen Group)

This formation consists predominantly of sandstone. Several thick claystone bands, which are similar in nature and thickness to the bands within the MYC, are also present. The unit is gradational with the underlying Caley Formation.

Caley Formation (Narrabeen Group)

Comprises sandstones similar to the Burra-Moko Head Sandstone, however, thick siltstone and claystone bands are more prevalent.

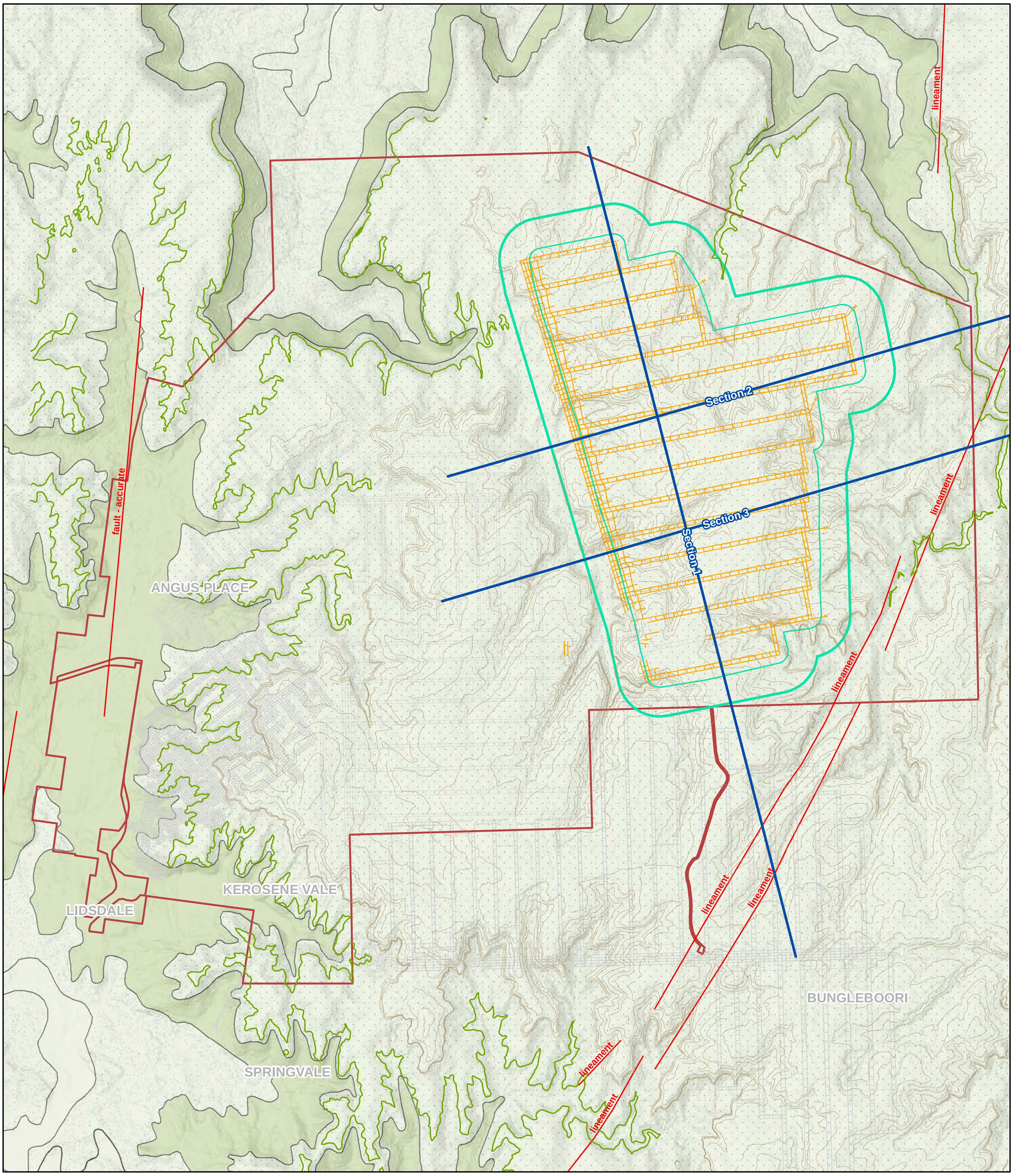
Katoomba Seam (Illawarra Coal Measures)

The Katoomba seam is generally considered to be the first occurrence of coal within the upper Permian strata. In parts of the adjacent Springvale Mine, the seam is often thin or deteriorated and may be confused with the Woodford of upper Middle River seams. The variability in the thickness and nature of the seam is not significant from a hydrogeological perspective. The Katoomba seam is mined at Clarence Colliery, to the south-east of Angus Place Colliery, however is not considered to be a viable mining target within the Project Application Area.

Denman Formation (Illawarra Coal Measures)

This is a fine grained to finely laminated unit which grades upwards into a sandstone (~4m thick). It is consistent in thickness and nature at Angus Place Colliery and is thought to inhibit groundwater flow to the underlying formations.

Figure 3.3: Regional Geology



Western Coalfield Geology

Quaternary

- Qa – Alluvium

Triassic

- Tn – Narrabeen Group
- Burralow Formation YS Ply Outcrop
- Mount York Claystone Outcrop

Permian

- Pi – Illawarra Coal Measures
- Pn-Ps Nile Subgroup - Shoalhaven Group
- Ps – Shoalhaven Group
- Pz - Undifferentiated Palaeozoic

Carboniferous

- Cg – Granite
- Section Lines (refer Figures 5.2 and 5.3

Geologic Structures

- Various

Infrastructure

- Proposed Workings
- Existing Workings
- Project Area
- 26.5 degree AoD
- 600m Study Area

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Data Sources - Centennial Angus Place Pty Ltd: Project Area, Infrastructure (2019); NSW Government Public Data: Roads, Hydrology, Placenames; Geosciences Australia (ELVIS): 50m Contours; Yoo E.K., 1992, Western Coalfield Regional Geology (southern part) 1:100 000, 1st edition. Geological Survey of New South Wales, Sydney; ESRI ArcGIS Image Service: World Elevation Terrain, World Topographic Map

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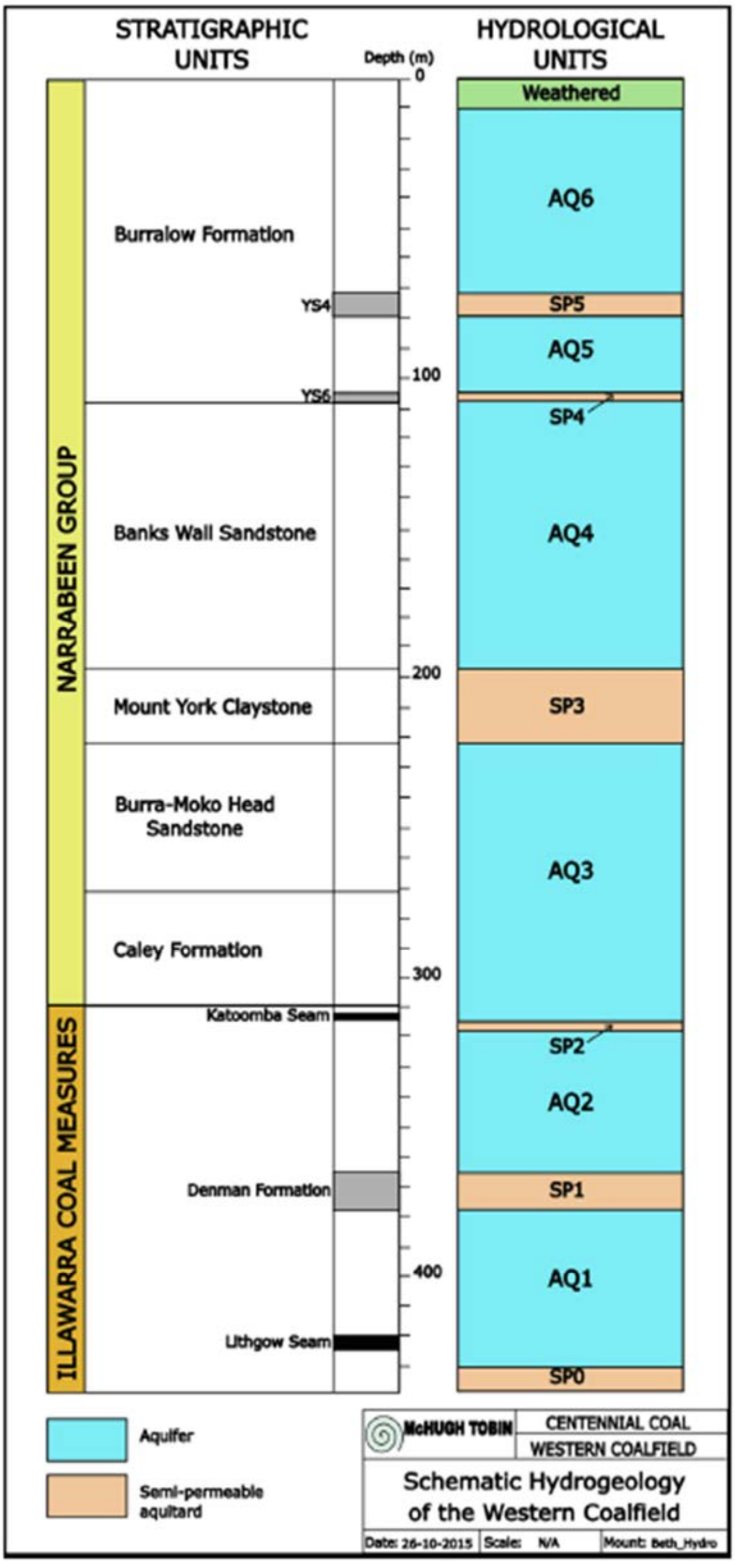


#	Hydrogeological Unit:
1	Sandstone
2	Shale (YS1)
3	Sandstone
4	Shale (YS2)
5	Sandstone
6	Shale (YS3)
7	Sandstone
8	Shale (YS4)
9	Sandstone
10	Shale (YS5)
11	Sandstone
12	Shale (YS6)
13	Quartzose Sandstone (Banks Wall Sandstone)
14	Quartzose Sandstone (Banks Wall Sandstone)
15	Claystone (Mount York Claystone)
16	Quartzose to quartz-lithic sandstone (Burra-Moko Head Sandstone)
17	Claystone/shalestone/sandstone (Caley Formation)
18	Coal Seam (Katoomba)
19	Claystone/Shale (Farmers C'k Form'n)
20	Lithic sandstone/claystone (Gap Sandstone)
21	Mudstone/silt-claystone (Denman)
22	Sandstone/Mudstone (Glen Davis /Long Swamp Formation)
23	Conglomerate (fluvial) (Blackmans Flat Conglomerate)
24	Coal Seam (Lithgow)
25	Conglomerate (fluvial) (Marrangaroo Conglomerate)
26	Sandstone (shoreline complex - delta front (Nile Subgroup)
27	Siltstone/Sandstone (Shoalhaven Group)
28	Tuff/Granite (Carboniferous)

Figure 3.4: Angus Place Stratigraphy and representation in the Hydrogeological Model (JBS&G, 2019a)

3.3.3 Structural Geology

The structural geology of the western coalfield is relatively benign, with seams generally dipping at one to two degrees towards the north-east. The dominant mapped structures on the 1:100,000 Western Coalfield Geology map (Yoo et al, 2001) structures are north–south trending regional scale monoclines (east of Project Application area) and associated sub-parallel faults and lineaments. Regionally faults can have throws of up to 200m, but such significant displacements are not apparent in the Project Application Area.

The presence of vertical jointing is apparent in the sandstone exposures along cliff lines of the Newnes Plateau, and through aerial imagery where structural control on drainage lines is often apparent. A study by Palaris (2013b) was undertaken to improve on previous understanding (SRK, 2012) and mapping of major geological structures in the vicinity of Springvale Mine and Angus Place Colliery to identify areas of potentially anomalous subsidence. The study was based on a variety of data sources including; review of regional geology, interpretations aeromagnetic data, and correlation with digital terrain models to identify surface expression of the structural geology.

Major structural types identified are summarised below, with occurrence shown on Figure 3.5.

1. **Type 1 -** are major geological structural zones characterised by their size and length and can be projected for many kilometres. The zones:

    a. Have a strong surface expression that includes linear segments of deep valleys/gorges, however, these zones may also extend beneath surface plateau.

    b. Can be mapped from aerial imagery / digital terrain models.

    c. Are recognised (in part) as basement features by previous studies (SRK, 2012).

    d. Have a north-northeast to north-northwest trend.

    e. Are recognised in underground workings as faulted or highly fractured ground. Typically, these occur as fault clusters with variable orientation – occurring within the structure zone but not necessarily related to the orientation of the zone. The density of faulting is noted to increase near the intersection of other basement structure zones.

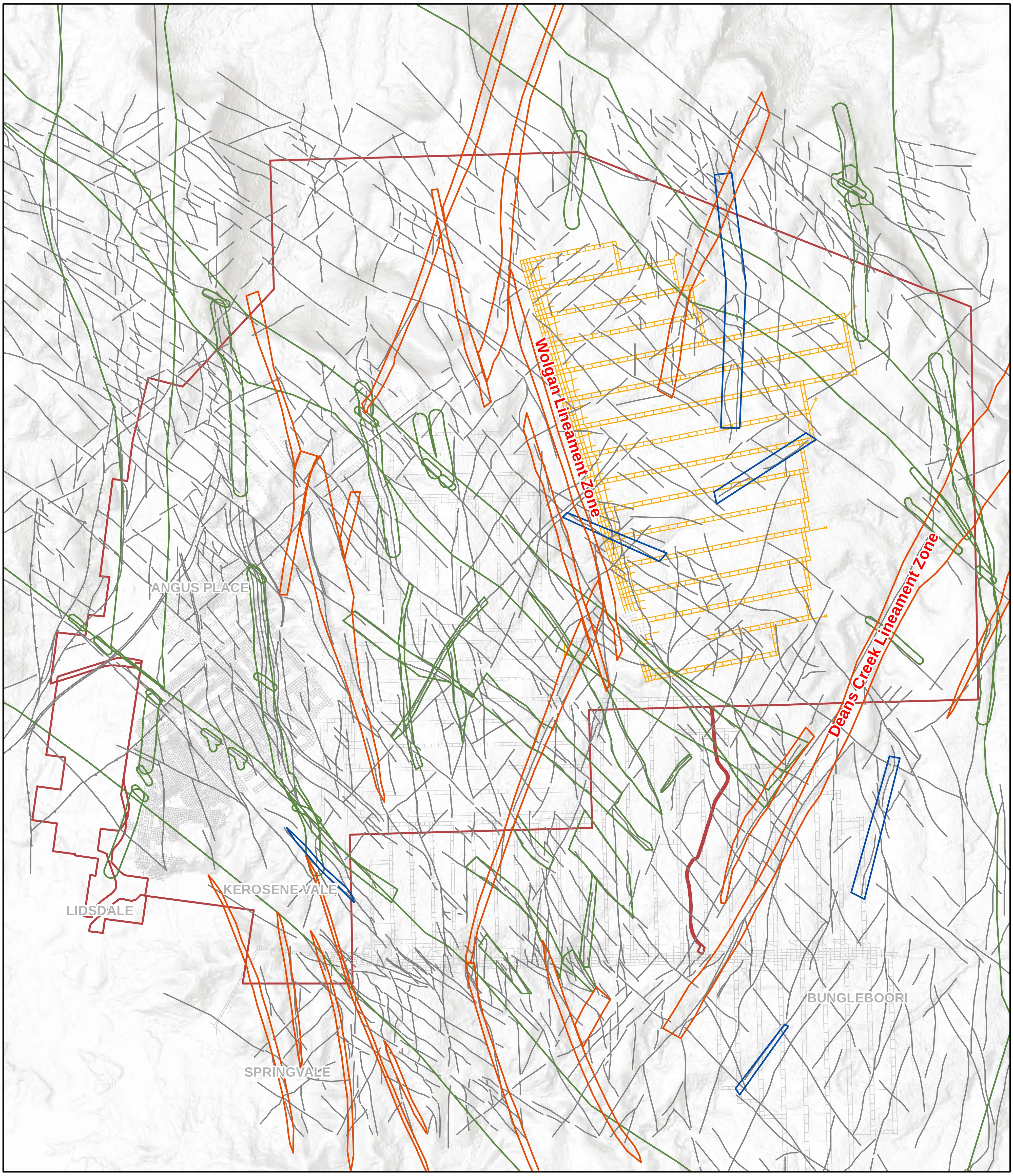
2. **Type 2** – similar to Type 1 but is not a sub set of Type 1. Type 2 structures have evidence of geological structure in the basement and mine workings except that the structure zone and the overlying topographic relief alignment extend only a limited distance – perhaps one or two kilometres. These segments of linear surface relief are not part of a longer surface lineament. In the immediate workings of Angus Place Colliery and Springvale Mine these are uncommon.

    Type 2 features, like Type 1 features, have identifiable valley or topographic breaks but may also extend into flatter plateau areas. Features with Type 2 attributes can be confidently predicted but the impact of the geological structure zone following mining has not been tested. Fundamentally it is uncertain if the basement fault structure underlying short lineaments (1 to 2 km) are linked with the surface expression or are coincidental.

3. **Type 3** – these geological structures are predicted from mapped underground structures (faults, joint zones or stress zones), and basement features. There is no associated surface topographic relief forming part of an alignment.

    This structural association is quite complex. Faults mapped in Lithgow seam workings are located along the line of basement structures or a zone of basement structures. The faults generally do not extend far and have various orientations but are not necessarily oriented with the basement structures. In addition, the density of faulting appears to increase near the intersection of basement structures. There are many examples of this type of geological association in the Angus Place Colliery and Springvale Mine area.

Figure 3.5: Local Structural Interpretation



Structures

- Type 1 Structures
- Type 2 Structures
- Type 3 Structures
- Type 4 Structures

Infrastructure

- Proposed Workings
- Existing Workings

Project Area

- Project Area

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Data Sources - Centennial Angus Place Pty Ltd: Project Area, Infrastructure (2019), Structures; NSW Government Public Data: Roads, Hydrology, Placenames; ESRI ArcGIS Image Service: World Elevation Terrain, World Topographic Map

A subset of Type 3 structures is the association between basement structures and zones of high stress in the mine workings that occur both with and without the presence of geological structures. Predicting Type 3 zones from basement structures alone is still a developing science but the more recent understanding of the importance of basement block boundaries helps to pick the significant basement structures. This is especially useful for Type 3 structures which by definition don't have a surface expression.

A number of faults have been mapped underground that do not appear to be related to basement features. Their origin is not certain.

4. **Type 4** – identified basement structures. SRK (2012) have identified basement structures – some of these are likely to have penetrated to seam level and some have extended to the surface appearing as lineament structures. Collectively the basement structures that penetrate into the overlying strata are grouped as Type 1, 2 or 3 structures. Geological structure Type 4 has no corresponding structures recognised in mine workings nor is it associated with surface relief. This type of structure prediction is the most common and is regarded as benign with respect to its impact on mining.

Further discussion on the interaction with major geological structures and the groundwater system is provided in Section 4.5.

3.4 Hydrogeology

The sedimentary strata in the Western Coalfield comprises a non-uniform sequence of interbedded rocks of differing grainsize, lithification and strength properties. This gives rise to layers of rock with a wide range of intrinsic permeabilities and potential to either transmit or inhibit the flow of groundwater, resulting in a hydrogeological regime which can be described as complex.

The hydrogeological regime is further complicated, locally, by the effects of large mine voids, which have the potential to act as preferential flow paths between discreet aquifer units, and as groundwater sinks or storages.

The complex nature of the groundwater system in the sedimentary deposits is in part due to the number of water bearing zones present which range from perched water tables to layered, semi confined and leaky horizons. Groundwater flow in the Illawarra Coal Measures is typically towards the northeast. This is coincident with the dip of the main strata. Groundwater flow is primarily through fracture systems with some minor pore / primary porosity (Bish, 1999). This fracture system is the major control on groundwater flow paths, as the rocks themselves generally have low primary permeability.

3.4.1 Local Hydrogeology

A review of local hydrogeology was carried out by CSIRO in 2004 (CSIRO, 2004). The CSIRO review based its understanding on the interpretation of data from vibrating wire piezometer sensors and mine water make, along with time-domain reflectometer (TDR - measures the separation / delamination of rock layers) measurements and regional hydrogeological reports.

The TDR interpretation identified five distinctive aquifers or water bearing sequences that could be correlated in the hydrostratigraphy underlying the study area and above the Lithgow seam. These water bearing horizons were identified in ascending order, starting at the Lithgow Seam, as AQ1, AQ2, AQ3, AQ4, and AQ5. These water bearing units were separated by intervening units of reduced permeability, termed semi-permeable units (SP1 to SP4).

Subsequent investigations (McHugh, 2011 and 2013; Palaris, 2013a) have identified a number of continuous claystone layers within the Burralow Formation consisting of medium to coarse grained sandstones, interbedded with fine grained sandstone/siltstone/claystone units. The bottom most of these claystone layers at the base of the Burralow Formation divides the previously identified AQ4 in two, so that now six aquifer units are identified (AQ1 to AQ6), as summarised on Table 3.3 and shown on Figure 5.2 and Figure 5.3.

It should be noted that the term aquifer adopted by CSIRO (2004) is used to distinguish between relatively permeable and less permeable groups of strata. The results of permeability testing (Golder Associates, 2012) show all the formations tested to be of generally low permeability and do not in themselves represent viable aquifers in the conventional sense. The adopted nomenclature is continued in this assessment, and brief summary of the identified aquifers and intervening aquitards (termed SP, or semi-permeable) is provided as follows (after CSIRO, 2013). The correlation of these hydrostratigraphic units with formation and representation within the groundwater model (JBS&G, 2019 and Appendix G) is provided in Section 5.1.2 and Table 5.2.

- AQ6 – This aquifer is located in the upper part of the Burralow Formation. This is a group of largely unconfined perched aquifers and only appears near the top of the Newnes Plateau. AQ6 includes a number of discrete aquitard units (YS1 to YS3) that sustain the perched aquifers.
- SP4 - A thin semi-permeable layer located in the Burralow Formation and comprises claystone (YS4) and sandstone/ siltstone.
- AQ5 – This aquifer is located in the lower Burralow Formation. AQ5 is separated from AQ4 by YS6 and also includes a continuous low permeability unit (YS5) that can result in perched conditions within the aquifer.
- YS6 – A thin semi-permeable claystone layer at the base of the Burralow Formation, separates AQ4 and AQ5.
- AQ4 – This aquifer is located in the Banks Wall Sandstone (Narrabeen Group).
- SP3 - A semi-permeable claystone layer (Mt York Claystone) separates aquifers AQ3 and AQ4. The Mt York Claystone forms an effective barrier between the deep and shallow groundwater systems; it averages over 20 m in thickness and is continuous throughout the Springvale/Angus Place area.
- AQ3 - Aquifer AQ3 can be identified in the sandstones of the Burra Moko Head Formation and the Caley Formation and located below the Mt York Claystone. It is hydraulically connected with, and includes, the Katoomba Seam.
- SP2 - A semi-permeable layer with coal, siltstone and mudstone is the boundary between aquifers AQ2 and AQ3. This semi-permeable layer occurs below the Katoomba Seam.
- AQ2 – This aquifer contains sandstone of the Gap and Watts Sandstones, with laminated siltstone and Middle River Coal Member.
- SP1 - Aquifer AQ1 is separated from aquifer AQ2 by a semi-permeable layer (SP1) located within the Denman Formation and comprises mudstone, siltstone and claystone.
- AQ1 – This aquifer sequence includes Lidsdale / Lithgow Coal Seams and overlying units. The base of AQ1 is the floor lithology of the Lithgow Seam, the Marangaroo Formation.
- SP0 – This is inferred to be the hydraulic basement for the purposes of groundwater modelling.

The permeability of the various formations is controlled by the porosity of the formation and the interconnection of the pore spaces, along with the degree of interconnective fracturing or cleating that is present. Within both the Narrabeen Group and Illawarra Coal Measures, significant primary porosity is likely to be limited and localised, with the majority of regional groundwater flow controlled by secondary fracture networks.

This series of aquifers and aquitards can be grouped together to form three basic groundwater systems underlying the Project Application Area as follows:

- A sequence of perched groundwater systems within the Burralow Formation (AQ5 and AQ6).
- A shallow regional groundwater system within the Banks Wall Sandstone, ranging from unconfined to semi-confined (AQ4).
- A deep groundwater system below the Mount York Claystone (AQ1 to AQ3, including coal seams). Ranging from confined to unconfined in proximity of outcrop or where depressurised by existing mine workings.

3.4.2 Surface water / Groundwater Interaction

The dominant surface water / groundwater interactions on the Newnes Plateau involve recharge to shallow groundwater and groundwater discharge to surface water.

Infiltration of rainfall and runoff is likely to occur along the ridgelines and areas of exposed or shallow sub-cropping bedrock in the upper catchment areas.

Groundwater discharge to surface water occurs as seepages and drips from exposed seepage faces on cliff lines or exposed bedrock in drainage lines, and as seepage from sub-cropping bedrock to regolith or detrital soil profiles on valley flanks and along valley floors. Where of sufficient magnitude, these seepages may support the development of Newnes Plateau Hanging Swamps (NPHS) or Newnes Plateau Shrub Swamps (NPSS) (Section 3.5.1).

Groundwater seepage may contribute to stream baseflows either directly as discharge to drainage lines in the valley floor, or indirectly as a contribution to catchment subsurface flow.

Springs

Other than the seepage faces that support the shrub and hanging swamps, there are no mapped springs within the Project Application Area or listed in the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011. It is noted that mineral water supplies for Lithgow Valley Springs are considered under Other Groundwater Users (Section 3.6 and 5.4.4).

3.5 Sensitive Receptors

Sensitive receptors that have been identified include:

- Temperate Highland Peat Swamps on Sandstone (THPSS) comprising NPHS and NPSS (discussed below, Section 3.5.1)
- Drainages and water ways as described in Section 3.2.
- Aquatic ecology associated with drainages and swamps (discussed in the Ecological Impact Assessment, RPS, 2019).
- Other groundwater users downstream of the Project including licenced water users and basic landholder rights.

3.5.1 Temperate Highland Peat Swamps on Sandstone

THPSS are listed as an Endangered Ecological Community (EEC) under the EPBC Act due to their restricted distribution and their vulnerability to ongoing threats. THPSS comprise both NPSS and NPHS. NPSS are listed as an EEC under the Biodiversity Conservation Act 2016.

THPSS are characterized by highly organic sandy loams to mineral peats overlying sandstone at altitude, which supports a unique assemblage of flora. The federally listed THPSS EEC occurs in the Blue Mountains, Lithgow, Bombala and Wingecarribee Local Government areas. They have a naturally fragmented distribution pattern forming in response to extremely localized conditions which are created by a unique combination of topographic, geological, hydrological and groundwater influences (BMCC, 2010).

THPSS generally occur at altitudes from about 650 m to 1200 m above sea level. On the Newnes Plateau the swamps are associated with Triassic sandstone plateau (Narrabeen Sandstone) and occur in shallow, low-sloping, often narrow headwater valleys, on long gentle open drainage lines in the lowest footslopes, low-lying broad valley floors, and in gully heads, open depressions on ridgetops, and steep valley sides associated with semi-permanent water seepage (SPRAT, 2019). On the Newnes Plateau, THPSS typically include Newnes Plateau Shrub Swamps as valley fill swamps and Hanging Swamps on the steep valley flanks and cliffs.

THPSS are generally associated with black to grey coloured, acid peaty soils, have moderate to high organic matter content often with a sandy or loamy texture, and are poorly drained and hence permanently or periodically/intermittently water logged.

A summary of the characteristic surface water and groundwater interactions of the NPSS and Hanging swamps is provided as follows (after Commonwealth of Australia, 2014).

3.5.1.1 NPSS

- NPSS occur further down the catchment than headwater swamps, in the steeper terrain of incised valleys associated with second- or third-order streams.
- The steeper incision into the underlying sandstones means the swamps are more likely to intersect water-bearing layers within the horizontally bedded sandstone.
- The water regime for valley infill swamps therefore combines rainfall and surface water run-off, as well as groundwater inputs.
- The NPSS surface can be either permanently or ephemerally wet.
- Water quality within the swamps is variable, and is controlled by a combination of rainfall, run-off and groundwater quality.
- The swamp is recharged through a combination of groundwater discharge from perched or regional sandstone aquifers, rainfall and run-off.
- Water flows through the swamps either as sheet flow along the surface of the peat, through the peat or through channels within the peat. These channels control the water level within the peat swamps.
- Groundwater discharge to the swamps is through either:
  - groundwater movement along fractures, joints or bedding planes that intersect the peat swamp
  - to a lesser extent, the lower permeability sandstone layers that intersect the peat swamp.
- Depending on location in the landscape, the groundwater flow system could be local, intermediate or regional.
- Connection between aquifer and swamp is either permanent (more likely where the regional aquifer is the groundwater source) or ephemeral (more likely where perched aquifers are the groundwater source).
- Groundwater quality is variable, depending on residence time within the aquifer.

3.5.1.2 NPHS

- NPHS occur on steep valley sides or cliffs and are predominantly reliant on groundwater discharge that seeps out along bedding planes and low-permeability layers in the sandstone.
- NPHS occur at the interface between higher and lower permeability sandstone/shale layers.
- Sediment and peat deposition is minimal due to the steep topography and is limited to sediment caught within vegetation roots.
- Groundwater discharge to the swamps is caused by the presence of low-permeability layers within the aquifer forcing water sideways to seep out of the cliff face.
- Groundwater contributions may be from perched aquifers, or as recently infiltrated water that flows along cracks and joints before discharging to the swamp.
- Groundwater flow system is local, and groundwater quality is expected to be fresh due to relatively short flow paths and residence times in the aquifer.
- Connection between aquifer and swamp is either permanent or ephemeral and occurs after rainfall.

3.5.1.3 Swamp Waterlogging

Water level responses and trends within swamps rely on a number of factors, including depths of swamp materials, catchment size and characteristics, and groundwater contribution. The degree of water logging of a swamp depends on the prevailing hydrology and water balance.

Where groundwater contribution and catchment sub-flow is relatively high, and swamp water levels are maintained at or near the surface by groundwater baseflow contributions, there is little available space for rainfall recharge, and rainfall and runoff are lost as surface flows. These swamps present relatively stable water levels with little fluctuation and are termed permanently waterlogged swamps.

Where swamp materials are thicker or groundwater contributions are lower, and water levels are maintained below the surface of the swamp, rainfall and runoff can infiltrate and recharge the swamp materials. This results in an increase in water levels with recharge and subsequent regression. Swamps displaying this behaviour are termed periodically waterlogged swamps, although the swamp materials may be saturated at depth or partially drained, during the intervening periods. It is recognised that swamps can transition from permanently water logged to periodically water logged along their length, or over time, depending on the prevailing conditions.

Water level responses will also vary according to the response time of the various influencing stresses. Indicative magnitudes of some typical stresses are provided below:

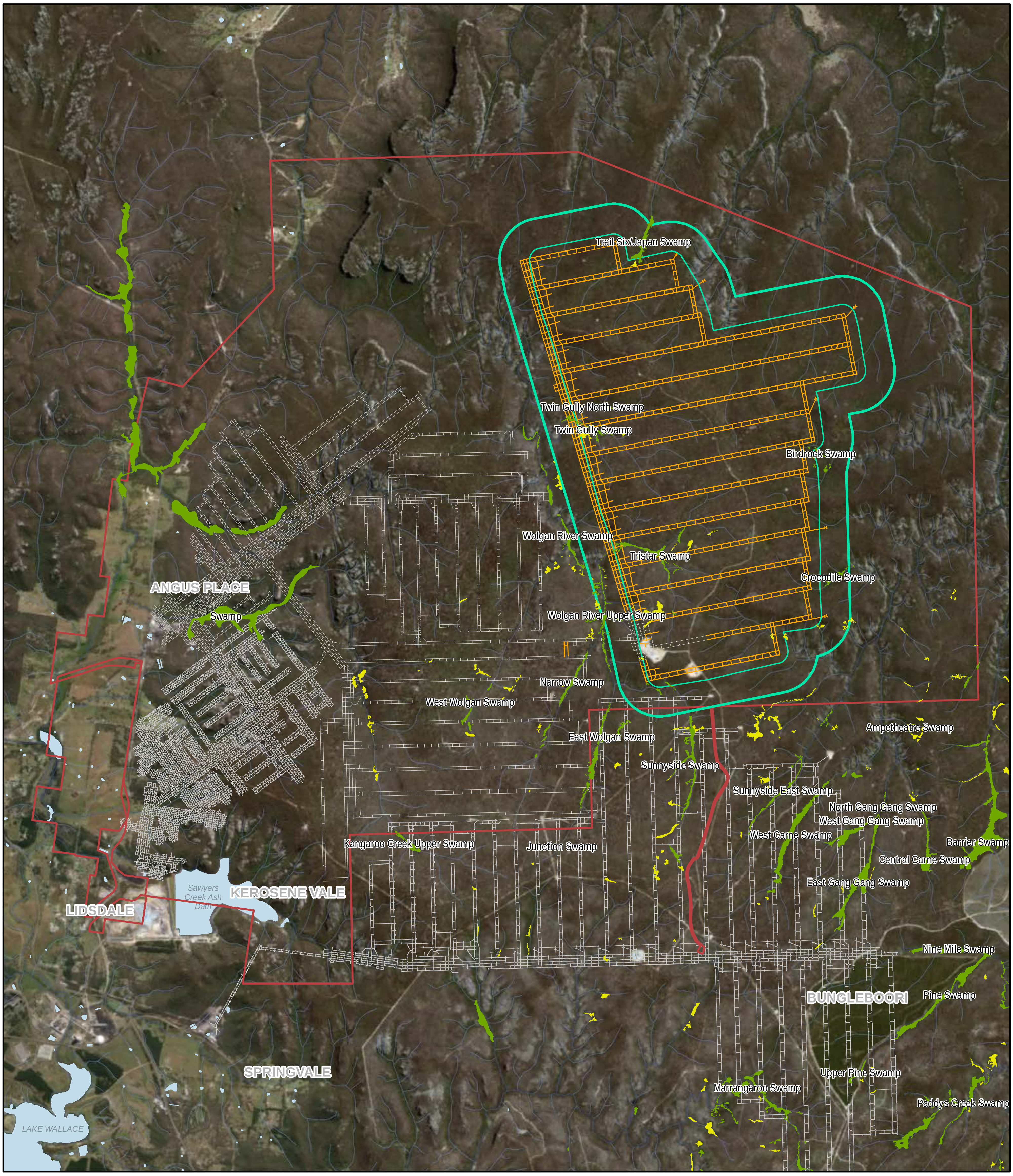
- Rainfall and runoff – hours to days
- Catchment sub-flow – weeks to months
- Groundwater – shallow perched – months to years
- Groundwater – deeper – years to decades.

3.5.1.4 Proposed Longwall Panels

Mapped THPSS in the vicinity of the APMEP are shown on Figure 3.6. Of these swamps:

- Tri Star and Twin Gully Swamps directly overly proposed longwalls;
- Trail Six/Japan Swamp lies within the angle of draw of the proposed longwalls, although will not be directly undermined;
- Birds Rock Swamp, Crocodile Swamp and Wolgan River Upper Swamp lie within the 600m Study Area; and
- Wolgan River Swamp lies just outside the 600m Study Area.

Figure 3.6: THPSS Occurrence



Infrastructure
- Proposed Workings
- Existing Workings

Project Area
- Project Area

Swamps
- Hanging
- Shrub

Hydrology
- Water Areas
- Stream Order 1 - 2
- Stream Order 3 - 6

APE Study Areas
- 26.5 degree AoD
- 600m Study Area

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3.6 Groundwater Users

A review of the NSW Department of Planning, Industry and Environment's online water database (DPIE, 2019) was undertaken to identify groundwater users in the vicinity of the Project Application Areas. The locations of groundwater users (as registered groundwater works) are provided on Figure 3.7. Details of the groundwater works, as downloaded from the DPIE database are presented in Appendix A and summarised as follows.

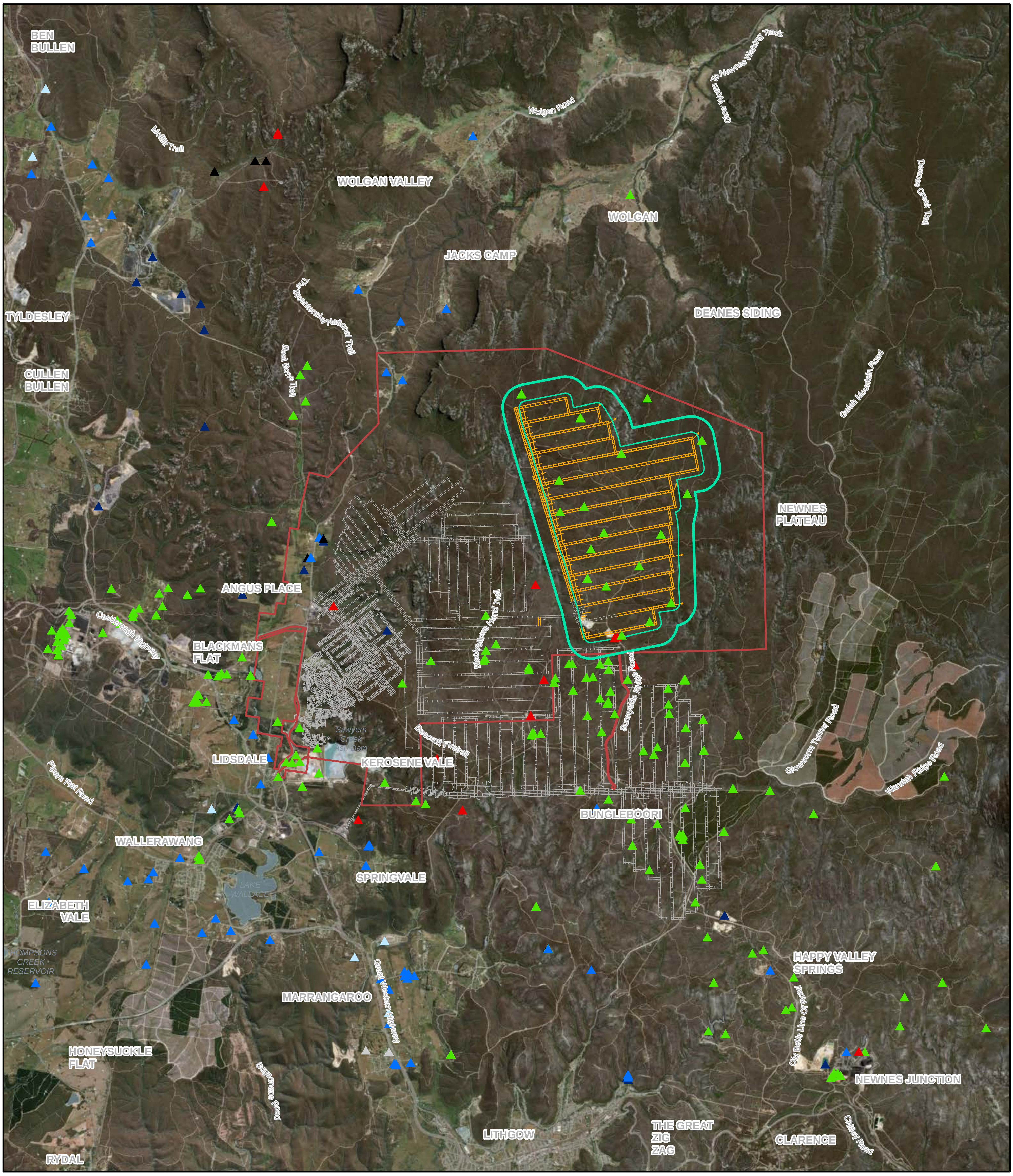
A total of 437 groundwater works are registered in the vicinity of the Project Application Area as defined by a rectangular search area with the following approximate extents: top left corner – easting 149.95, northing -33.18, lower right corner easting 150.63, northing -33.76 (approximately 60x60km).

Of these groundwater works:

- 138 are registered for groundwater supply, including:
  - water supply (109)
  - commercial and industrial (20), including three for mineral water extraction
  - irrigation (7)
  - and stock and domestic (2).
- 258 are registered as monitoring bores.
- 14 are registered as dewatering bores
- 5 are registered as exploration bores
- 18 have no recorded use.
- 4 have purpose recoded as "other".

Consideration for potential impacts to groundwater users are discussed in Sections 5.4.4 and 5.7.

Figure 3.7: Groundwater Users



Groundwater Works Use
- Commercial and Industrial
- Monitoring
- Dewatering
- Irrigation
- Water Supply
- Other
- Unknown

Infrastructure
- Proposed Workings
- Existing Workings

Project Area
- Project Area

APE Study Areas
- 26.5 degree AoD
- 600m Study Area

Roads
- Primary Road
- Arterial Road
- Sub-Arterial Road
- Local Road
- Track-Vehicular

Hydrology
- Water Areas

Newcastle
Sydney
Wollongong

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3.7 Groundwater Dependent Ecosystems

The NSW Department of Planning, Industry and Environment – Water (then DPI Water, 2016) defined ecosystems that depend on groundwater as those ecosystems that require access to groundwater to meet all or some of their water requirements so as to maintain their communities of plants and animals, and ecological processes.

Within the Project Application Area, a number of GDEs and potential GDEs have been identified including terrestrial vegetation, river baseflow systems and stygofauna.

3.7.1 Terrestrial Vegetation

Terrestrial vegetation GDEs include vegetation which has seasonal or episodic dependence on groundwater. Within the Project Application Area Terrestrial vegetation GDEs are likely to include THPSS specific vegetation. Specific vegetation communities are discussed in the Ecology Impact Assessment.

3.7.2 Riverine Baseflow Systems

Riverine baseflow systems include ecosystems that are dependent on groundwater derived baseflow in streams and rivers (Dresel et al., 2010). Baseflow is that part of stream flow derived from groundwater discharge and bank storage.

Ecosystems that exist in baseflow dependent streams can themselves be groundwater dependent and differentiating between groundwater dependent terrestrial vegetation, wetlands, and baseflow systems can be difficult, as the different communities can represent a spectrum of habitat and groundwater dependency (Dresel et al., 2010). Groundwater levels can be important in maintaining flows or pools that sustain ecosystems, particularly during times of drought.

3.7.3 Stygofauna

Stygofauna are highly specialised aquatic macroinvertebrates that are adapted to living in specific groundwater habitats. Stygofauna can be characterised into three broad groups depending on the specific reliance on groundwater:

- Stygoxenes, which occur in subterranean waters but must leave for some period(s) to complete their life cycles;
- Stygophiles, which are able to live out life cycles in subterranean or surface waters; and
- Stygobites, which are obligate dwellers in subterranean waters.

Obligate stygofauna (stygobites) typically display distinctive morphological characteristics, such as loss of eyes, lack of pigmentation and enhanced non-optic sensory structures. Stygofauna groundwater habitat requires open and connected fractures or pore spaces large enough for the respective species size. As such, the low permeability formations present at Angus Place, in general, are not provide a prospective habitat for stygofauna. Deep groundwater systems, anoxic groundwater, groundwater electrical conductivity exceeding 3,000 µS/cm, or outside pH 4.3 to 8.5 are also generally unsuitable for stygofauna.

Comparative studies in NSW and Queensland have indicated that stygofauna in alluvial groundwater systems tend to be present in greater diversity and abundance than in Permian coal seam groundwater systems. The frequently high electrical conductivity of waters, low oxygen concentrations and limited connectivity within Permian aquifers and between coal seam aquifers and upper, alluvial aquifers has been suggested as a cause of low numbers of stygofauna identified.

Cardno (2019) has under taken stygofauna sampling at Angus Place and Springvale Collieries, as well as Airly Mine and Neubeck Coal Project, also within the Western Coalfields. Details of the stygofauna sampling and results are provided in the Aquatic Ecology and Stygofauna Impact Assessment. Sampling was undertaken at a number of ridge piezometers screened predominantly within the Bankswall Sandstone ranging from 40m to 94m in depth, as well as from swamp piezometers within Tri-Star, Twin Gully and Trail Six/Japan Swamp.

Up to seven stygofauna taxa were identified from groundwater bores at Angus Place. Four of these were identified in bores at Airly, Neubeck and Springvale mines. Two taxa were found at Angus Place only, these were ostracoda (a class of planktonic crustaceans) and Naididae (a family of clitellate oligochaete worms). Oligocheates were also only found at Angus Place, and it is possible these may have been Haplotaxidae or Naididae.

A total of 316 stygofauna were captured from 31 discrete samples at Angus Place, 298 of these were Nematoda returned from one single sampling event at TS01 in Tri Star Swamp in May 2012, leaving 18 individual stygofauna from the remaining 30 sampling events. It is noted that only 4 individual stygofauna, from 12 sampling events, were obtained from the ridge piezometers.

Cardno concluded that the stygofauna assemblage present in aquifers at Angus Place are largely comparable to that present at the other mine areas sampled.

3.7.4 BoM GDE Atlas

Potential GDEs identified from the Bureau of Meteorology (BoM) GDE Atlas are shown on Figure 3.8. The Wolgan River (Western Branch) is identified as a potential aquatic GDE. The river is mapped as low to moderate potential on the Newnes Plateau, and moderate to high potential in the Wolgan Valley.

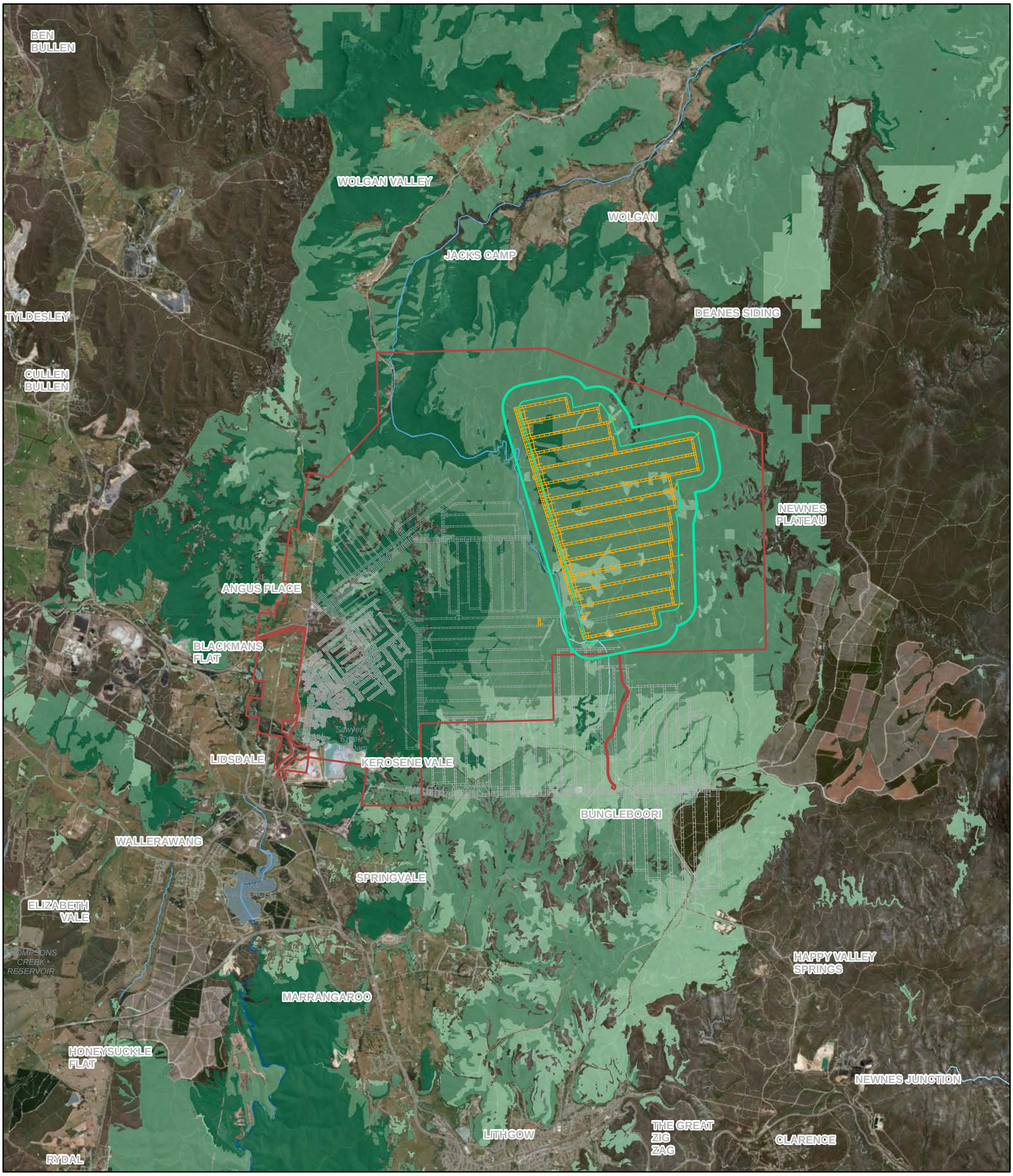
Potential terrestrial GDEs include moderate potential GDE – Narrabeen Montane Eucalypt Forest, predominantly on the Newnes Plateau, and high potential GDE – Permian Wolgan Sheltered and Exposed Woodland, occurring predominantly in the valley areas below Newnes Plateau.

3.7.5 Water Sharing Plans

The Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011, list THPSS as a high priority groundwater dependant ecosystem. No other high priority GDEs are identified in the vicinity of the Project. The locations of THPSS are indicated on Figure 3.6.

Schedule 4 High priority groundwater dependent ecosystems of The Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 are provided in Appendix B.

Figure 3.8: Groundwater Dependent Ecosystems



Aquatic GDE

- High potential - from national assessment
- Moderate potential - from national assessment
- Low potential - from national assessment

Terrestrial GDE

- High potential - from national assessment
- Moderate potential - from national assessment
- Low potential - from national assessment

Infrastructure

- Proposed Workings
- Existing Workings

Project Area

- Project Area

APE Study Areas

- 26.5 degree AoD
- 600m Study Area

GDA 1994 MGA Zone 56

A3 1:100,000

N

0 1 2
Kilometres

JACOBS

Data Sources - Centennial Angus Place Pty Ltd: Project Area, Infrastructure (2019); NSW Government Public Data: Roads, Hydrology, Placenames; BoM: Groundwater Dependent Ecosystems Atlas; ESRI ArcGIS Image Service: World Elevation Terrain, World Topographic Map. Imagery.

4. Groundwater Monitoring

4.1 Monitoring Network

Centennial maintains an extensive groundwater monitoring network on the Newnes Plateau that comprises monitoring of water levels and pore water pressure, water quality, and soil moisture data at a series of monitoring bores, vibrating wire piezometers and soil moisture probes. The layout of the monitoring network is provided on Figure 4.1. Monitoring locations relevant to the APMEP are discussed in the following sections. The groundwater monitoring installations are summarised on Table 4.1.

4.1.1 Reference Sites

In addition to the monitoring within the mine area, monitoring is also undertaken at several locations remote from the active mining area to serve as reference sites for assessment of potential future impacts from mining. These sites include Barrier Swamp, Best Swamp, and Fire Tail Swamp (Figure 4.1). Swamp monitoring has also been established at Long Swamp on the Coxs River.

Table 4.1: Swamp Piezometers and Soil Moisture Probes

Bore ID	Depth (mbgl)	Soil Moisture Sensors (cmbgl)	Undermined[1]
Tri Star Swamp			
TS1	3.95	-	Proposed longwalls
TS2	2.08	10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120 cm	Proposed longwalls
TS3	1.65	10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120 cm	Proposed longwalls
Twin Gully Swamp			
TG1	1.1	10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120 cm	Proposed longwalls
TG2	0.85	10, 20, 30, 40, 50, 60, 70, 80 cm	Proposed longwalls
Trail Six / Japan Swamp			
TX1		-	No
Narrow Swamp			
NS1	2.7	-	LW950
NS2	2.7	-	LW950
NS3	2	-	No
NS4	2	-	LW910
Kangaroo Creek Swamp			
KC1	1.2	-	LW940
KC2	1.6	-	LW950
East Wolgan Swamp			
WE1	2.8	-	LW960
WE2	1.3	-	LW960
West Wolgan Swamp			
WW1	2	-	LW940
WW2	2.5	-	LW940
WW3	2.53	-	LW940
WW4	2.2	-	LW930
Long Swamp			

Bore ID	Depth (mbgl)	Soil Moisture Sensors (cmbgl)	Undermined[1]
LS4	1.86	-	No
LS5	1.71	-	No
LS6	2.58	-	No
Barrier Swamp (Reference)			
BA1	1.18	5, 15, 25, 35, 45, 55, 65, 75, 85, 95, 105 cm	No
BA2	0.95	10, 20, 30, 40, 50, 60, 70, 80 cm	No
BA3	0.9	10, 20, 30, 40, 50, 60, 70, 80 cm	No
Best Swamp (Reference)			
BE1	1.39	10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120 cm	No
BE2	1.39	10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110 cm	No
Fire Tail Swamp (Reference)			
FT1	2.83	10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120 cm	No
FT2	0.5	10, 20, 30, 40 cm	No

Note: [1] – or within angle of draw.

Table 4.2: Shallow Aquifer Piezometers, Ridge Piezometers and Stygofauna Monitoring Bores

Bore ID	Screen from (mbgl)	Screen to (mbgl)	Screened formation / Aquifer	Undermined [1]
Shallow Aquifer Piezometers				
SPR1609 (proposed)	tba	tba	Banks Wall Sandstone / AQ4	Proposed longwall
SPR1610 (proposed)	tba	tba	Banks Wall Sandstone / AQ4	Proposed longwall
SPR1608 (Ref)	4	10	Burralow Formation / AQ5	No
SPR1611 (Ref)	4	10	Burralow Formation (inferred) / AQ5	No
SPR1612 (Ref)	4	10	Burralow Formation (inferred) / AQ5	No
Ridge Piezometers				
AP1PR	23	38	Burralow Formation / AQ6	Proposed longwall
AP4PR	36	51	Burralow Formation / Banks Wall Sandstone / AQ5 Lower / AQ4 Upper	Proposed longwall
AP5PR	79	94	Banks Wall Sandstone / AQ4 Lower	Proposed longwall
AP8PR	76	91	Burralow Formation / Banks Wall Sandstone / AQ5 Lower / AQ4 Upper	Proposed longwall
AP9PR	67.3	82.3	Banks Wall Sandstone / AQ4 Upper	Proposed longwall
AP10PRSP	24.6	39.6	Banks Wall Sandstone / AQ4 Upper	Proposed longwall
AP1102SP	95	110	Banks Wall Sandstone / AQ4 Upper	No
AP1104SP	65	80	Banks Wall Sandstone / AQ4	Proposed longwall
AP1105SP	60	75	Banks Wall Sandstone / AQ4	Proposed longwall
AP1107SP	35	50	Banks Wall Sandstone / AQ4	Proposed longwall
AP1110SP	56	71	Burralow Formation / AQ5	Proposed longwall
AP1204SP	85	100	Banks Wall Sandstone / AQ4	Proposed longwall

Bore ID	Screen from (mbgl)	Screen to (mbgl)	Screened formation / Aquifer	Undermined [1]
REN	40.08	55.08	Burralow Formation / AQ6 Lower / AQ5 Upper	LW950
RNW	35.46	50.46	Burralow Formation / AQ6 Lower / AQ5 Upper	LW950
AP1801	310	320	Lithgow Seam / AQ1	No
Deep Stygofauna Monitoring Bores				
SPR1801	306	324	Glen Davis / Newnes Formation / AQ1 Upper	No
SPR1802	309	318	State Mine Creek Formation / Watts Sandstone / AQ2	No
SPR1803	230	242	Burra-Moko Head Sandstone /Caley Formation / AQ3	No

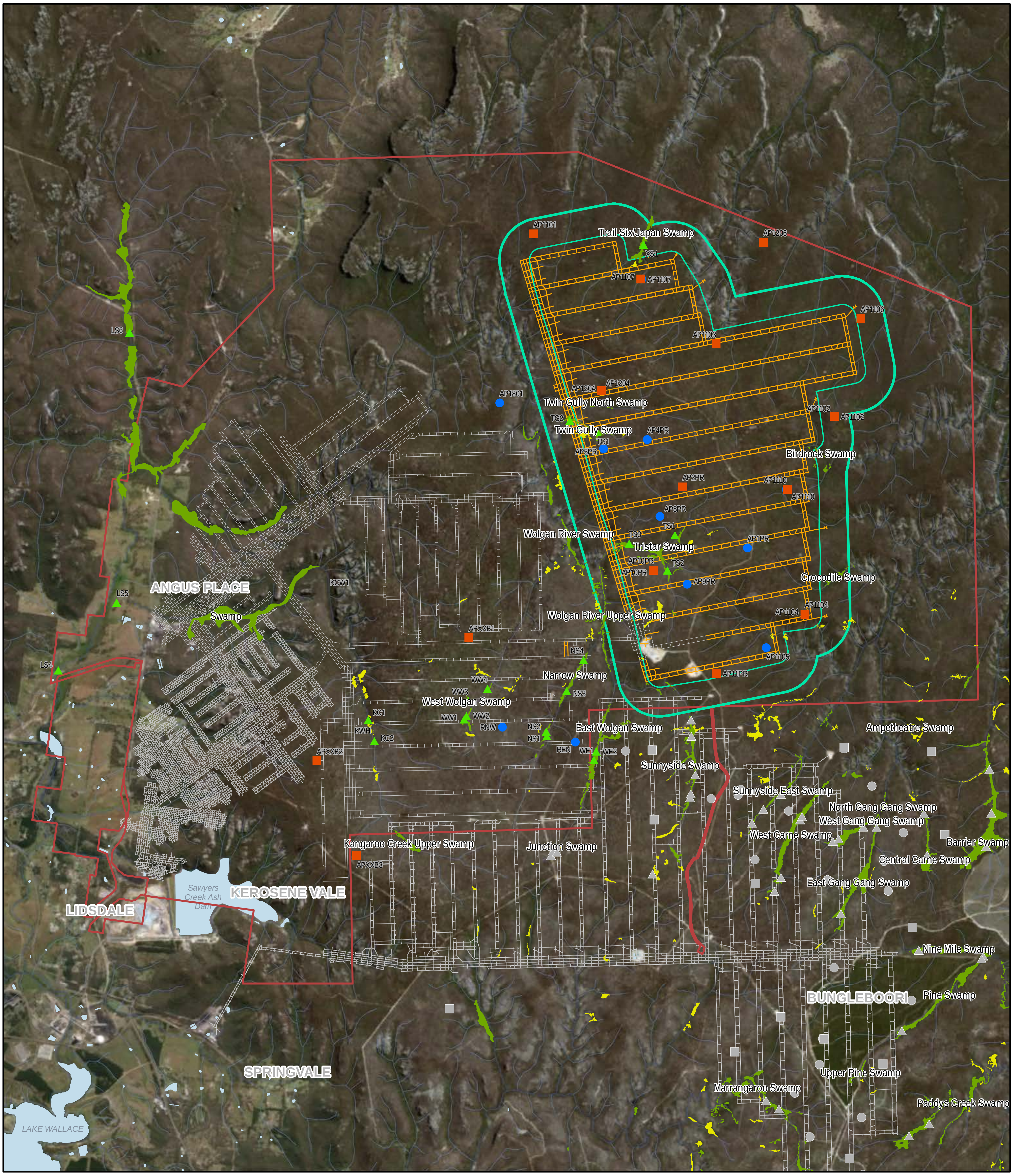
Note: [1] – or within angle of draw.

Table 4.3: Vibrating Wire Piezometers

Bore ID	Sensor Depths (mbgl)	Aquifer	Undermined [1]
AP2PR	92, 181, 213, 299.5, 381, 411	YS6, SP3/MYC, AQ3, SP2, AQ1, Lithgow Floor (AQ1)	Proposed longwall
AP10PR	60, 103, 150, 205, 248, 270, 300, 327, 343	AQ4, AQ4, AQ3, AQ3, AQ2, SP1, AQ1, AQ1, Lithgow Floor (AQ1)	Proposed longwall
AP11PR	43, 72, 93, 128, 167, 233, 263, 295, 320	AQ6, YS5, AQ4, AQ4, AQ4, AQ3, AQ3, AQ3, AQ2	No
AP1101	92, 150, 210, 235.5, 248, 299.5, 327.5	AQ4, AQ3, AQ3, AQ2, AQ2, AQ1, AQ1	No
AP1102	123, 210, 265, 338, 392, 426.3, 435.1	AQ4, AQ3, AQ3, AQ2, AQ1, AQ1, Lithgow Floor (AQ1)	No
AP1103	105, 153, 200, 260, 290, 341.8	AQ4, AQ3, AQ3, AQ2, SP1, AQ1	Proposed longwall
AP1104	170, 240, 255.6, 277, 300, 360, 370.8	AQ3, AQ3, SP2, AQ2, SP1, AQ1, Lithgow Floor (AQ1)	Proposed longwall
AP1106	174, 251, 275, 335, 356.3, 380.31	AQ3, SP2, AQ2, AQ1, AQ1, Lithgow Seam (AQ1)	No
AP1107	54, 81, 147.5, 210, 212.5, 238, 290	AQ4, AQ4, AQ3, SP2, SP2, AQ2, AQ1	Proposed longwall
AP1110	127, 224, 304.4, 331.8, 383, 399.7	AQ4, AQ3, AQ3, AQ2, AQ1, Lithgow Floor (AQ1)	Proposed longwall
AP1204	92.5, 138.5, 198.5, 269, 316.5, 332.2, 355.3	AQ4, AQ4, AQ3, AQ2, AQ1, AQ1, AQ1	Proposed longwall
AP1206	152, 244, 257.5, 305, 322, 342	AQ3, SP2, AQ2, AQ1, AQ1, AQ1	No
APXXB1	143, 179, 250, 275, 335, 356.5	AQ4, AQ3, SP2, AQ2, AQ1, Lithgow Seam (AQ1)	Planned longwall
APXXB2	69, 135, 160.5, 185, 243	YS5, AQ4, SP3/MYC, AQ3, AQ2, AQ1, Lithgow Floor (AQ1)	Planned longwall
APXXB3	83.5, 111.5, 156.5, 242, 285, 301.5, 331.5	AQ4, AQ4, AQ3, AQ2, AQ1, AQ1, Lithgow Floor (AQ1)	Planned longwall

Note: [1] – or within angle of draw.

Figure 4.1: Groundwater Monitoring Network



Angus Place
- Ridge
- Swamp and soil moisture probes
- Vibrating Wire

Springvale
- Ridge
- Swamp and soil moisture probes
- Vibrating Wire

Infrastructure
- Proposed Workings
- Existing Workings

Project Area
- Project Area

APE Study Areas
- 26.5 degree AoD
- 600m Study Area

Hydrology
- Water Areas
- Stream Order 1 - 2
- Stream Order 3 - 6

GDA 1994 MGA Zone 56

A3 1:55,000

N

0 1 2
Kilometres

JACOBS

Data Sources - Jacobs: Monitoring Locations; Centennial Angus Place Pty Ltd: Project Area, Infrastructure (2019); NSW Government Public Data: Roads, Hydrology, Placenames; Geosciences Australia (ELVIS): 50m Contours; Office of Environment and Heritage NSW: Tenures; ESRI ArcGIS Image Service: World Elevation Terrain, World Topographic Map

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4.2 Water Levels

4.2.1 Swamp Piezometers and Shallow Aquifer Piezometers

Water hydrographs for swamp piezometers and shallow aquifer piezometers are provided in Appendix C. Water level responses and trends within swamps rely on a number of factors, including depths of swamp materials, catchment size and characteristics, and groundwater contribution. Mining also has potential to influence swamp hydrology. Several examples are summarised below.

Not Yet Undermined

- At Tri Star Swamp, TS1 displays a permanently waterlogged trend throughout the monitoring record (from 2011) with water levels near surface and a maximum range of fluctuations of the order of 20 to 30cm. Over the same monitoring period, TS2 has transitioned from an initial permanently waterlogged state in 2011 and 2012, to periodically water logged and showing annual recharge cycles up until 2017, with water levels then declining and remaining predominantly below the base of the piezometer. TS3 displays a similar trend to TS2, although the range in water levels is significantly exaggerated. It is noted that the trends at TS2 and TS3 correlate closely with CRD. The two years leading up to commencement of monitoring at Tri Star Swamp experienced strongly above average rainfall. 2012 to 2016 was a period of fluctuating but generally average rainfall, characterised by fewer but more intense rainfall events. 2017 and 2018 was generally a period of strongly below average rainfall.
- At Twin Gully Swamp, water levels at TG1 display a response that is intermediate between permanent and periodic water logging. During periods of rainfall, water levels are typically maintained within 10 to 15cm of ground surface. However, with sustained below average rainfall conditions, water levels at TG1 decline fairly rapidly. Low water levels generally occur during summer months of November through to March. Since installation in 2018, TG2, has displayed similar responses to TG1.
- At Trail Six/Japan Swamp, TS1 shows a decline in average water levels of approximately 15 to 20cm over 2016 and 2017, coinciding with declining CRD. TS1 still displays a permanently waterlogged response at the lower water level, with significant depth of saturation retained.

Previously Undermined

- Following undermining in 2008, KC1, in Kangaroo Creek Swamp transitioned from being permanently water logged, to periodically water logged, and then to predominantly dry during a period of above average rainfall. The saturated thickness of swamp sediments at KC1 prior to undermining was only of the order of 35 cm, which is not inducive of resilience to climatic or external stresses.
- Flows and water levels in Narrow Swamp were historically artificially maintained by mine water discharge. As such, a pre-mining baseline has not been established. Following the cessation of discharge in 2009, water level at NS4 displayed sporadic and short-term water logging, showing only brief responses to large rainfall events followed by rapid water level regression during a period of above average to predominantly average rainfall conditions. From 2015 NS4 has been predominantly dry. The other piezometers, NS1, NS2, and NS3, have been predominantly dry since the cessation of discharge.
- As with Narrow Swamp, flows and water levels in East Wolgan Swamp were historically artificially maintained by mine water discharge and a pre-mining baseline has not been established. Following the cessation of discharge in 2009, water level at WE1 and WE2 have displayed intermittent and short-term water logging, showing only brief responses to large rainfall events followed by rapid water level regression during a period of above average to predominantly average rainfall conditions. From November 2016 to October 2018, when the CRD was displaying a strongly below average trend, water levels at WE1 and WE2 remained below the base of the piezometer.
- West Wolgan swamp has been undermined by longwalls LW930, LW940, and LW960, between May 2006 and July 2009. WW1 and WW2 were undermined in late October / early November 2007, WW3. Located above the LW930 chain pillar was passed by LW930 in June 2006 and LW940 in October 2007, and WW4 was undermined by LW930 in May 2006.

- Water levels in WW4 have been below the base of the piezometer since monitoring commenced in April 2006, and prior to being undermined.
- Water levels in WW3 have been displaying a periodically waterlogged trend since monitoring commenced in December 2005. Following significant rainfall, water levels at WW3 rise by up to 1.5m and remain above the base of the piezometer for a number of months. Between rainfall events, water levels are typically below the base of the piezometer. No significant change is observed following undermining.
- WW1 and WW2 display identical trends although the base of WW2 is 0.5m deeper than WW1. WW1 and WW2 historically show several alternating cycles of elevated water levels, where water level responses are intermediate between permanent and periodic water logging, and low water levels where water levels are typically below the base of the piezometer. Following undermining, the elevated water levels have not been sustained and from September 2013 water levels have transferred to a periodically waterlogged response, only showing responses to significant rainfall events. WW1 and WW2 show a delayed response to observing the full impacts of undermining, possibly offset by the above average rainfall from January 2010 to July 2012.

Reference

- The three piezometers installed in Barrier Swamp, display generally stable trends. The trends are typical of a permanently waterlogged swamp but are overprinted with recharge events particularly in the mid to lower reaches (BA2 and BA3). Since monitoring commenced in early 2018, BA1 in the upper reaches of the swamp shows a slight declining trend, while BA3, located in the lower reaches of the swamp displays a gradual trend of increasing water levels, albeit very minor. BA2, located midway between BA1 and BA3, is stable. The slight decline at BA1 is attributed to the preceding below average rainfall conditions, combined with a smaller contributing catchment, and shallower perched aquifers compared to BA3.
- Shallow aquifer piezometer SPR1608, installed in the lower reaches of Barrier Swamp, displays very stable water levels at around ground level. A very minor decline is observed after February 2019 in response to below average rainfall.
- Two piezometers are installed at Best Swamp, BE2 located in the lower reaches of the swamp, displays relatively stable water levels, with minor rainfall fluctuations evident above a fairly stable baseline water level. BE1, located in the upper reaches of the swamp, displays considerably greater fluctuation and from early 2019, water levels display a declining trend. With declining water levels there is also an increase in the magnitude of the fluctuations due to rainfall. The trends observed at BE2 are consistent with a permanently waterlogged swamp, transitioning to more periodically water logged in the upper reaches at BE1.
- Shallow aquifer piezometer SPR1612, installed in the lower reaches of Best Swamp, displays stable water levels with up to 20 to 30cm fluctuations due to rainfall. Water levels are typically in the range 1.4 to 1.8mbgl, a gradual decline is evident over the period of observation in response to below average rainfall.
- Two piezometers are installed at Fire Tail Swamp, FS1 located in the upper reaches of the swamp, and FS2 located in the lower reaches of the swamp. At FS2 there is considerably greater depth of swamp sediments (approximately 2.8m) compared with FS1 (0.5m). Water levels at both sites show significant fluctuation, indicating an intermediate response between permanent and periodic water logging. The observed fluctuations at FS2 are typically of smaller magnitude but are more significant with respect to the depth of saturated materials. From early June 2018, water levels at FS1 displayed a rising trend, despite below average rainfall at the time. Significant responses to on moderate rainfall events are apparent. From February 2019 there has been a recession in water levels with increased magnitude of fluctuations in response to rainfall events.
- Shallow aquifer piezometer SPR1611, installed in the lower reaches of Fire Tail Swamp, displays stable water levels almost identical to SPR1612 at Best Swamp. Water levels are typically in the range 1.4 to 1.8mbgl, a gradual decline is evident over the period of observation in response to below average rainfall.

4.2.2 Ridge Piezometers

Water hydrographs for ridge piezometers are provided in Appendix C. Out of the ridge piezometers only REN and RNW have been undermined, by LW950 in September 2008 and May 2009 respectively.

AP1PR, REN and RNW are screened within the Burralow Formation (AQ5 and AQ6) and display elevated water levels compared to the remainder of the ridge piezometers.

AP4PR and AP8PR are noted as being screen across the lower Burralow Formation and the Bankswall Sandstone (AQ5/AQ4) but display level more representative of the other Bankswall Sandstone monitoring bores. AP1110SP is recorded as being screened within the Burralow Formation (AQ5) yet displays water levels similar to Bankswall Sandstone. It may be that the drill hole penetrates AQ4 and has not been sealed.

Water level responses across all of the ridge piezometers show a variety of responses to the prevailing climatic conditions. Water levels typically increase until around 2013 with the above average CRD from 2010 until mid-2012 and then begin a gradual regression. The magnitude of the fluctuations varies depending on depth and distance from recharge and ranges up to approximately 9m observed water level variance at AP1102. It is noted that none of the ridge piezometers respond significantly to shorter term rainfall fluctuations with hydrographs showing a muted response to the longer-term trends.

4.2.3 Vibrating Wire Piezometers

VWP Hydrographs are provided in Appendix C. While none of the Angus Place VWP have been directly undermined, APXXB1, APXXB2 and APXXB3 are located in proximity of existing Angus Place workings, and APXXB3 is also in close proximity to Springvale workings. AP11PR is located close to Springvale workings. Undermined VWP at Springvale are considered in the conceptual hydrogeology and the calibration of the hydrogeological model (JBS&G, 2019a).

Key water pressure trends and observations are as follows:

- All sensors at APXXB2 show a response to the passing of LW900W in December 2014. The response is most pronounced in sensors 3 to 6, with sensor 6 located in the Bankswall Sandstone above the Mount York Claystone. The response is less pronounced in the deeper sensors (AQ1) due to prior depressurisation. A small response is also observed in sensor 7 in the Burralow Formation with a subsequent recovery in water levels.
- APXXB3 sensors 1 and 2 (AQ1) show a pressure drop in July 2013. This is likely due to the LW900W development headings as no other longwall activity occurring nearby. The sensors then show a further decline over a period when the logger was non-functional from January to September 2014, the decline is also observed at sensor 5 below the Mount Yok Claystone. During this time LW900W was extracted past APXXB3. Sensors 3 and 4 show a corresponding step up in pressure of the same period. Sensors 6 and 7, installed in the Bankswall Sandstone, show fluctuations that are consistent with CRD, with no mining influences apparent.
- At AP11PR, the lower sensors, one to three, show a depressurisation response in April 2012 that coincides with the commencement of LW415 at Springvale. Sensor 4 displays a more gradual decline in pressure commencing at the same time. Sensor number 7 in the Bankswall Sandstone was originally unsaturated, but from December 2011 displays an increasing head in response to the above average CRD. Water levels peak in September 2013 with a gradual regression back to unsaturated conditions in 2018.
- For the VWP away from the immediate influence of mining, those closest to existing operations (AP10PR and AP1104) show reduced heads in the Lithgow Seam and AQ1 of the order of 815 to 830mAHD, that increase away from the influence of mining. The highest heads within the lower aquifer are observed at AP1204 (919mAHD), AP2PR (896mAHD) and AP1110 (890mAHD). Heads then diminish to the northeast in the direction of groundwater flow with approximately 760mAHD at AP1106 and 720mAHD at AP1206. It is noted that AQ1 outcrops in Carne Creek further to the northeast at an elevation of approximately 700mAHD and is a point of discharge.

- An initial trend of recovery within the Lithgow Seam and lower aquifer is apparent at most installations, with AP1102 also displaying an initial stepped depressurisation response with subsequent recovery. As this is also observed away from the influence of mining the response it is attributed to the local depressurisation of the formation during drilling and grouting of the VWP installations with subsequent gradual re-equilibration.
- A number of shallow sensors show responses to the prevailing CRD, as do several sensors installed below the Mt York Claystone, including AP10PR sensors 6 and 7, AP1110 sensor 5, AP2PR sensor 5, and AP1106 sensor 6.

4.3 Soil Moisture

Soil moisture is water that is held in the pore spaces of a soil within the vadose, or unsaturated zone. Soil moisture content is typically reported as a volumetric percentage of the total volume of water held in a given volume of soil (%vol). Soil moisture is influenced by rainfall infiltration, evapotranspiration, and deep drainage or infiltration to the water table. Soil moisture close to the water table is also influenced by capillary action drawing water up from the water table.

Three soil moisture states, or soil moisture characteristics, are used to describe water content across different water potentials in soil. These being; saturation, field capacity and permanent wilting point. The different states related to the energy required to move water, or extract water from soil. When the soil is at or near saturation the direction of the potential energy gradient is downward through the soil profile or laterally down slope. This gravity flow, or drainage, occurs mainly in macro-pores. As the soil dries, field capacity is reached after free drainage of macro-pores has occurred. Field capacity represents the soil water content retained against the force of gravity by matric forces at tension of approximately -30 kPa. As water content decreases, soil matric potential decreases, becoming more negative, and as a result, water is held more strongly to mineral surfaces due to cohesive forces between water molecules and adhesive forces associated with water and mineral particles (capillary forces).

Soil moisture probes have been installed at locations in Twin Gully and Tri Star Swamps at Angus Place and in reference swamps in Barrier Swamp, Best Swamp and Fire Tail Swamp (Table 4.1 and Figure 4.1).

The sensors utilised at Angus Place are EnviroPro soil moisture probes. The EnviroPro sensors monitor changes in the dielectric properties of the soil to provide, continuous monitoring of soil moisture and soil temperature. The sensors respond to changes in the dielectric properties of the soil. The relationship between dielectric properties and volumetric moisture content is well understood and widely documented. The sensors are calibrated at the time of manufacture, to a standardized soil media (fine sand). The values returned in other soils will differ in accordance with the average particle size distribution in the soil, which is in turn dependent on the percentages of sand, loam and clay in the soil. Other factors such as organic matter and rock fraction will also alter the net water holding capacity. A study by Fares et al (2016) in to the effects of soil organic content of the accuracy of soil water content sensors, found the presence of organic matter results in more water bound to the organic matter particles which becomes less accessible to soil water content sensors, and therefore leads to an underestimation of the sensor readings.

For each soil moisture installation, the sensor loggers have been reprogrammed with calibration coefficients more appropriate to the actual soil type present (based on field logging and laboratory particle size distribution). Representative soil water characteristics for each installation have also been estimated based on the Soil Water Characteristics Model (Saxton and Rawls, 2006) developed by the United States Department of Agriculture, Agricultural Research Service. It is noted that the characteristics presented are generalised for a specific soil type and may not be applicable to all sensors.

Plots of soil moisture are provided in Appendix D. Key soil moisture content trends and observations are summarised as follows:

Twin Gully and Tri Star Swamps

- TG1SM – generally saturated below 50cm. Shallower sensors fluctuate around field capacity with minor dips during prolonged dry periods. TG1 piezometer water levels typically 5 to 40cm below ground level.
- TG2SM – Generally saturated below 40cm. Shallower sensors fluctuate around field capacity. TG2 piezometer water levels typically 5 to 40cm below ground level.
- TS2SM – No sensors saturated. The majority of sensors typically around field capacity, a brief period of saturation following sustained rainfall in January and February 2019. 10 and 20cm sensor often plotting at wilting point, however, moisture content maybe underestimated due to organic material. TS2 piezometer water levels typically below 1.9mbgl.
- TS3SM – Generally saturated below 30cm. Shallow sensors gradually increase to field capacity and fluctuate with rainfall. TG3 piezometer water levels typically 10 to 20cm below ground.

Reference Sites

- BA1SM – all sensors except 5cm generally saturated. 5cm fluctuates with rainfall. BA1 piezometer water levels typically 0 to 6cm below ground level.
- BA2SM - all sensors except 10cm generally saturated. 5cm fluctuates with rainfall. BA2 piezometer water levels typically 15 to 20cm below ground level.
- BA3SM - typically saturated below 30cm. 20 to 30cm near saturation. 10cm fluctuating with rainfall. BA3 piezometer water levels typically 10 to 15cm below ground level.
- BE1SM - typically saturated below 60cm. 40 and 50cm sensors fluctuate rapidly between saturation and near wilting point (sand?). Remaining sensors fluctuate around field capacity. BE1 piezometer water levels show significant fluctuation in the range 40 to 80 cm below ground.
- BE2SM – 30 and 40cm sensors periodically saturated, 10 and 20cm sensors typically around field capacity occasionally spiking to saturation with rainfall. BE2 piezometer water levels typically around 50 cm with higher fluctuation due to rainfall.
- FS1SM – typically saturated below 90cm. 50 to 80cm periodically saturated. 20 and 30cm typically fluctuate around field capacity. 30 and 40cm typically lower moisture content, possibly underestimated due to high organic content. FS1 piezometer water levels fluctuate in the range 60 to 100cm below ground.
- FS2SM – 40cm generally saturated and 30cm periodically saturated. 10 and 20cm display increasing moisture content typically increasing to field capacity. FS2 piezometer water levels typically fluctuate around 25cm below ground.

4.3.1 Relationship to swamp water levels

From observations at Springvale Mine, water levels in swamps that have been undermined have declined significantly, there has been a corresponding decline in soil moisture levels. Two examples, BS2 and GG3, are provided below.

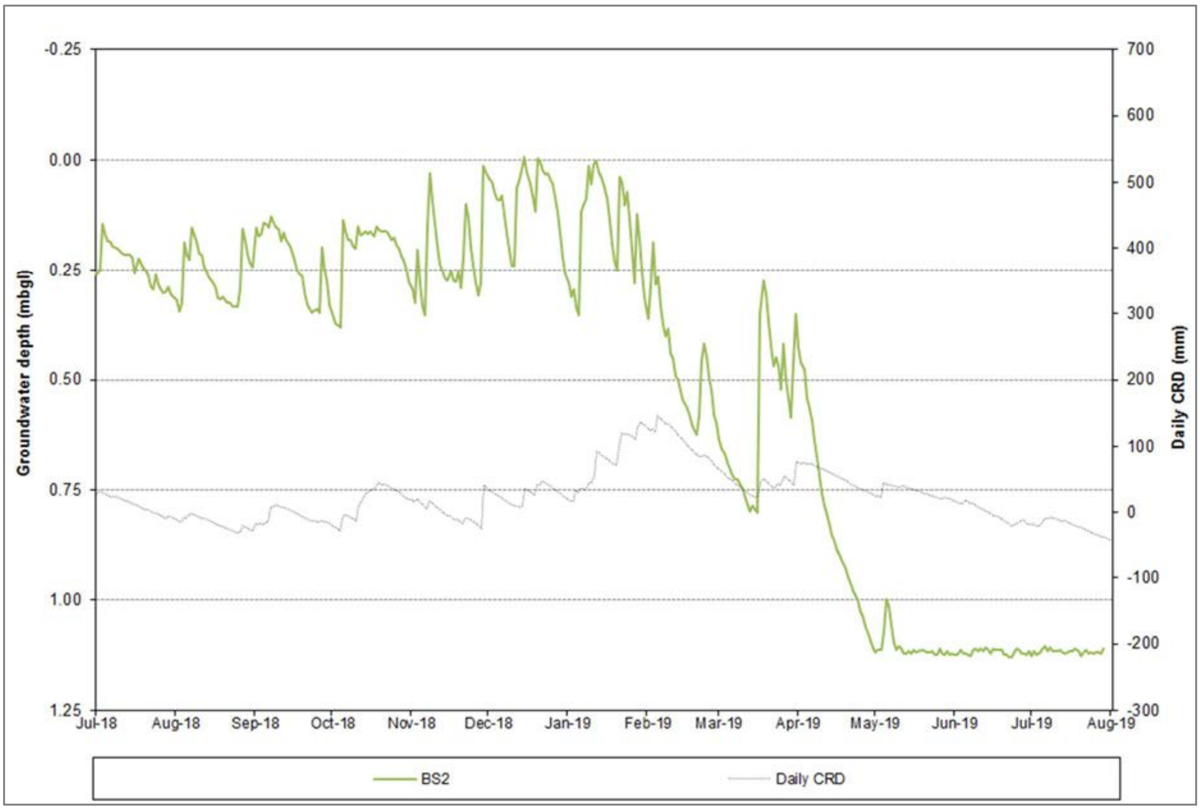
BS2 – Pine Swamp

BS2 has not been directly undermined, but Pine Swamp was undermined during January and February 2019 and water levels in BS2 piezometer declined by over one metre over a period of three months (Figure 4.2).

Following the water level decline, soil moisture at the 10 and 20cm sensors, which had previously been periodically saturated, and the 30 and 40cm sensors, which had previously been predominantly saturated declined significantly. The decline at deeper sensors was delayed corresponding to the ongoing water level decline. The 10 and 20cm sensors stabilised at around 25% moisture content and the 30 and 40cm sensors at approximately 15% moisture content. Shallow soil moisture shows responses to rainfall and the moisture content remains above the indicative field capacity. The deeper sensors indicate an ongoing decline.

GW3 – Gang Gang Swamp South West

LW420 passed by GW3 and undermined Gang Gang Swamp South West in July 2017. Water levels in GW3 piezometer were already declining but dropped below the base of the piezometer in early August 2017. Swamp moisture level declined coinciding with the water level decline and subsequently stabilised in the range 10 to 15% moisture content which is equivalent to the indicative field capacity of the soil. All sensors show responses to rainfall events following the decline.



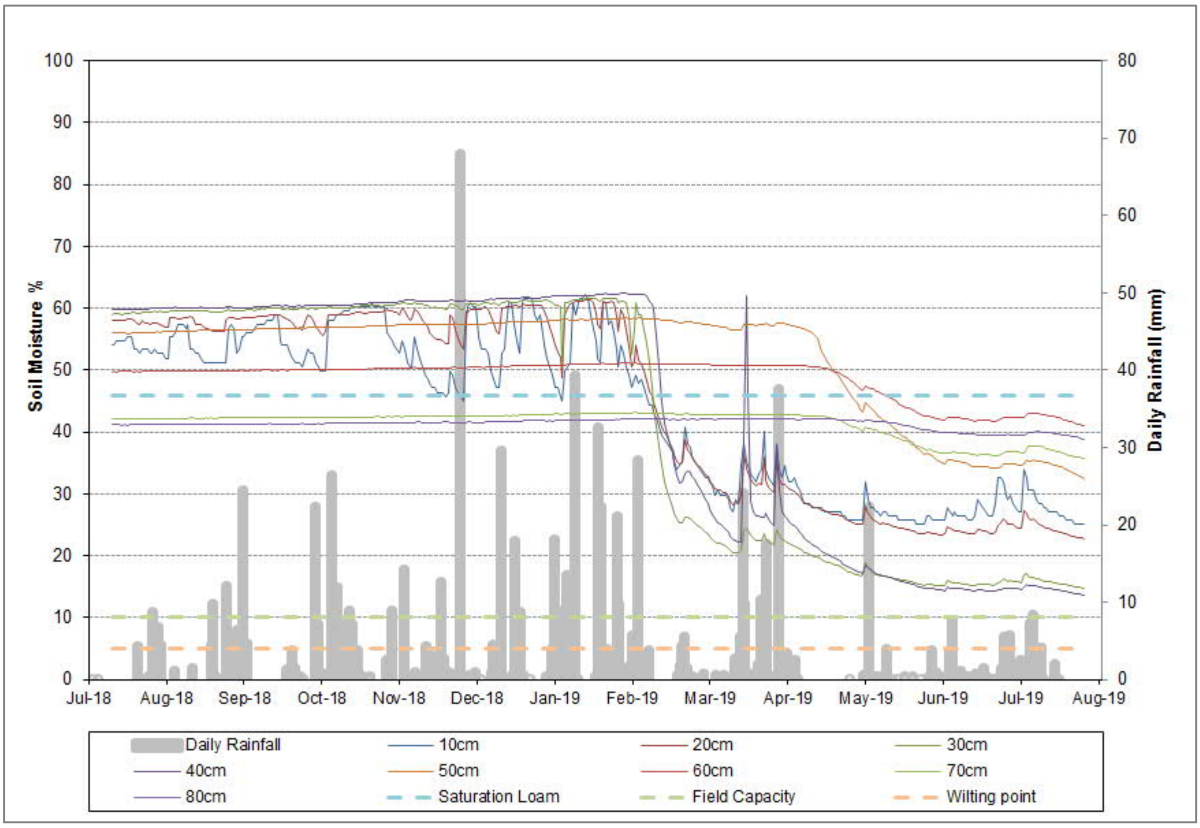
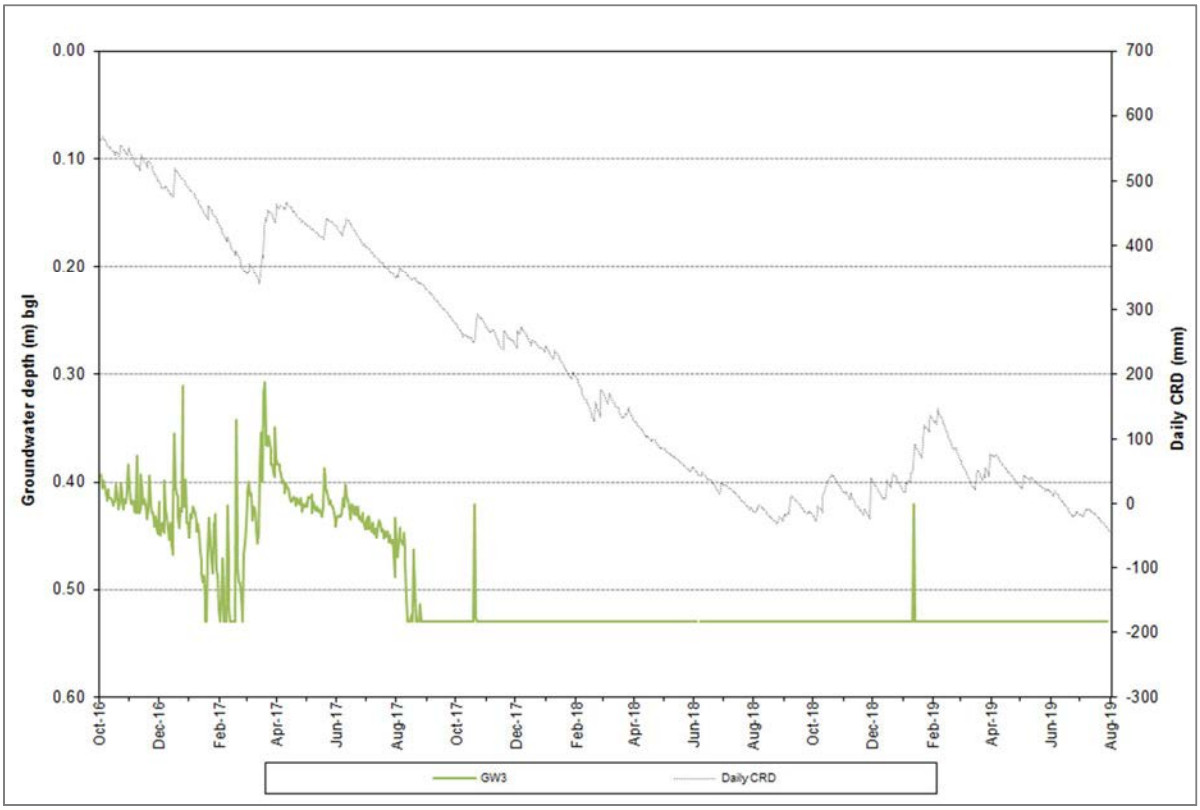


Figure 4.2: Pine Swamp BS2 Water Levels (Top) and Soil Moisture (Bottom)



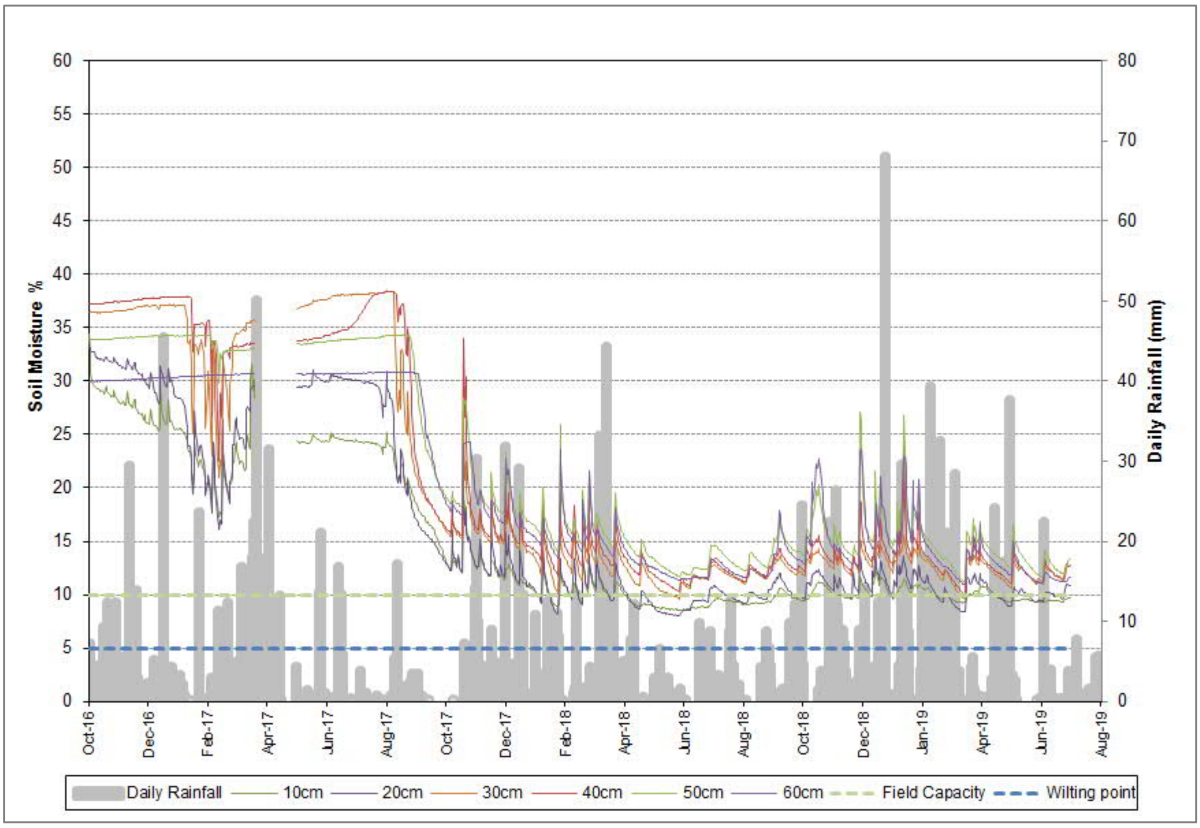


Figure 4.3: Gang Gang Swamp South West GW3 Water Levels (Top) and Soil Moisture (Bottom)

4.4 Water Quality

4.4.1 Swamp Piezometers

Summary statistics of water quality from swamp piezometers are provided on Table 4.4. Plots of water quality parameters are provided in Appendix E.

Key swamp water quality observations are summarised as follows:

- Swamp water is very fresh. Salinity (as electrical conductivity) is typically below 100 µS/cm, with average salinity in the range 27 to 62 µS/cm.
- Salinity tends to vary with rainfall (Appendix E)
- Swamp water is typically moderately acidic. pH is typically in the range 4.7 to 6.6, with fairly uniform average pH in the range 5.2 to 6.0.

Table 4.4: Swamp Piezometer Water Quality Summary

ID	EC (us/cm)					pH				
	Count	mean	10%	50%	90%	count	mean	10%	50%	90%
Twin Gully Swamp										
TG1	66	44.8	29.5	41.0	55.0	70	5.6	4.9	5.5	6.2
TG2	3	62.0	34.8	50.0	94.0	3	5.3	4.9	5.1	5.8
Tri Star Swamp										
TS1	16	27.2	21.5	29.5	34.0	17	5.2	4.7	5.3	5.7
TS2	58	57.4	30.7	46.0	104.9	63	6.0	5.5	5.9	6.6
TS3	67	46.6	30.0	43.0	62.0	72	5.5	5.0	5.4	6.1
Trail Six/Japan Swamp										
XS1	67	54.4	32.2	43.0	78.8	71	5.5	4.9	5.3	6.1
Barrier Swamp										
BA1	5	47.2	40.4	45	55.2	5	0.33	0.20	0.25	0.53
BA2	5	162.8	100	182	206.8	5	0.92	0.20	1.07	1.62
BA3	5	90.4	65.4	102	104.8	5	0.42	0.14	0.27	0.85
Best Swamp										
BE1	5	44.8	39.8	46.0	49.4	5	0.28	0.13	0.23	0.47
BE2	4	41.25	38.3	40.5	44.8	3	0.27	0.21	0.24	0.34
Fire Tail Swamp										
FS1	43	43.0	43.7	43.0	43.0	3	0.12	0.08	0.12	0.17
FS2	48	48.0	48.0	48.0	48.0	1	0.32	0.32	0.32	0.32

4.4.2 Ridge Piezometers

Summary statistics of water quality from ridge piezometers are provided on Table 4.5. Comprehensive water quality data is provided in Appendix F.

Key water quality observations are summarised as follows:

- Shallow groundwater within the Burralow Formation and Bankswall Sandstone water is very fresh. Salinity (as electrical conductivity) is typically below 80 µS/cm, with average salinity in the range 26 to 50 µS/cm.

- Swamp water is typically moderately acidic. pH is typically in the range 4.6 to 6.5, with fairly uniform average pH in the range 5.4 to 5.6.
- Given the very low electrical conductivity and total dissolved solids (Appendix F) assessment of water typing using Piper Diagrams or similar is not feasible with conventional laboratory limits of detection.

Table 4.5: Ridge Piezometer Water Quality Summary

ID	EC (us/cm)					pH				
	Count	mean	10%	50%	90%	count	mean	10%	50%	90%
AP1204	20	50.2	33.9	42.8	71.2	20	5.5	4.6	5.5	6.5
AP4PR	22	30.8	25	29	36	21	5.4	4.8	5.3	6.1
AP5PR	22	26.1	19.8	26.2	32.7	21	5.6	5	5.7	6.3
AP8PR	20	45.7	38.7	44.5	50.8	19	5.4	4.8	5.4	6.2
AP9PR	21	26.3	22	25.3	30.5	20	5.6	5.1	5.6	6.5

4.4.3 Deep Groundwater

Summary statistics of water quality from the Bore 940 dewatering bore is provided on Table 4.6. Comprehensive water quality data is provided in Appendix F. Water quality observed at Bore 940 represents a blended sample of all contributing inflows underground at Angus Place.

Key water quality observations are summarised as follows:

- Deep groundwater derived from dewatering is marginally brackish. Salinity (as electrical conductivity) is typically in the range 850 to 1290 µS/cm, with an average of 1116 µS/cm.
- The deep groundwater is typically neutral with pH in the range 7.2 to 7.8, with an average pH of 7.5.
- It is noted that mine inflows that report to the Bore 940 dewatering facility, comprise roof leak, as well as seam wall and floor seepages, and inflows from the collapsed goaf areas. The water will have flowed over the pit floor and have been transferred by pumping. During this process considerable aeration is likely to occur, raising the pH from that of the natural formation. There is also potential for precipitation of dissolved minerals which could alter (reduce) the electrical conductivity from that of formation water.

Table 4.6: Dewatering Water Quality Summary

ID	EC (us/cm)					pH				
	Count	mean	10%	50%	90%	count	mean	10%	50%	90%
Bore 940	190	1116	856	1183	1289	190	7.5	7.2	7.6	7.8

4.4.4 Groundwater Age

An assessment of groundwater age was undertaken at Springvale Mine to analyse potential connectivity between the mine and shallow groundwater (Jacobs, 2017). Apparent groundwater age was analysed for a number of samples from ridge piezometers and water collected underground in Springvale Mine.

Results were as follows:

- A mean apparent age from CFC dating of the order of 27 to 42 years for the ridge piezometer samples.
- A potential age from Tritium analysis of the order of 40 years or younger for the ridge piezometers.
- Calibrated (un-corrected) radiocarbon ages of modern (<100 years) for the ridge piezometers and 6,750 to 22,900 years for samples collected from the underground.

- The younger radiocarbon ages may be indicative of a potential recharge source to the deeper aquifers via a convoluted/tortuous pathway from the shallower groundwater system, although contamination of the sample in the underground with introduced younger water could not be ruled out.

4.5 Interactions between Subsidence and Major Geological Structures

Several studies have been completed by Centennial on the interaction between major geological structures and subsidence, and the subsequent interaction with groundwater systems (Centennial Coal, 2017 and 2018).

The studies present case studies of Kangaroo Creek (Mid) Swamp, Sunnyside East Swamp, Carne West Swamp, Gang Gang Swamp South West and Gang Gang Swamp East to assist with the identification of causal mechanisms for changes to water levels identified in some of the THPSS overlying the Springvale and Angus Place mining areas.

The locations of significant lineaments in the underground was identified through mapping of anomalous extensometer responses at extensometer installations in roadway roof lithologies. The studies identified a strong correlation between the roof dilation behaviour measured by the underground extensometers early in their lifecycle and the location of lineaments identified by Palaris (2013b), in addition to other significant geological faults within the current mine workings.

Case studies at Sunnyside East Swamp, Carne West Swamp, Gang Gang Swamp South West, and Gang Gang Swamp East demonstrated that periods of significant swamp hydrological change were immediately preceded by the intersection of the longwall face with identified major lineaments and other significant faults. The distance of the position of the longwall face intersection of the major lineament from the swamp at time of observation of change ranged from being directly undermined, to up to 1620m away in the case of GW2 in Gang Gang Swamp South West.

A general summary of observed impacts at undermined swamps at Angus Place and Springvale Mines is provided on Table 4.7. Detailed observations are provided in the following sections.

Table 4.7: THPSS and Previous Longwall Mining at Angus Place and Springvale Collieries

Swamp	Longwalls	Type 1 or Type 2 structures	Measured subsidence effects (near swamp)	Observed changes to piezometer levels	Observed physical impacts and environmental consequences
Junction Swamp	Above Springvale LW408 and LW409	Wolgan lineament zone (Type 1)	1058mm subsidence 4.1mm/m tensile strain 13.1 mm/m compressive	Correlation between aquifer standing water levels adjacent to swamp and the cumulative rainfall deviation over 15 years of monitoring. Baseline monitoring commenced in May 2002 NB Wolgan Lineament (west) was undermined to the southwest of Junction Swamp by Longwall 405 in December 2000, October 2001 by Longwall 406, and August 2002 by Longwall 407.	Vegetation dieback, major incision and erosion (in some instances down to bedrock), associated with loss of peat layer, significant loss of ecosystem function and ecological resilience, and ecological and geomorphic threshold exceedance
Kangaroo Creek Swamp	Above Angus Place LW940 and LW950	Kangaroo Creek lineament (Type 1)	1012mm subsidence 5.8mm/m tensile strain 26.3 mm/m compressive	Reduction in swamp piezometer levels when LW940 mined directly beneath the swamp and lineament. Following declines all water levels remain predominantly below base of piezometer.	Decline in water levels –now predominantly below base of piezometer. Change in species assemblage (diversity of native species), change in condition of key species, increase in non-live vegetation
West Wolgan Swamp	Above Angus Place LW930 to LW950	J Lineament (identified by J. Shepherd)	1071mm subsidence 4.0mm/m tensile strain 6.2 mm/m compressive	Correlation between swamp standing water levels and the cumulative rainfall deviation over 14 years of monitoring. Baseline monitoring commenced in May 2005 NB J Lineament was undermined to the north of West Wolgan Swamp by Longwall 920 in October 2004 and Longwall 24 in Quarter 1, 2000.	Piezometer data reflects periodic waterlogging in response to rainfall. Vegetation monitoring undertaken but sufficient baseline data not available to assess impact of mining.
Narrow Swamp North	Above Angus Place LW920 and LW940	Wolgan lineament zone (Type 1)	1739 mm subsidence 6.2 mm/m tensile strain 15.4 mm/m comp. strain	Narrow Swamp North Swamp piezometers (NS3 and NS4) were installed in February 2008, after mining beneath Narrow Swamp North was completed in May 2007. All water levels remain predominantly below base of piezometer.	Water ripping, waterlogging and changes to water quality. Observed impacts likely due to mine water discharge from Springvale Mine, any impacts due to longwall mining likely to be completely masked.
Narrow Swamp South	Above Angus Place LW950 and LW960	Wolgan lineament zone (Type 1)	Not measured, expected to be similar to Narrow Swamp North	Reduction in swamp piezometer levels when LW940 mined directly beneath the lineament approximately 0.2 km north of the swamp. Some changes may be due to the cessation of mine water discharge along the drainage line. Following declines all water levels remain predominantly below base of piezometer.	Incision, a massive active head cut, and with significant impairment of resilience and ecosystem processes. Observed impacts likely due to mine water discharge from Springvale Mine, any impacts due to longwall mining likely to be completely masked.

Swamp	Longwalls	Type 1 or Type 2 structures	Measured subsidence effects (near swamp)	Observed changes to piezometer levels	Observed physical impacts and environmental consequences
East Wolgan Swamp	Above Angus Place LW960 to LW980 and Springvale LW411 and LW412	Wolgan lineament zone (Type 1)	365mm subsidence 13.3mm/m tensile strain 17.6 mm/m compressive	Reduction in swamp piezometer levels (bottom of bores) when LW411 mined directly beneath the swamp and lineament. Some changes may be due to the cessation of mine water discharge along the drainage line. Following declines all water levels remain predominantly below base of piezometer.	Vegetation dieback, major incision and erosion (in some instances down to bedrock), associated with loss of the peat layer, significant loss of ecosystem function and ecological resilience, and with ecological and geomorphic threshold exceedance. Some impacts likely to be associated with mine water discharge from Springvale Mine
Sunnyside Swamp	Between Springvale LW413A/B, LW414 and LW415	-	100 mm subsidence 1 mm/m tensile strain 3 mm/m comp. strain	No detected mining-related changes in swamp piezometers levels.	No surface cracking or deformations identified
Sunnyside East Swamp	Above Springvale LW416 to LW419	Deanes Creek lineament (Type 1)	607 mm subsidence 5.8 mm/m tensile strain 6.5 mm/m comp. strain	Temporary changes in swamp piezometer levels when LW414 mined beneath the Deanes Creek lineament at a distance of 2.25 km. Reduction in swamp piezometer levels when LW415 mined beneath the Deanes Creek lineament at a distance of 1.5 km. Following declines all water levels remain predominantly below base of piezometer.	No surface cracking identified. Decline in water levels – now predominantly below base of piezometer. Change in species assemblage (diversity of native species), change in condition of key species, increase in non-live vegetation
Carne West Swamp	Above Springvale LW418 and LW419	Deanes Creek lineament (Type 1)	750 mm subsidence 1.0 mm/m tensile strain 3.1 mm/m comp. strain	Temporary changes in swamp piezometer levels when LW415 mined beneath the Deanes Creek lineament at a distance of 1.8 km. Reduction in swamp piezometer levels when LW416 mined beneath the Deanes Creek lineament at a distance of and 1.6 km. Following declines all water levels remain predominantly below base of piezometer.	No surface cracking identified, Decline in water levels – now predominantly below base of piezometer. Change in species assemblage (diversity of native species), change in condition of key species, increase in non-live vegetation cover,
Gang Gang Swamp South West	Above Springvale LW420 and LW421	Type 2	969mm subsidence 3.4 mm/m tensile strain 9.6 mm/m comp. strain	Reduction in swamp water levels at GW1 and GW2 prior to being directly undermined. Possibly related to LW417 and LW418 intersection of structures. Decline at GW3 following undermining of swamp and intersection of lineament at GW1. Following declines, all water levels remain predominantly below base of piezometer.	No surface cracking identified. Decline in water levels – now predominantly below base of piezometer. Change in species assemblage (diversity of native species), change in condition of key species, increase in non-live vegetation

Swamp	Longwalls	Type 1 or Type 2 structures	Measured subsidence effects (near swamp)	Observed changes to piezometer levels	Observed physical impacts and environmental consequences
Gang Gang Swamp East	Above Springvale LW420 and LW421	Type 2	652mm subsidence 3.3 mm/m tensile strain 3.3 mm/m comp. strain	Slow decline at GG1 from August 2016 consistent with CRD. Decline accelerates August 2017 as LW420 intersects underlying lineament. GG2 decline in October 2016, no apparent correlation to LW activity (note limited baseline data). GG3 abrupt decline from March 2018 as LW421 approached lineament beneath GG1. Following declines all water levels remain predominantly below base of piezometer.	No surface cracking identified. Decline in water levels – now predominantly below base of piezometer. Change in species assemblage (diversity of native species), change in condition of key species, increase in non-live vegetation
Pine Swamp Upper Swamp	Outside and adjacent to Springvale LW425	-	253mm subsidence 12.0 mm/m tensile strain 7.7 mm/m comp. strain	Declines in water levels at BS1 and BS2 from October 2017 that are consistent with CRD. Further strong declines from January 2019 that coincide with intersection of LW425 with underlying lineament.	No surface cracking identified. Decline in water levels – now predominantly below base of piezometer.
Paddy's Creek Swamp	150 m south-west of Springvale LW425	-	<20mm subsidence	Several water level declines and recovery following commencement of LW425 in August 2018. Possibly climate related but water levels stable prior to LW425.	No surface cracking or deformations identified. Temporary changes in swamp piezometer levels which may be related to the extraction of Longwall 425

4.5.1 Carne West Swamp and Gang Gang Swamp South West Case Study

Carne West Swamp overlies a major Type 1 structural zone known as the Deanes Creek Lineament Zone (DCLZ). Gang Gang Swamp overlies a Type 2 structural zone that is interconnected with the DCLZ by several interconnecting basement structures. Hydro graphs for swamp piezometers CW1 and CW2 (Carne West Swamp) and GW1 and GW2 (Gang Gang Swamp South West) are shown on Figure 4.4. The timing of longwalls and the preceding development headings intersecting the DCLZ are also shown on Figure 4.4.

LW416 was the first longwall to mine through the DCLZ. Water levels at CW2 were already in decline due to below average rainfall conditions, however the decline accelerated after the DCLZ was mined through by LW416. The decline at CW2 was preceded by a rapid decline at CW1, which occurred prior to LW416, but coincides with the driving of the LW417 development headings through the DCLZ. LW416 was approximately 1400m from CW2, and the LW417 development heading approximately 700m from CW1 at the time of mining through the DCLZ. The decline at CW2 occurred approximately 1 month after the DCLZ was mined through, with the initial decline delayed, or offset, by significant rainfall recharge. The decline at CW2 was followed by a similar decline at GW1 two months later. A further decline, at GW2, coincided with the mining through of the DCLZ by LW418. GW1 was approximately 1500m, in a straight line, from the point of LW416 mining through the DCLZ and GW2 was approximately 1000m from the point of LW418 mining through the DCLZ.

The significance of this case study is that in addition to potential impacts of the undermining of structures that underlie swamps, there is also potential for impacts to be transmitted, or realised, via intersecting structures and also for depressurisation from development heading to be transmitted via significant structures, although this has not been observed elsewhere at Springvale Mine or Angus Place.

It is noted that propagation of depressurisation from development headings is not considered likely as that would require a continuous hydraulic connection between the seam and the swamp. As is seen from the VWP data (Appendix C) and previous studies delineating the hydrostratigraphic units (CSIRO, 2004), this has not been observed.

At the time of the LW417 development headings passing through the DCLZ, the LW416 longwall face was also approximately level with the development headings. It is possibly that lateral strain resulting from the subsidence above LW416 was attenuated across the DCLZ, acting to dilate the fracture sufficiently for the depressurisation observed at CW1 to occur.

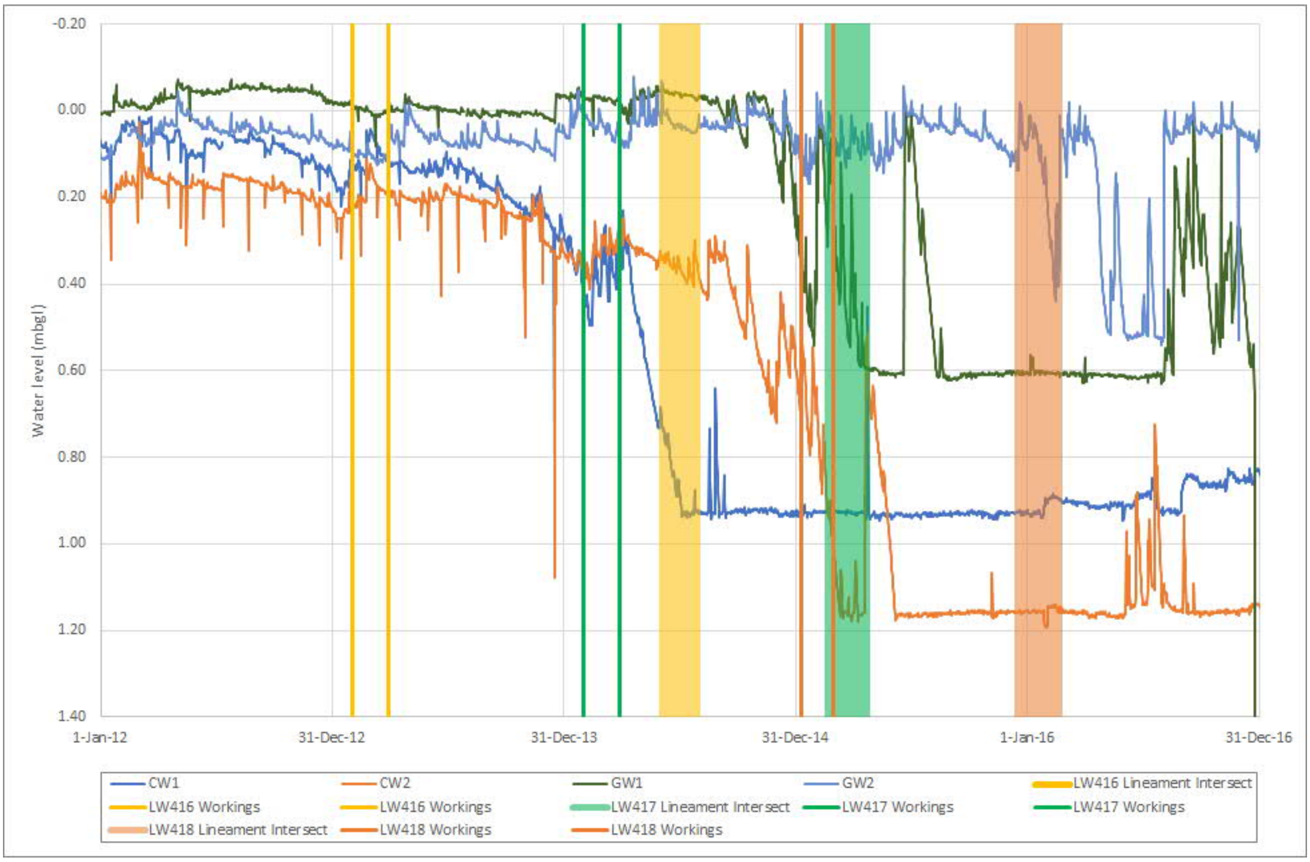


Figure 4.4: Timing of impacts at Carne West Swamp and Gang Gang Swamp South West

4.5.2 SPR67 VWP

SPR67 is a VWP installation located above LW417 of Springvale Mine and within the DCLZ. Three of the VWP sensors at SPR67 are installed below the Mount York Claystone, with the remaining five sensors located above the Mount York Claystone in the Bankswall Sandstone and Burralow Formations.

All sensors, including those above the Mount York Claystone, display declining pressures prior to being undermined, with stepped responses as the longwalls get closer. Significant depressurisation is observed with the passing of LW416 in May 2014 and with subsequent undermining by LW417 at the end of March 2015. Following undermining, all sensors, including those above the Mount York Claystone become unsaturated.

An initial response is observed, including above the Mount York Claystone, when LW414 commences south of Sunnyside Swamp in March 2011 at a distance of approximately 1300m.

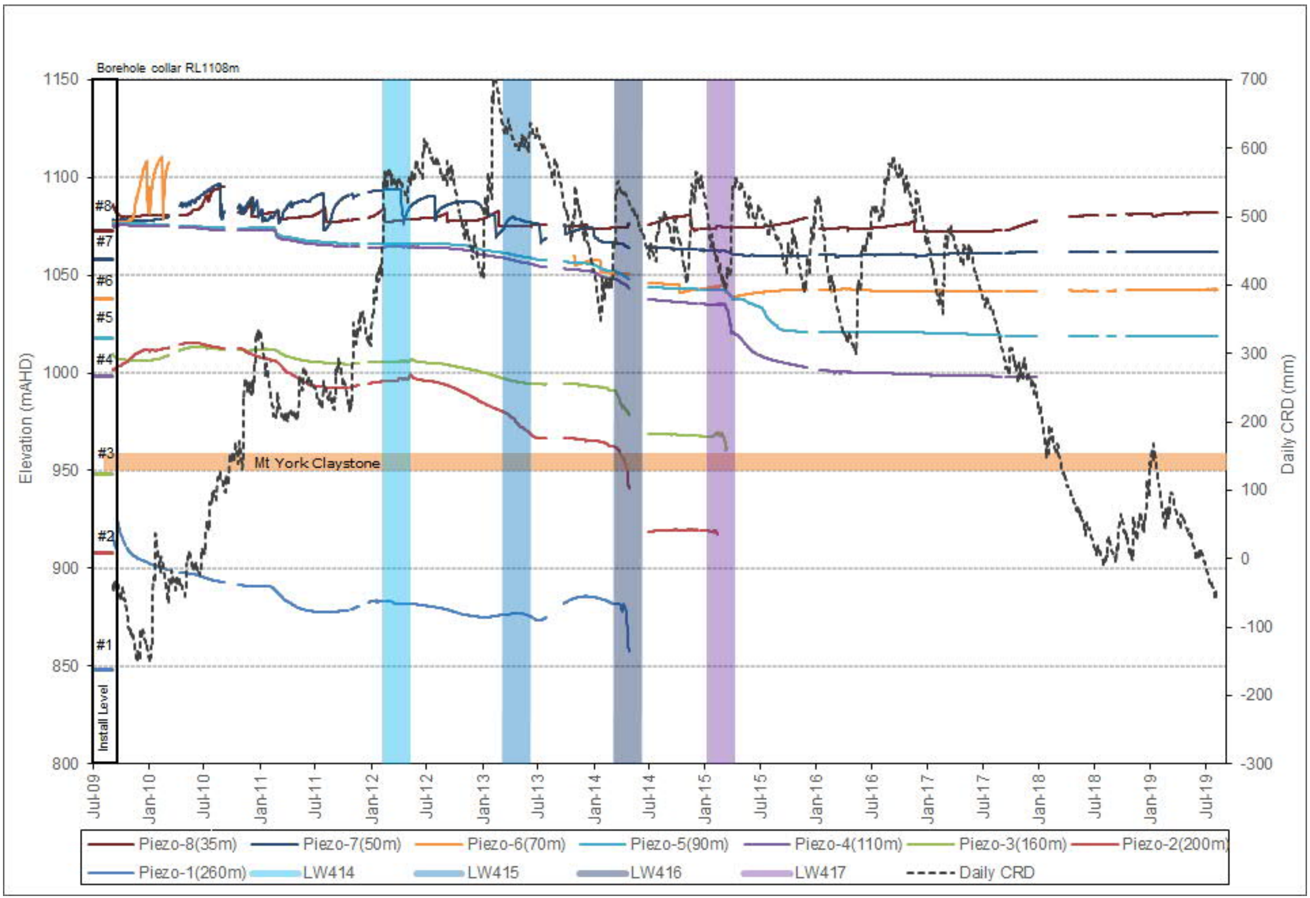


Figure 4.5: SPR67 VWP

4.5.3 SPR1106 Standpipe and VWP

SPR1106 is a paired VWP installation and standpipe piezometer, located to the north of Springvale Mine on the margins of the DCLZ. All of the VWP sensors at SPR1106 are installed below the Mount York Claystone, while the standpipe is screened in the Bankswall Sandstone.

The VWP sensors all display a sequence of stepped depressurisation associated with the commencement of the sequential longwalls from LW416 through to LW421 (Figure 4.6). All seven sensors above the Lithgow seam show a relatively uniform depressurisation of the order of 50m over the six longwall extractions. Yet SPR1106SP located above the Mount York Claystone does not display any response to longwall extraction.

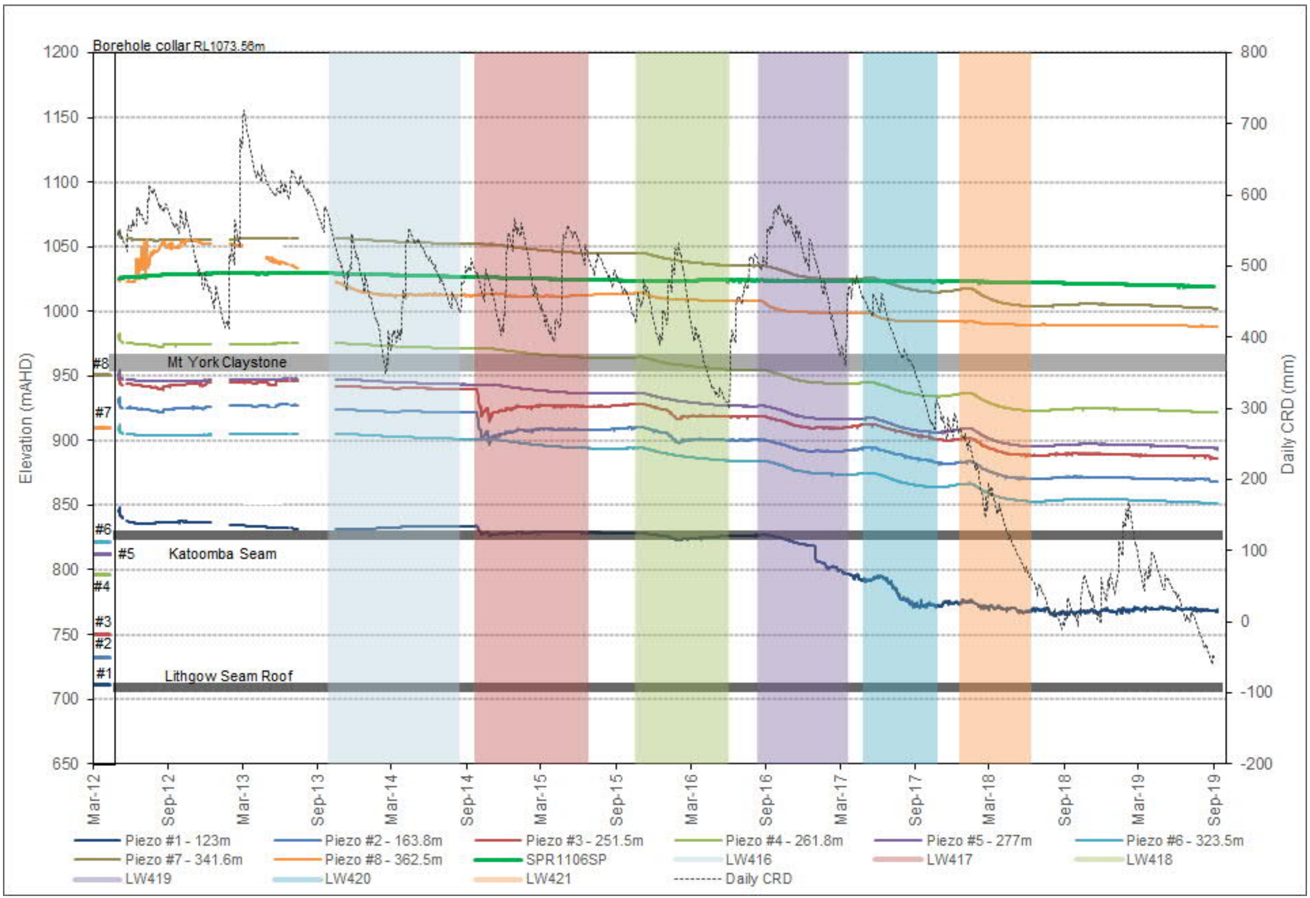


Figure 4.6: SPR1106 Standpipe and VWP

4.5.4 Summary

There is potential for groundwater impacts to be transferred via major geological lineaments and interconnecting lineaments, particularly Type 1 and Type 2 geological structures (Section 3.3.3).

As observed at SPR1106SP, the impacts did not propagate above the Mount York Claystone, whereas at SPR67 the entire sequence of formation was affected, and at Carne West and Gang Gang Swamps the impacts were transferred to the shrub swamps overlying the structures. The difference at SPR1106 is inferred to be due to the lack of adjacent longwall subsidence and the lack of lateral strains. Within the Springvale extraction area, successive approaching longwalls have incrementally built up strains which would have been attenuated across the DCLZ, with potential for dilation, albeit likely very minor, of the pre-existing and previously closed fractures.

5. Groundwater Assessment

5.1 Conceptual Hydrogeology

The understanding of the hydrogeological system at Angus Place has been advanced and refined since the groundwater assessment for the Angus Place Mine Extension Project was developed. Fundamental concepts such as recharge, and perched groundwater systems supporting NPHS and NPSS remain essentially the same, however, the understanding of depressurisation due to longwall subsidence and the potential interacts between subsidence and major geological structures has been advanced considerably.

The conceptual hydrogeological model for the APMEP is described in the following sections. Key elements of the conceptual hydrogeological model in the vicinity of the Project Application Area are presented on Figure 5.1.

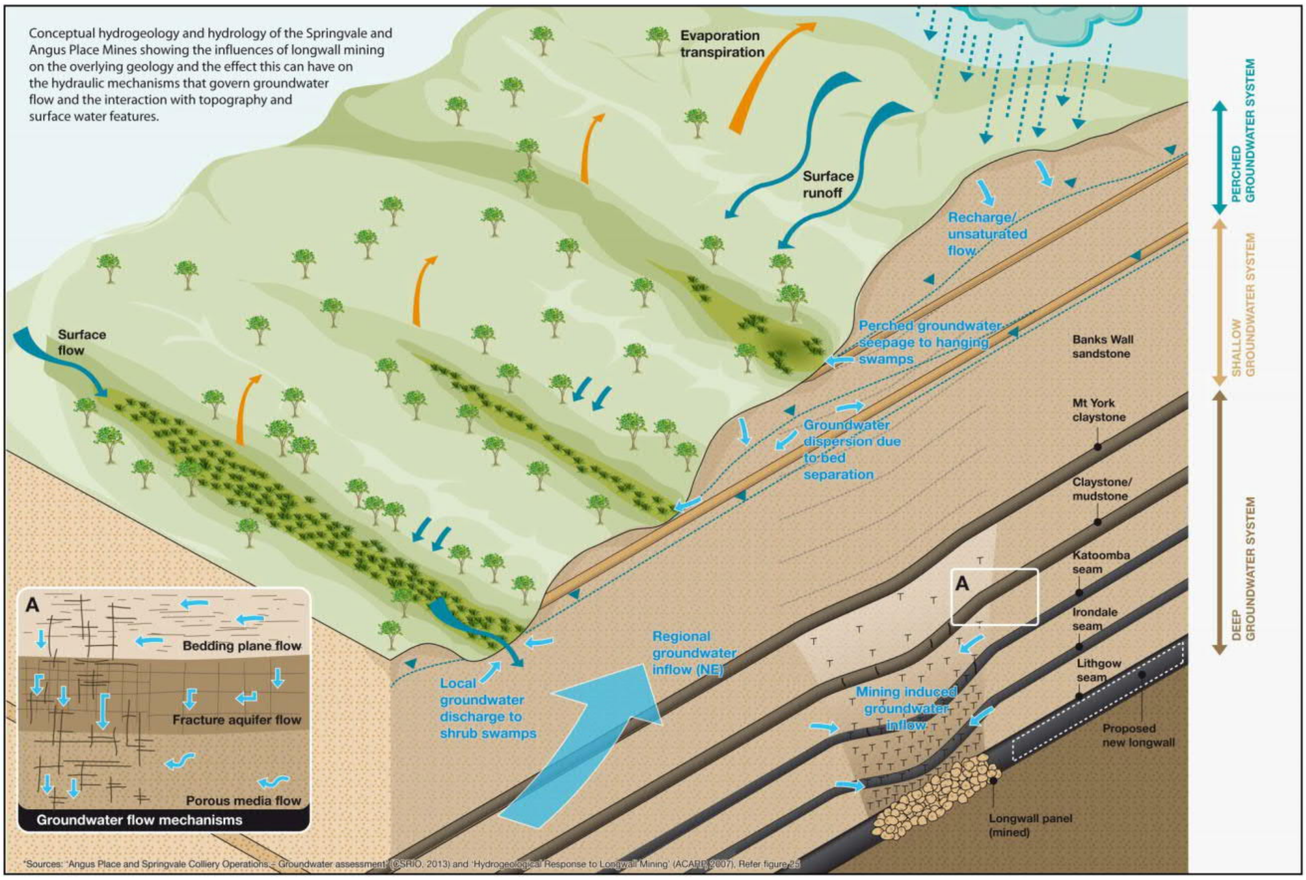


Figure 5.1: Conceptual Hydrogeological Model

5.1.1 Risk Assessment

As outlined in the IESC Information Guidelines for proponents preparing coal seam gas and large coal mining development proposals and the supplementary Explanatory Note on Uncertainty Analysis (IESC, 2018a,b), environmental assessment should be conducted within a risk assessment framework.

A risk assessment was conducted as part of the development of the numerical groundwater model for Springvale Mine and Angus Place Colliery. As identified, a risk assessment was required in response to the draft Explanatory Note on Uncertainty Analysis being issued by the IESC.

Details of the risk assessment process are provided in JBS&G (2019a) and Appendix G. The outcomes of the risk assessment and the approach adopted in the numerical groundwater model to manage the risk is summarised on Table 5.1.

Table 5.1: Risk Assessment Outcomes and Modelling Approach

Step	Risk Rating	How incorporated into the Groundwater Model?
1. Perched Groundwater	12 (Significant)	Variably saturated flow approach in MODFLOW-USG. Similar approach in COSFLOW. 28 layers implemented to facilitate. Consideration of the role of lineaments via Pilot Point methodology (heterogeneity), subsidence-induced change to hydraulic properties via Stacked Drains methodology followed by Time-Varying Material property change following cessation of dewatering. Improved temporal and spatial resolution. Predictive uncertainty analysis (NSMC) also undertaken. Significant - because current observations at Springvale Mine imply that predictions for Angus Place Mine Extension Project will be different from that presented in RPS (2014a).
2. Shallow Groundwater	7 (Moderate)	As above. Moderate - because current observations at Springvale Mine imply that predictions for Angus Place Mine Extension Project will be different from that presented in RPS (2014a).
3. Deep Groundwater	4 (Low)	Included in the model but no specific action required.
4. Newnes Plateau Hanging Swamps	13 (Significant)	Hanging swamps not specifically reported on in RPS (2014a). All hanging swamps included in the groundwater model and predicted change to flow quantified through the swamp water balance. Significant - because current observations at Springvale Mine imply that predictions for Angus Place Mine Extension Project will be different to that presented in RPS (2014a).
5. Newnes Plateau Shrub Swamps	22 (Extreme)	Consideration of lineaments via Pilot Point methodology (heterogeneity), subsidence-induced change to hydraulic properties via Stacked Drains methodology followed by Time-Varying Material property change following cessation of dewatering. Increased temporal and spatial resolution. Improved quantification of predicted change to flow. Extreme - because current observations at Springvale Mine imply that predictions for Angus Place Mine Extension Project will be different to that presented in RPS (2014a).
6. Surface and groundwater connectivity	12 (Significant)	All relevant surface watercourses incorporated into the model (1:25,000 scale hydrology layer in the vicinity of the 1000 Panel Area and major watercourses further afield). Significant - because there have been, locally, changes to surface water flow on the Newnes Plateau at Springvale Mine, which were outside of that presented in the EIS for Springvale Mine. Response to the IMP at Springvale Mine indicate re-emergence of diverted flow further downstream, rather than total loss.
7. Groundwater bores	5 (Low)	There are no significant non-mining groundwater users in the vicinity of the 1000 Panel Area. Predicted drawdown at groundwater users will be determined from model output. Low, given the discussion immediately above.
8. Groundwater dependent ecosystems	22 (Extreme)	As above for Newnes Plateau Hanging and Shrub Swamps. Long Swamp was raised during Angus Place MOD5. Investigation and instrumentation completed.

Step	Risk Rating	How incorporated into the Groundwater Model?
		Extreme - because significance of long-term change. NB. Other GDEs (facultative and stygofauna) were Low.
9. Groundwater licensing	8 (Moderate) 12 (Significant)	A limitation in COSFLOW was, post-construction, the ability to track the take from different, adjacent water sources. The revised model allowed calculation of take from adjacent sources but was found to be small/minor. Moderate - for groundwater because strategic planning of water take is currently underway; Significant - for groundwater-induced surface water take as this is a significant constraint.
10. Groundwater quality	2 (Low)	Negligible change to groundwater due to operations therefore not required to be considered.
11. Validation of model parameters with site data	12 (Significant)	Requirement for updated model to explain (calibrate) observed change in perched and shallow groundwater levels at Springvale Mine. Incorporate outcome of SPR1101 investigation at Springvale Mine via consideration of Height of Fracturing studies by Tammetta (2013) and Ditton and Merrick (2014). Incorporate consideration of lineaments via Pilot Point methodology (heterogeneity). Significant - current observations at Springvale Mine imply that predictions for Angus Place Mine Extension Project will be different to that presented in RPS (2014a).
12. Site water and salt balance	12 (Significant)	Mine inflow estimates provided by COSFLOW and will be provided in the updated model, however, at a higher temporal resolution. Significant - because of mine water management considerations. Note however that Angus Place Mine Extension Project: Amended Project will be a nil discharge site.
13. Surface water users	2 (Low)	Modelled change to groundwater contribution to surface water considered in detail, however, is expected to have negligible impact. No specific action required.
14. Cumulative impacts	5 (Low)	Regional model was developed incorporating adjacent operations (Springvale Mine, Clarence Colliery and Baal Bone and Invincible Colliery). Some limitations based on incomplete knowledge of non-Centennial operations, but not significant.

5.1.2 Major Hydrostratigraphic Units

The major hydrostratigraphic units at Angus Place as proposed by CSIRO (2004) and refined by McHugh (2011 and 2013) have been retained for this assessment.

It is noted that in the Hydrogeological Model (Section 5.3 and JBS&G, 2019a) lithological unit boundaries have been adopted to allow greater vertical discretisation. A correlation of the key hydrostratigraphic units with model layering is provided in Table 5.2.

The key relationship of the key hydrostratigraphic units and environmental receptors are shown in relation to the proposed longwalls in section on Figure 5.2 and Figure 5.3. The stratigraphic layers presented in Figure 5.2 and Figure 5.3 are based on the Centennial geological model for Springvale and Angus Place. The model surfaces have been imported into Leapfrog Works 3D geological modelling software to enable the visualisation of the groundwater system.

Table 5.2: Key Hydrostratigraphic Units

Formation / Seam	Hydrostratigraphy / Aquifer Unit	Model Layer[1]
Burralow Formation	Aquifer - AQ5 / AQ6 Aquitards – YS Plies including SP4	Layers 1 to 12
Bankswall Sandstone	Aquifer – AQ4	Layers 13 and 14
Mt York Claystone	Aquitard – SP3	Layer 15
Burra-Moko Head Sandstone	Aquifer – AQ3	Layer 16
Caley Formation		Layer 17
Farmers Creek Formation		Layer 18 (Katoomba Seam and Layer 19
Gap Sandstone	Aquitard – SP2 Aquifer – AQ2	Layer 20
State Mine Creek Formation		
Watts Sandstone		
Denman Formation	Aquitard – SP1	Layer 21
Glen Davis Formation	Aquifer – AQ1	Layer 22
Newnes Formation		
Irondale Coal		
Long Swamp Formation		
Lidsdale Coal		Layer 23
Blackmans Flat Formation		
Lithgow Coal		Layer 24
Marangaroo Formation		Layer 25
Gundangaroo Formation	Aquitard – SP0	Layer 26
Coorongooba Creek Sandstone		
Mount Marsden Claystone		
Berry Siltstone		Layer 27
Snapper Point Formation		

Note: [1] – Dominant layer per formation, noting that layers may pinch out or become “dummy” layers.

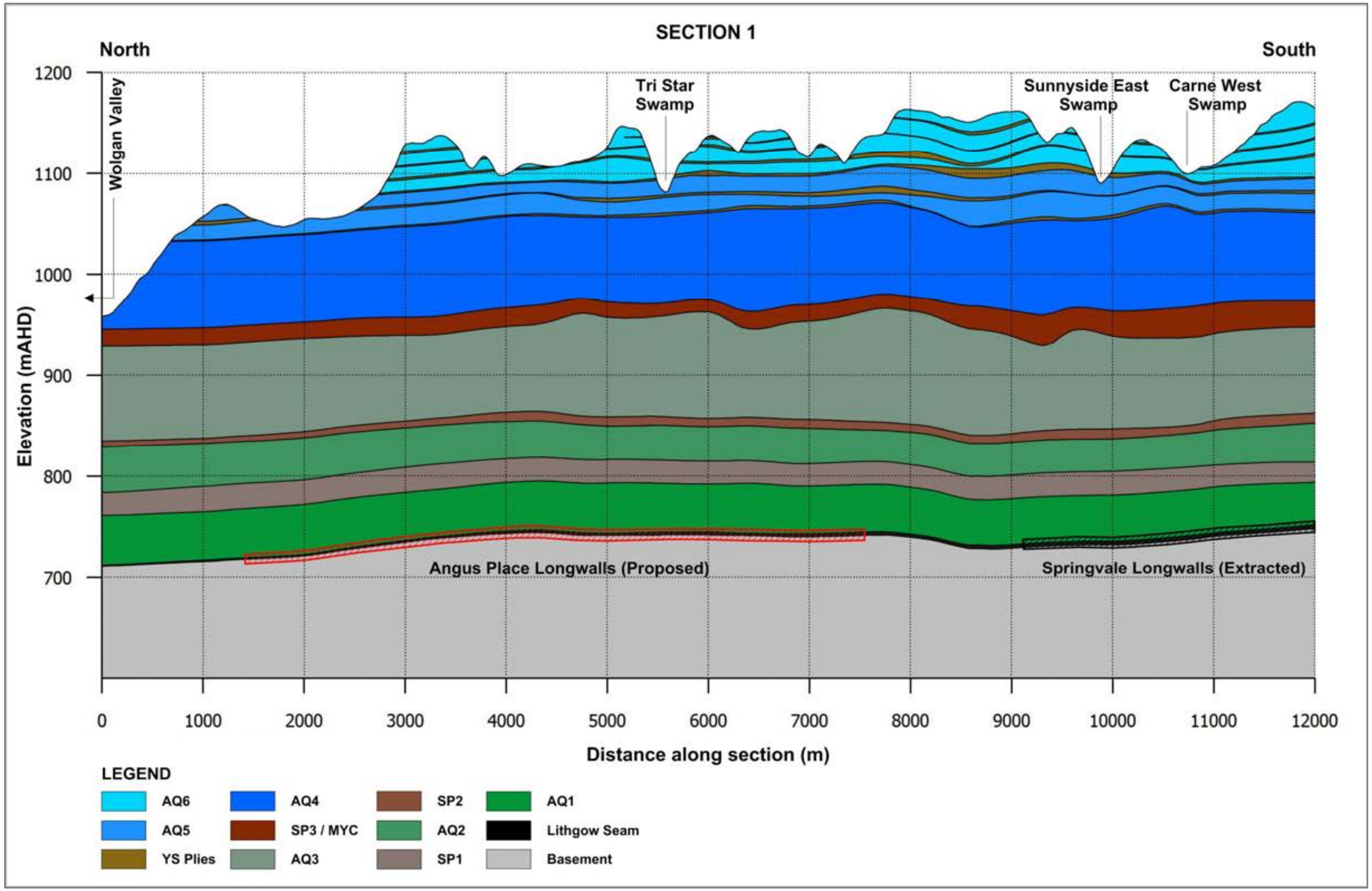


Figure 5.2: North – South Cross Section

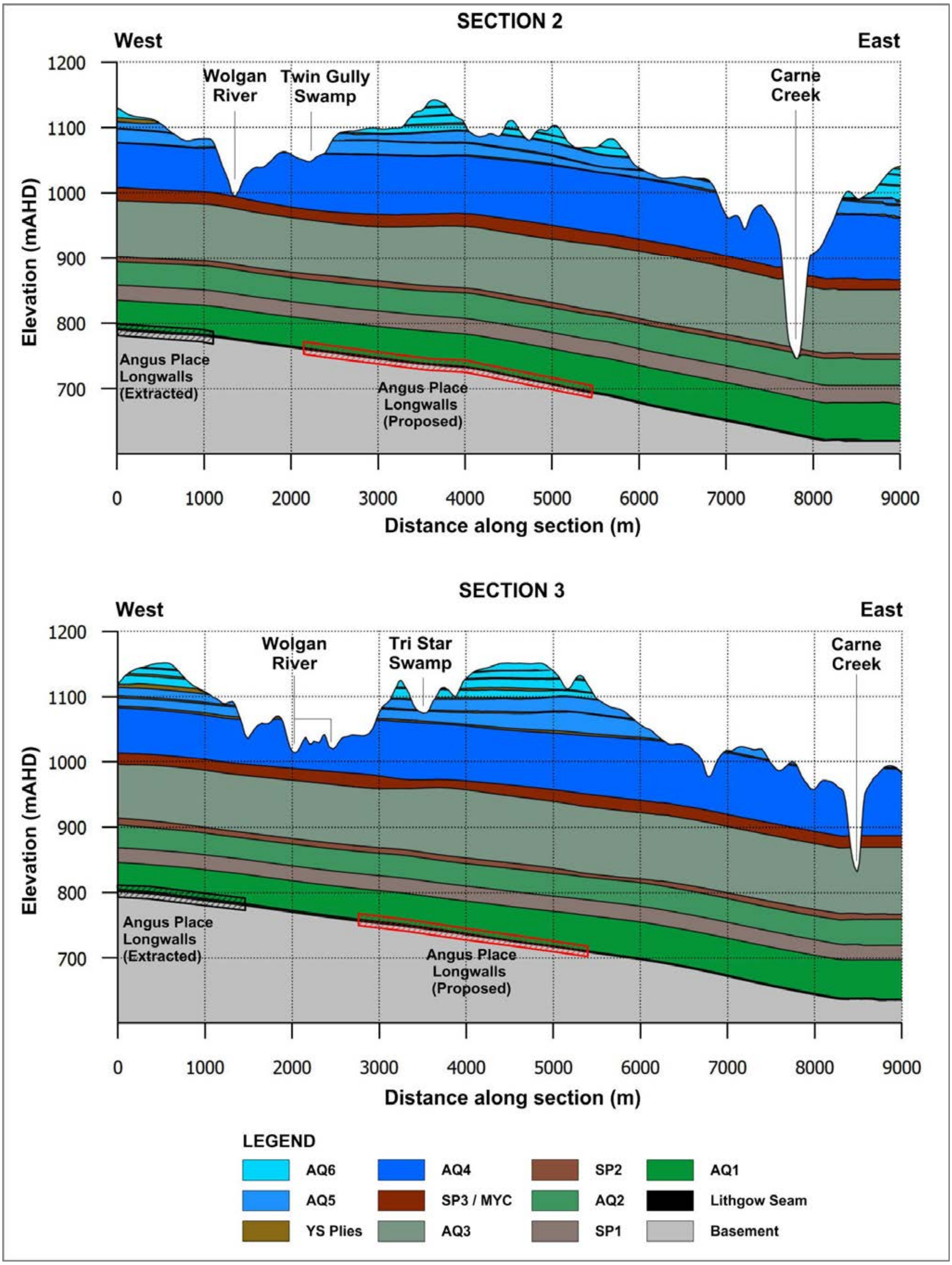


Figure 5.3: East West Cross Sections

5.1.3 Groundwater Recharge and Discharge

Recharge to swamps occurs as incident rainfall and runoff. Recharge to the hardrock aquifers will occur primarily through infiltration of rainfall and runoff along the ridgelines and areas of exposed or shallow sub-cropping bedrock in the upper catchment areas.

Recharge to the deeper aquifers is not expected to be significant from overlying formations and will be via slow and tortuous infiltration and leakage from overlying aquifers. A component of recharge to deeper aquifers may also occur where the formation is exposed by incised valleys and to a lesser extent on escarpments.

Groundwater discharge to surface water will occur as seepages and drips from exposed seepage faces on cliff lines or exposed bedrock in drainage lines, and as seepage from sub-cropping bedrock to regolith or detrital soil profiles on valley flanks and along valley floors.

From Section 2 of Figure 5.3, the Wolgan River is likely a point of discharge for the Bankswall Sandstone (AQ4) from up-dip, but during times of high flow could potentially be a source or recharge to the formation in the down-dip direction. In Section 2, Carne Creek completely truncates both AQ4 and AQ3, so will likely predominantly be a point of discharge for these formations. The valley is incised into the top of AQ2 along this section so is likely a source of net groundwater recharge to AQ2 at this location. Further south (Section 3), Carne Creek has no interaction with AQ2, but is likely predominantly a source of recharge to AQ3.

As indicated on Figure 5.2 and Figure 5.3, the Bankswall Sandstone, Burralow Formation and Burra Moko-Head Sandstone and other formations of AQ3 have potential to have seepage faces and discharge to the Wolgan Valley to the North and Carne Creek and the Wolgan Valley to the east and northeast.

In the vicinity of Angus Place, mine dewatering from the exiting Angus Place workings and neighbouring Springvale and Clarence Collieries also contribute a significant component of groundwater discharge.

5.1.4 Groundwater Flow

Groundwater flow in the near-surface and shallow groundwater systems is expected to be a subdued reflection of the prevailing topography, that is, there will be a general sense of groundwater flow from areas of higher topographic relief to areas of lower topographic relief.

The modelled water table prior to the commencement of the APMEP is provided on Figure 5.4.

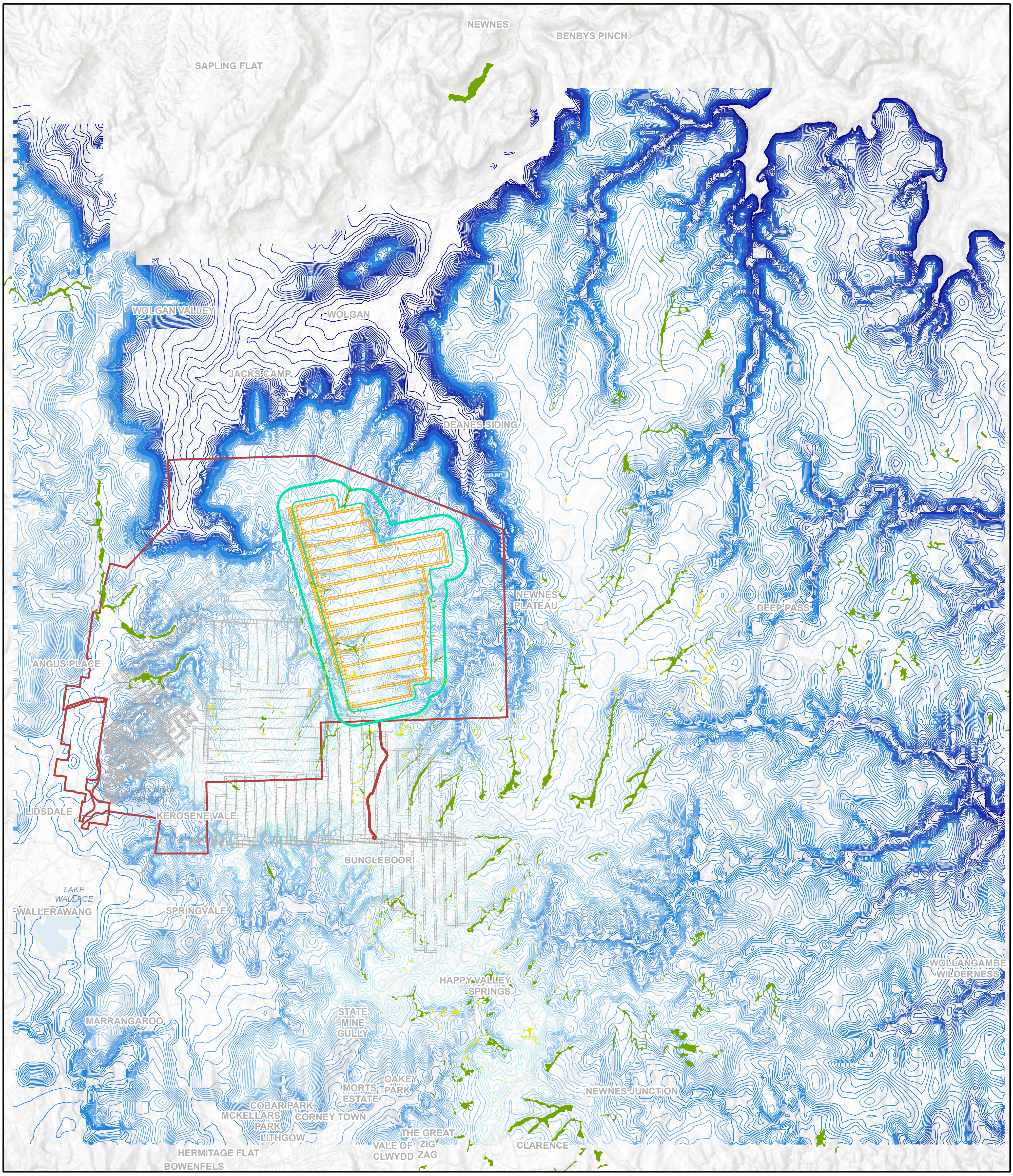
The regional stratigraphic dip is in a general northeasterly direction, with minor localised and subtle variations. The stratigraphy plays a key role in the transmission of groundwater flow and as such regional groundwater flow is consistent with the regional dip direction (to the northeast).

Where aquifers are exposed in valley sides and escarpments, localised groundwater divides will exist resulting from a groundwater mounding effect (where the rate of recharge exceeds the rate of throughflow) with flow and seepage of groundwater towards the exposed faces in across and up-dip locations.

5.1.5 Influence of Major Geological Structures

During an early version of the updated groundwater model, all major geological structures were included in the model, as discrete features. It was found, however, that that configuration of the model was not able to be successfully calibrated. Instead pilot points were used (heterogeneous distribution of hydraulic parameters, hydraulic conductivity and storage), which has resulted in zones of elevated permeability in the vicinity of major structural zones (refer Appendix G).

Figure 5.4: Pre-Angus Place Amended Project – Uppermost Watertable



Watertable contours [mAHD]
- 500 - 600
- 600 - 700
- 700 - 800
- 800 - 900
- 900 - 1000
- 1000 - 1100
- 1100 - 1200

Swamps
- Hanging
- Shrub

Hydrology
- Water Areas

Infrastructure
- Proposed Workings
- Existing Workings

Project Area
- Project Area

APE Study Areas
- 26.5 degree AoD
- 600m Study Area

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JACOBS

Angus Place Amended Project

Data Sources - Centennial Angus Place Pty Ltd: Project Area, Infrastructure (2019); NSW Government Public Data: Roads, Hydrology, Placenames; JBS&G (2019a): Waterable contours; ESRI ArcGIS Image Service: World Elevation Terrain, World Topographic Map. Imagery.

X:\GIS_Resources_TempProject\Random_Tasks\IA161511_Angus_Place\Spatial\WorkInProgress\20192608_JRykr_GroundwaterImpactAssessmentGISFigures\Figure5_4_Uppermost Watertable.mxd Produced: 25/10/2019 Author: rykrj

5.2 Potential Impacts

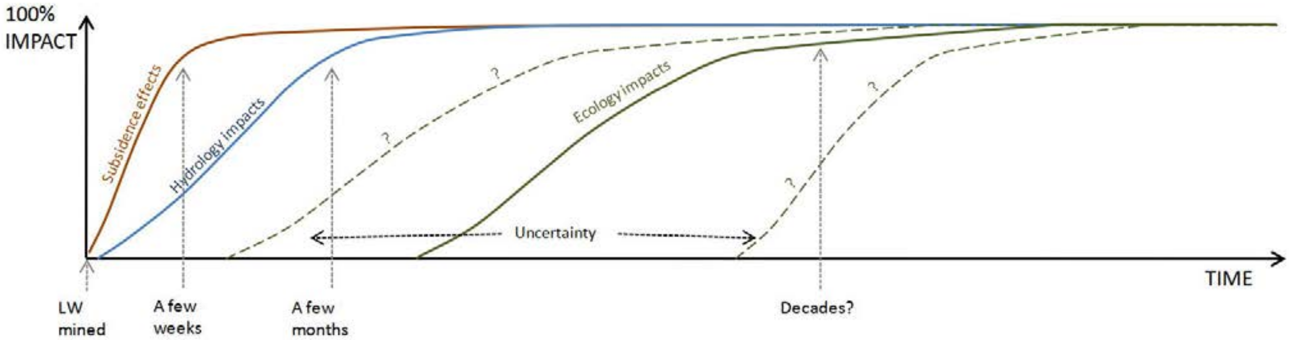
Key potential groundwater related impacts associated with the Project relate to mine inflows and associated groundwater drawdown, and subsidence impacts and interactions with groundwater. In particular:

- Groundwater drawdown impacting on other groundwater users or groundwater dependent ecosystems
- Subsidence impacts resulting in loss of water from, or reduced contribution of water to, creeks or THPSS,
- Changes in groundwater quality due to groundwater drawdown or subsidence impacts.
- The installation of vent shaft and service boreholes may have potential localised impacts on groundwater.

5.2.1 Subsidence

Subsidence has potential to impact directly on the hydrological and hydrogeological regimes that support swamps. The IESC (Commonwealth of Australia, 2014) presents three broad impact categories that reflect the time lag between mining and potential impact (Figure 5.5):

- First-order subsidence impacts, which refer to the immediate impacts of subsidence (also called subsidence effects), such as cracking, shearing, tilting and reopening of bedding planes and joints within the sandstone
- Second-order hydrological impacts, which refer to the impacts that result from subsidence effects, such as changes to swamp hydrology from altered groundwater or surface water flow paths, and water quality impacts
- Third-order ecological impacts, which are the result of changes to swamp hydrology and water quality, such as peat erosion and the ecological response of flora and fauna.



Source: Commonwealth of Australia, 2014.

LW = longwall

Figure 5.5: Potential Timeline for Observation of Impacts

It is noted that third-order impacts have the potential to lag significantly behind initial undermining and the occurrence of subsidence and hydrological impacts, potentially by years or even decades.

In addition to the potential impacts of being directly under mined, Centennial (Centennial, 2018) note the potential for swamps, which reside in structurally controlled valleys, to be impacted by longwalls up to two kilometres away if the geological structure is intercepted by the longwall (refer Section 4.5).

Table 4.7 provides a summary of observed responses to longwall extraction in NPSS at Angus Place Colliery and Springvale Mine. Predicted mine subsidence is presented and discussed in the MSEC (2019) Subsidence Impact Assessment.

5.2.2 Ventilation Shaft Drilling and Dewatering Bore Holes

During drilling of the ventilation shaft and dewatering bore drill holes there is potential for interaction with the local groundwater systems. Methodologies for drilling and construction are described as follows.

5.2.2.1 Ventilation Shaft

Following the establishment of all necessary siteworks at surface, the drilling and construction of the ventilation shaft will comprise:

- Blind boring to final depth
- Installation of a steel or composite liner
- Grouting of the liner

Drilling muds will be used during drilling to stabilise the drill-hole, lubricate and cool the drilling head, and to lift the drill cuttings from the drill hole. The cuttings will be lifted to surface via reverse circulation through the drill string. Both the density and viscosity of the drilling fluids with be controlled to minimise drilling fluid ingress to the formation, aid in the lifting of cuttings, and to balance the hydrostatic pore fluid pressure where required to minimise groundwater inflows during drilling progresses.

The ventilation shaft service borehole will also be blind bored using mud rotary or reverse rotary methods with the same mud control principals applied.

Once lined and sealed there will be no net interaction between the ventilation shaft and its service borehole and the local groundwater system.

5.2.2.2 Dewatering Bores

The dewatering bores will be blind bored using mud rotary or reverse rotary methods with the same mud control principals applied as for the ventilation shaft. The dewatering bores will be cased and fully grouted.

It is anticipated that the ancillary bores will be drilled by conventional diamond drilling techniques and, other than the casing and grouting, with not differ significantly from standard resource exploration drilling.

5.3 Hydrogeological Model

Details of the setup, and calibration of the hydrogeological model are provided in the Hydrogeological Model Report (JBS&G, 2019a, Appendix G). Key aspects of the model are summarised below.

5.3.1 Model Summary

A numerical groundwater flow model (the hydrogeological model) has been developed in MODFLOW for Unstructured Grid (MODFLOW-USG) (USGS, 2013). The version of MODFLOW-USG used was MODFLOW-USG-Transport which allows for the calculation of variably saturated flow and multiple water tables. MODFLOW-USG-Transport was run under the Groundwater Vistas (Version 7.24 Build 56) graphical user interface.

The model mesh was constructed with Quadtree Refinement, incorporating cell sizes ranging from 100m in areas of interest to 400m in areas where detailed resolution was not required, with 200m transitional cells.

The model was constructed with 28 layers for a total of 793,884 cells. A correlation of model layers with the hydrostratigraphy and relative geological formations is provided on Table 5.3. It is noted that Layer 28, not represented on Table 5.3, represents the Carboniferous Basement lithologies beneath the Sydney Basin, including lithologies of the Lachlan Fold Belt.

Unsaturated flow within the model is solved using the Richards Equation with van Genuchten parameters (JBS&G, 2019a). The Richards equation is considered preferable to other available options (such as the psuedo-soil algorithm or similar) as model performance with respect to stability and run-time is superior. The adopted model layering is to provide sufficient vertical resolution to allow the Richards Equation to describe the vertical variation in saturation.

Rainfall recharge to the model was applied as recharge zones based on the SILO gridded rainfall data (collated into quarterly intervals), with an appropriate recharge factor applied depending on lithology and land use.

For future predictions, data from the New South Wales and Australian Capital Territory Regional Climate Modelling Project (NARCliM) was accessed. Of the models available, after adaptation to the SILO grid presented above:

- 'Average' Climate conditions were represented by the ECHAM5_R3 model
- 'Lowest Cumulative Rainfall, Higher Cumulative Evapotranspiration' conditions were represented by the CSIRO-MK3.0_R1 model
- 'Highest Cumulative Rainfall, Lower Cumulative Evapotranspiration' conditions were represented by the MIROC3.2_R2 model.

River (RIV) boundary conditions were used to represent the Wolgan River and the Coxs River (Lake Wallace through to Lake Lyell). With drain boundaries applied to represent ephemeral water courses and swamps. Where a particular model layer outcropped, it was 'pinched-out' and a seepage face drain element, with an appropriately high conductance applied, implemented immediately adjacent the 'pinch-out'.

Evapotranspiration to the groundwater model was based on an evapotranspiration factor applied to the SILO gridded FAO56 data (collated into quarterly intervals as per rainfall). It is noted that an extinction depth of 3m was applied to all zones. The extinction depth was set at 3m to, partly, account for the limitation of the default MODFLOW Recharge package in consideration of soil moisture deficit. This is despite the root depth, for swamps, being such that they are much less than 3m.

Mine dewatering at Angus Place and in the surrounding mining operations was simulated via drain cells. Depressurisation due to subsidence was simulated via stacked drains, whereby drain cells were added to every layer above an extracted longwall up until the Height of Fracturing, Zone A, which was based on the Tammetta (2013) equation.

In accordance with the Australian Groundwater Modelling Guidelines (Barnett et. al., 2012), the intended model confidence level classification for the numerical groundwater model is Class 2 as presented in Table 5.3.

Table 5.3: Model Confidence Level Classification – characteristics and indicators (Class 2)

Data	Calibration	Prediction	Key indicator
• Groundwater head observations and bore logs are available but may not provide adequate coverage throughout the model domain. Consistent: There is a significant groundwater monitoring network available encompassing Angus Place Colliery, Springvale Mine and Clarence Colliery. Far-field monitoring not included but outside of area of interest. • Metered groundwater- extraction data may be available but spatial and temporal coverage may not be extensive. Consistent: Detailed mine dewatering data is available at Angus Place Colliery, Springvale Mine and at Clarence Colliery (through back calculation using a Site Water Balance). • Streamflow data and baseflow estimates available at a few points. Consistent: On-the-ground monitoring (THPSS and within the Coxs River) was calibrated against using the Swamp Water Balance Model. The Swamp Water Balance model received groundwater model output • Reliable irrigation-application data available in part of the area or for part of the model duration. N/A: No comment needed	• Validation* is either not undertaken or is not demonstrated for the full model domain. Consistent: Validation not attempted • Calibration statistics are generally reasonable but may suggest significant errors in parts of the model domain(s). Consistent: Reasonable calibration achieved with respect to heads and mine dewatering rates. • Long-term trends not replicated in all parts of the model domain. Consistent: Reasonable calibration to long-term trends. Some differences to the commencement of mining-induced depressurisation in some vibrating wire piezometers. • Transient calibration to historic data but not extending to the present day. • Seasonal fluctuations not adequately replicated in all parts of the model domain. N/A: Whilst model included seasonal variation, through quarterly stress periods, the model domain is dominated by mining, rather than irrigation, therefore this characteristic is not relevant. • Observations of the key modelling outcome data set are not used in calibration.	• Transient calibration over a short time frame compared to that of prediction. Consistent: Calibration period was 1979 through to 2018. Prediction period was 2018 through to 2091 (valid model output). • Temporal discretisation used in the predictive model is different from that used in transient calibration. Consistent: Same discretisation used in calibration and prediction models, except for recovery period. • Level and type of stresses included in the predictive model are outside the range of those used in the transient calibration. Exceeded: Mining has been on-going within the model domain since before 1979. Magnitude of stresses in calibration model are the same as those in the prediction model. • Validation* suggests relatively poor match to observations when calibration data is extended in time and/or space. N/A: Validation not undertaken.	• Key calibration statistics suggest poor calibration in parts of the model domain. Exceeded: Calibration statistics (sRMS) was 6.6%. • Model predictive time frame is between 3 and 10 times the duration of transient calibration. • Consistent: Calibration period was 1979 through to 2018. Prediction period was 2018 through to 2091 (valid model output). Stresses are between 2 and 5 times greater than those included in calibration. • Temporal discretisation in predictive model is not the same as that used in calibration. Exceeded: Mining has been on-going within the model domain since before 1979. Magnitude of stresses in calibration model are the same as those in the prediction model. • Mass balance closure error is less than 1% of total. Consistent: Mass balance closure error was less than 0.1% for the calibration model and for the predictive uncertainty analysis. A minor exception was SP198 and SP199 of the predictive uncertainty analysis. Accordingly, these SPs were omitted from processed model results. • Not all model parameters consistent with conceptualisation. Consistent: As noted in detail further below, during calibration with PEST, some parameters do adopt compensatory/surrogate roles; however, remained consistent with conceptual model. • Spatial refinement too coarse in key parts of the model domain. Exceeded: Quad-tree refinement used to optimise grid resolution in area of interest. This was supplemented by construction of the

Data	Calibration	Prediction	Key indicator
	Exceeded: All key modelling outcome data set were used in calibration. These included mine dewatering rates, swamp piezometers, standpipe piezometers and vibrating wire piezometers		Swamp Water Balance Model to assess sub-catchment detail in a separate hydrological model. • The model has been reviewed and deemed fit for purpose by an independent hydrogeologist. Consistent: Model has been reviewed by a 3rd party hydrogeologist and deemed fit for purpose.

5.3.2 Model Calibration

The model was calibrated using the PEST parameter estimation software.

5.3.2.1 Calibration Targets

The calibration included 18,624 target observations including:

Head Targets (divided into those that were appropriate for quasi-steady-state calibration and those where heads were available, however, after potentially being impacted by mining) and Change in Head Targets. For the Head or Change in Head targets, these were obtained from 371 monitoring sites, of which approximately 25 sites were omitted due to various identified issues.

Flux Targets - Operational dewatering rates to Springvale Mine, Angus Place Colliery and Clarence Colliery were included calibration datasets.

5.3.2.2 Calibration Parameters

Over 4000 parameters were included in the initial calibration attempt. The parameters included:

- horizontal and vertical hydraulic conductivity at Pilot Points;
- specific storage and specific yield (used as porosity for Richards Equation at Pilot Points;
- variably saturated flow parameters (partially calibrated);
- recharge factors (36 parameters);
- evapotranspiration factors (36 parameters);
- general head boundary conductances (5 parameter zones);
- drain conductances of ‘Stacked Drains’ (9 sets of Top and Bottom K-M factor);
- drain conductances of surface watercourses (1 value used for all watercourses); and
- time-varying material properties (4 parameters).

PEST tests an observation’s sensitivity to parameter perturbation in the model and develops a Jacobian matrix that records the response of each observational match to a perturbation of each parameter. The initial Jacobian matrix took 29 days to generate. The input parameters were then refined to a set of super-parameters (groups of base parameters), whose collective sensitivity are most important to model outcomes. The original 4334 parameters were refined down to 456 super-parameters.

PEST was the run to calibrate parameters at a number of pilot points, with model parameters between pilot points derived by interpolation. The parameters at each pilot point are typically constrained to within a range of known or reasonable values.

Pilot points were distributed throughout the model and model layers, with particular focus on the location of major geological lineaments, which in turn are associated with the location of THPSS. It is noted that, due to the very significant computation requirement, the number of Pilot Points were optimised in the upper part of the model where most of the layer was ‘pinched-out’.

5.3.2.3 Calibration Results

Detailed calibration results are reported in the Hydrogeological model report (Appendix G).

From Figure 5.6, the Scaled Root Mean Square error between observed and modelled heads is 6.6% and the Root Mean Square Error (RSME) is 30.1m. The Australian Groundwater Modelling Guidelines (AGMG) (Barnett et. al., 2012) suggests a sRMS of 10% is an indicator of reasonable calibration.

There is an acceptable match to observed mine dewatering rates and to the change to water table level within swamp catchments at Springvale Mine. The hydrologic response of swamps to mining is important as adverse changes have been previously observed. A match to observed swamp water level decline provide confidence in the model's ability to predict future impacts.

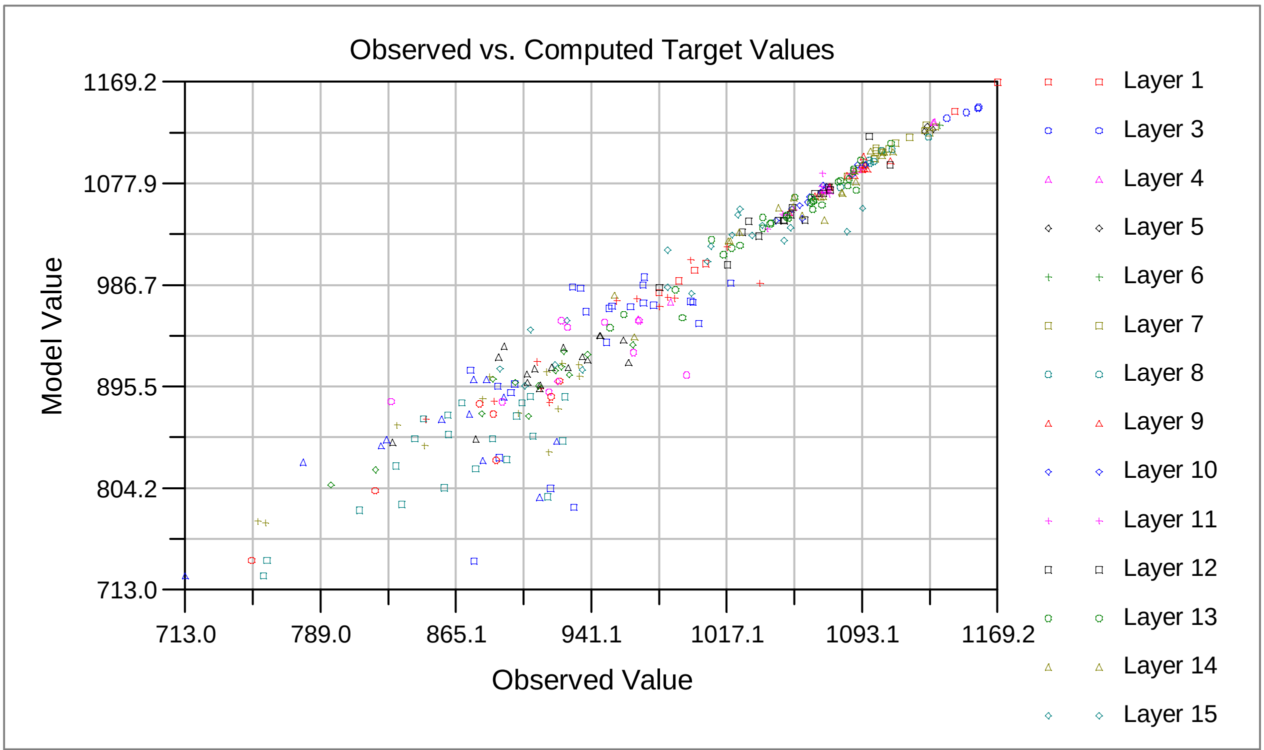


Figure 5.6: Observed vs Modelled Heads

5.3.3 Prediction Runs

Model predictive runs incorporated stochastic uncertainty analysis consistent with the IESC guidance on approaches to uncertainty analysis (IESC, 2018). For this assessment, the adopted uncertainty method was *stochastic modelling with Bayesian probability quantification.*

The calibrated parameter dataset, in combination with a parameter uncertainty file (based on expected 5th and 95th percentile range of values, to derive an appropriate standard deviation), was used to generate 300 sets of randomised parameters via the Latin Hypercube Sampling technique. The 300 sets of parameters were then run sequentially through PEST to simulate the Angus Place Amended Project mining and dewatering (the proposed case). In addition to the proposed case, the same parameter sets were also used to simulate a null case, in which the Angus Place Amended Project did not proceed. Details of the proposed case and null case scenarios are provided in Appendix G.

Of the 300 sets of randomised parameter values, 299 sets were successfully executed. The single set that was unsuccessful was due to model run failure.

As outlined in the IESC (2018) guidance document, it was necessary to confirm that 'uncertainty analysis convergence' was achieved. In practice, this means that the number of model runs is sufficient that the 10th percentile and 90th percentile model output has stabilised. Uncertainty analysis convergence was investigated with respect to modelled dewatering rate and it was found that convergence was achieved when the number of runs exceeded about 150. For the results presented in the Hydrogeological Model report, the 299-run compilation was used.

From the 299 sets of successful model runs, the output files were processed to identify the 'envelope' of 10th, 33rd, 50th, 66th and 90th percentile results with respect to difference in groundwater elevation.

5.3.3.1 Proposed Case versus Null Case

Details of the proposed case and Null case groundwater modelling scenarios are provided as follows:

- Proposed Case:
  - Dewatering at Angus Place Colliery (300, 700, 800 and 900 Panel Areas) will continue as per the requirements of approval of Angus Place Modification 5 and be maintained through to 31 December 2053.
  - Angus Place Colliery (1000 Panel Area) would commence on 1 July 2025 (LW1002) and complete on 31 October 2038 (LW910N on retreat), as per the Mine Schedule provided
  - Angus Place Colliery (300, 700, 800, 900 and 1000 Panel Area) would be maintained in a dewatered state through to 31 December 2053. On 1 January 2054, dewatering at Angus Place Colliery would cease
  - Mining at Springvale will complete on 28 February 2025 (LW424), as per the Mine Schedule provided (refer Section 5.3.4), and dewatering will cease, temporarily, in the model from April 2025 through to December 2027. From January 2028, dewatering at Springvale Mine in the model will recommence to maintain groundwater elevation at 810mAHD. 810mAHD being the elevation (bottom of Lithgow Seam) such that access between Angus Place and Springvale (new connection between the mines) is maintained. The dewatered elevation of 810mAHD will be maintained from January 2028 (SP139) through to 31 December 2053 (SP190). On 1 January 2054, dewatering at Springvale will cease.
  - Clarence Colliery is included in the model for cumulative impact. Clarence will be maintained in its current state (301 Area sump included) through to 31 December 2041. On 1 January 2042, dewatering at Clarence would cease.
- Null Case
  - Dewatering at Angus Place Colliery (300, 700, 800 and 900 Panel Areas) will continue as per the requirements of approval of Angus Place Modification 5 and be maintained in a dewatered state through to 31 December 2029.
  - Angus Place Colliery (1000 Panel Area) would not commence on 1 July 2025 as it is not currently approved.
  - Angus Place Colliery's consent expires on August 2024 (active mining) and it is assumed that Care & Maintenance would continue for another five years, so Angus Place Colliery is assumed to be maintained in a dewatered state until 31 December 2029. On 1 January 2030, pumps at Angus Place Colliery would be turned off.
  - Mining at Springvale will complete on 28 February 2025 (LW424), as per the Mine Schedule provided. Springvale would be maintained in a dewatered state (Care & Maintenance) for a further five years, until 31 December 2029. On 1 January 2030, pumps at Springvale Mine would be turned off.
  - Clarence Colliery is included in the model for cumulative impact. Clarence will be maintained in its current state (301 Area sump included) through to 31 December 2041. On 1 January 2042, dewatering at Clarence would cease.

It is noted that in the Proposed Case and the Null Case, mining at other operations was kept the same.

5.3.4 Mine Schedule

The mine development schedule as implemented in the Hydrogeological Model, is provided on Table 5.4. Longwall labels are provided on Figure 1.1.

Mining is proposed to commence at LW1002 in July 2025, followed by LW1001. LW1003 to LW1015 will then be mined sequentially through to February 2038. LW910N will be mined on retreat from April 2038 to October 2038, completing extraction for the APMEP.

Table 5.4: Mine Development Schedule

Longwall	Proposed Start Date	Proposed End Date
LW1002	July 2025	January 2026
LW1001	March 2026	September 2026
LW1003	January 2027	September 2027
LW1004	October 2027	June 2028
LW1005	August 2028	April 2029
LW1006	June 2029	February 2030
LW1007	May 2030	February 2031
LW1008	April 2031	February 2032
LW1009	April 2032	February 2033
LW1010	April 2033	May 2034
LW1011	July 2034	July 2035
LW1012	October 2035	April 2036
LW1013	June 2036	January 2037
LW1014	March 2037	August 2037
LW1015	October 2037	February 2038
LW910N	April 2038	October 2038

5.3.5 Model Technical Review

Third party peer review of the Hydrogeological Model was undertaken by Dr Noel Merrick, Technical Director, SLR Consulting. Reviews were conducted throughout the development and calibration of the model and on completion. Thorough review of the model setup, calibration and outputs was undertaken and found the model to be suitable for the purpose of groundwater impact assessment. A copy of Dr Merrick's review report is appended to the Hydrogeological Model Report in Appendix G.

5.4 Model Results

5.4.1 Mine Inflows

It is noted that predictive uncertainty results are not presented with respect to modelled mine dewatering rates. Model outputs are from simulations using calibrated parameter values. Predicted inflows have also been smoothed due to the quarterly stress periods resulting in significant spikes in inflow that would not be observed during actual mine progression.

Predicted inflow to Angus Place are shown on Figure 5.7. Figure 5.7 also includes the observed and predicted inflows to the existing workings in 300, 700, 800 and 900 Panel areas.

Inflows can be seen to increase significantly in 2025 with the re-commencement of mining in the new 1000 Panel area, with predicted inflow peaking at over 25 ML/day. Following the initial peak, inflows are then predicted to be relatively stable and in the range 18 to 20 ML/day as mining progresses to the north. Following extraction of LW1015 in 2038, the formations surrounding and overlying the workings become increasingly depressurised and inflows begin to decline, falling to around 7 ML/d at the end of mining in 2053.

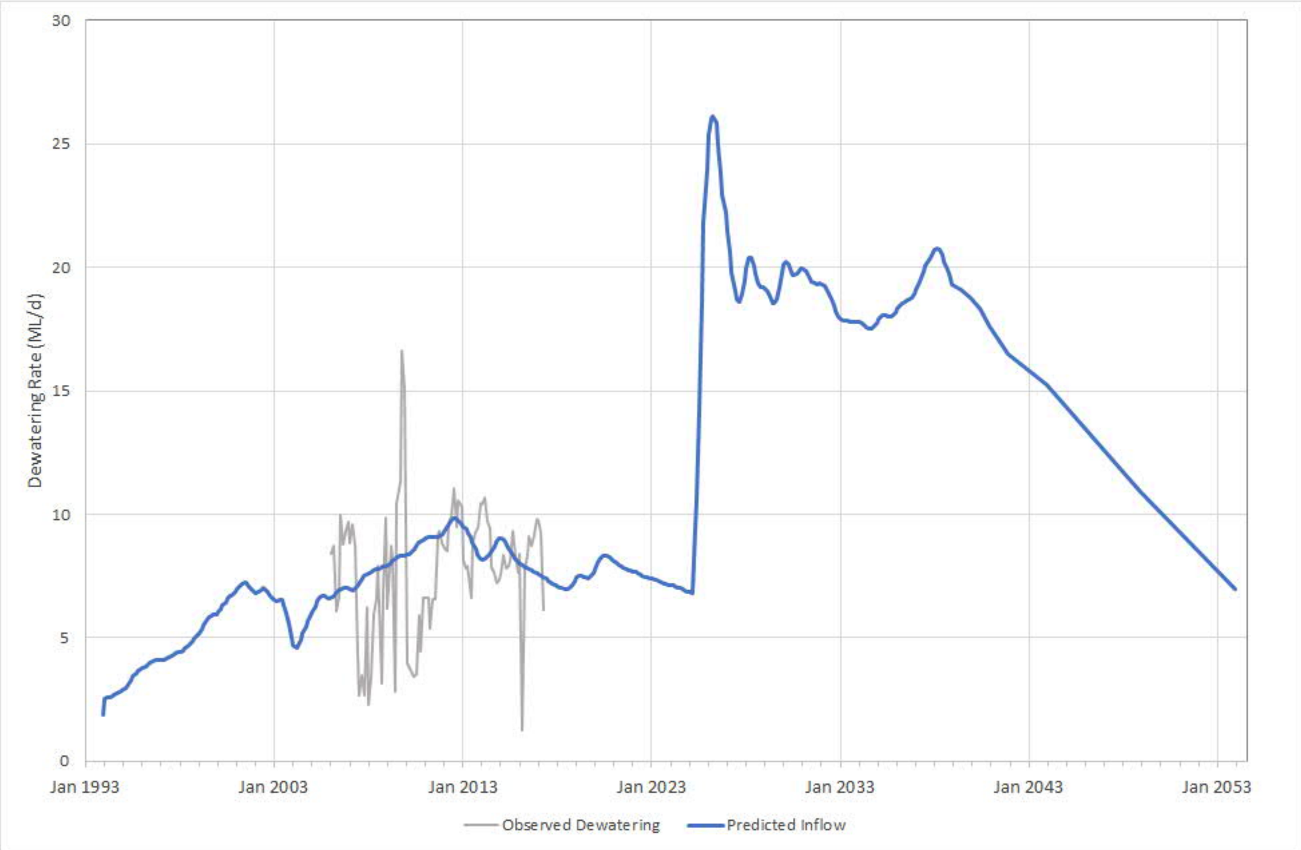


Figure 5.7: Predicted Inflows – Angus Place

Water levels within the completed Springvale Mine will be maintained in a dewatered state such that access from the Springvale portal to the Angus Place longwalls is maintained and water does not top over into the Angus Place workings. At the end of mining at Springvale, the pumps will be turned off until mine void water levels recover to 810mAHD. At this level dewatering will resume again to maintain the water below 810mAHD. The associated inflow and dewatering rate for Springvale Mine is presented on Figure 5.8.

Residual inflows to Springvale mine peak at approximately 19ML/d at the resumption of dewatering, reducing to around 14.6ML/day in 2038, and 12.9ML/day prior to the pumps being turned off in 2053.

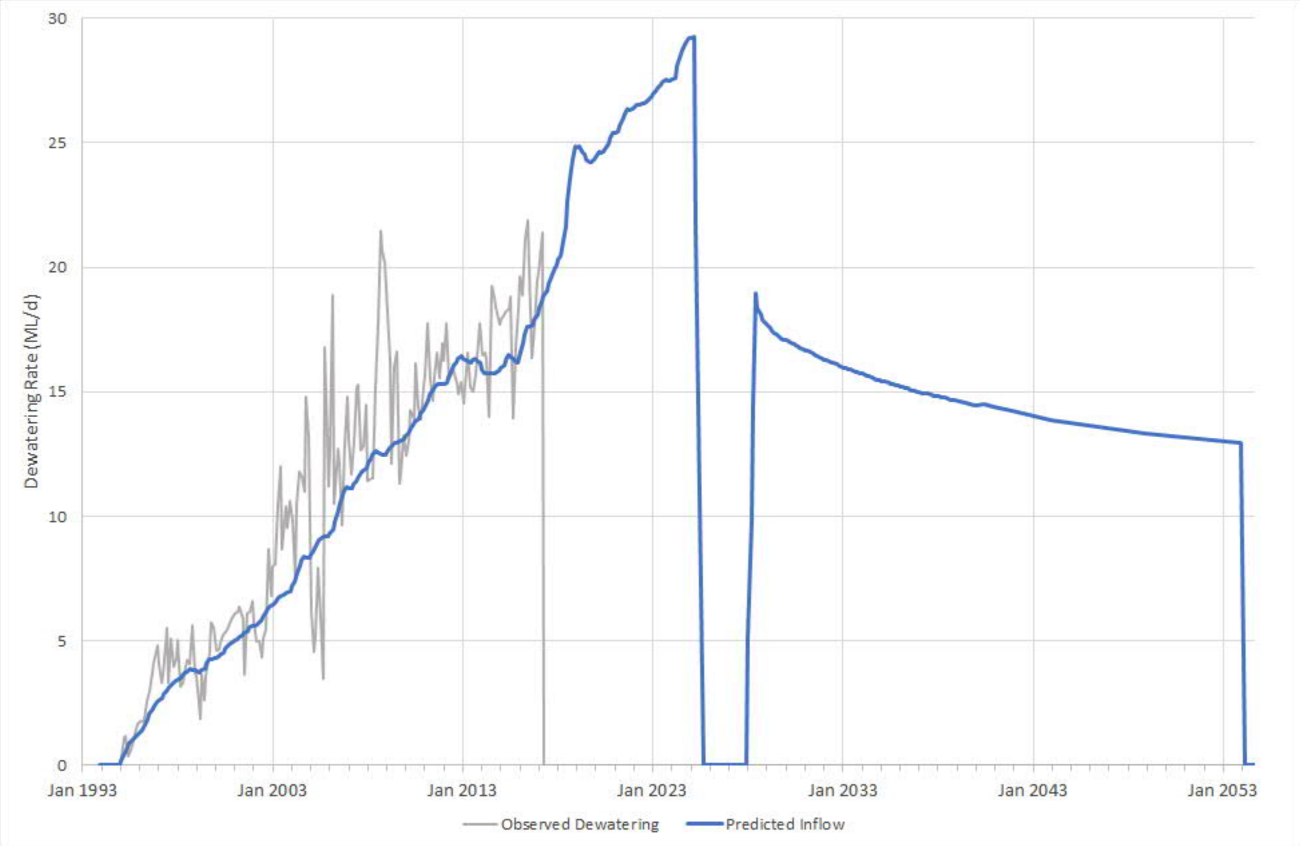


Figure 5.8: Predicted Inflows – Springvale

5.4.2 Groundwater Drawdown

Drawdowns presented in the following sections and figures are for the 10th percentile case, or greatest predicted water level decline.

Predicted drawdowns and pressure declines (10th percentile) at end of mining in the Lithgow Seam, Bankswall Sandstone and at the uppermost water table are presented in Figure 5.9 to Figure 5.11 respectively.

The 10th percentile drawdowns within the Lithgow Seam (Figure 5.9) are attenuated fairly rapidly upgradient, to the east and south, due to the seam subcropping and becoming unsaturated. Depressurisation towards the east and northeast, where the Lithgow Seam remains confined is more significant with the 1m drawdown contour extending to the model boundary at approximately 17km. In contrast the 90th percentile drawdown (not shown) extends to approximately 14km from the mining area at the 0.5m contour.

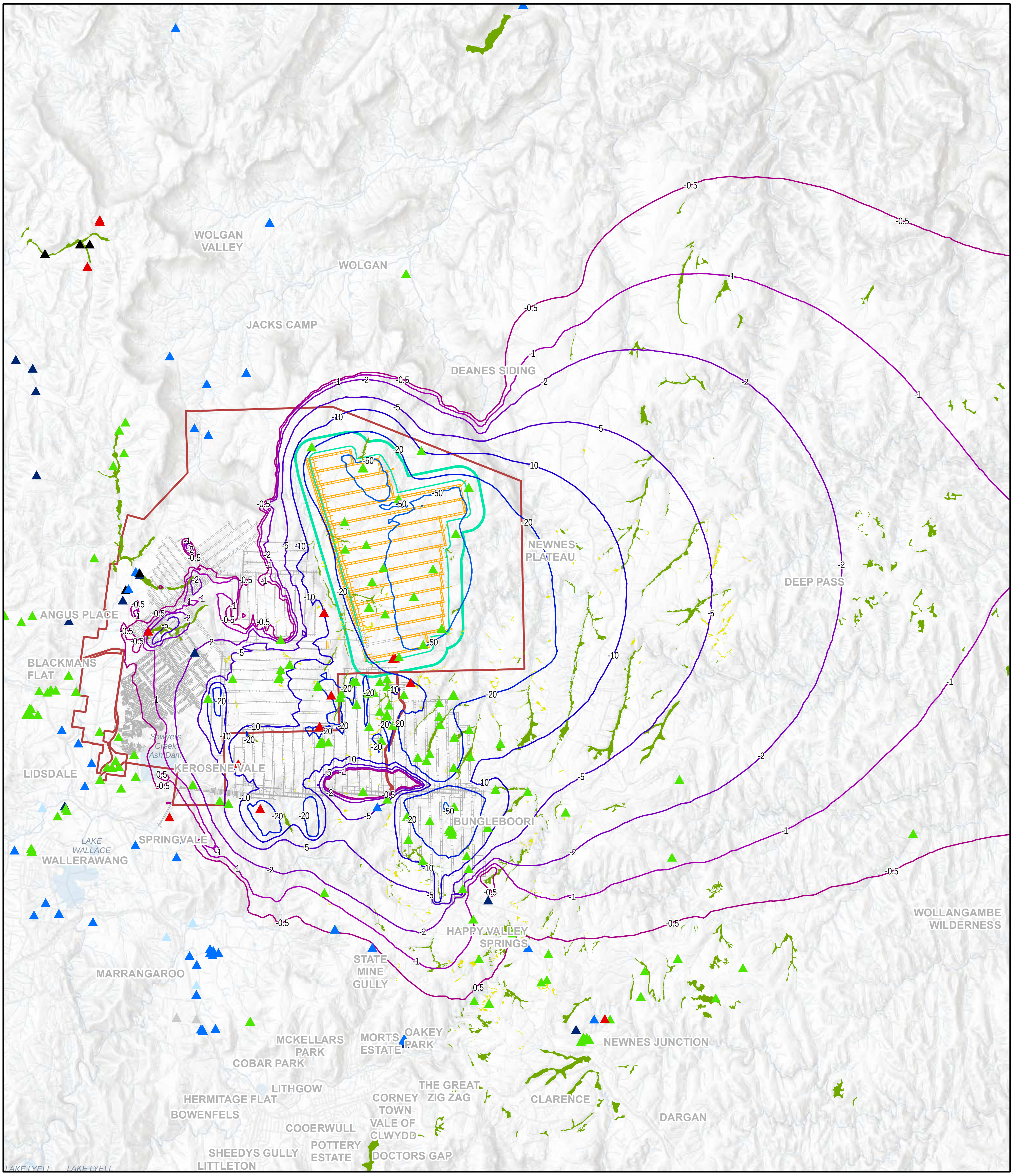
The drawdown to the south of Angus Place Colliery is due to Springvale Mine being maintained in a semi-dewatered state (elevation at 810mAHD) through to the end of 2053. This is required to retain access between Angus Place Colliery and Springvale Mine via an underground roadway. In the Null Case, dewatering at Springvale Mine would cease after 31 December 2029.

Drawdown in overlying layers, beneath the Mount York Claystone is of similar extent and magnitude with the eastwards propagation of drawdown diminishing slightly. In Layer 18 (Katoomba Seam) for example, the 10th percentile drawdown, 0.5m contour, extends to the eastern boundary, while the 90th percentile drawdown, 0.5m contour extends less than 10km east.

Above the Mount York Claystone, drawdown is limited to the immediate mining area, largely due to the Bankswall Sandstone being truncated and isolated from the east by the incised Carne Creek valley. The 10th percentile groundwater drawdown is generally limited to within approximately 2km of the active mining areas, with one isolated area of drawdown east of Carne Creek (Figure 5.10).

The predicted decline in the uppermost water table has also been extracted from the model, the predicted 10th percentile (greatest) decline is presented on Figure 5.11. Predicted water table decline is generally limited to the Newnes Plateau above the area of mining, although some areas of decline are also predicted where deeper formations subcrop in the valleys of the Wolgan River and Carne Creek adjacent to the mining area. Zoomed in figures showing drawdown in the uppermost water table are shown on Figure 5.12 to Figure 5.14.

Figure 5.9: Predicted Drawdown at End of Mining – Lithgow Seam



Drawdown contour [m]
- -50
- -20
- -10
- -5
- -2
- -1
- -0.5

Groundwater Works Use
- Commercial and Industrial
- Monitoring
- Dewatering
- Irrigation
- Water Supply
- Other
- Unknown

Infrastructure
- Proposed Workings
- Existing Workings

Project Area
- Project Area

APE Study Areas
- 26.5 degree AoD
- 600m Study Area

Swamps
- Hanging
- Shrub

Hydrology
- Water Areas

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GDA 1994 MGA Zone 56

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JACOBS

Angus Place Amended Project

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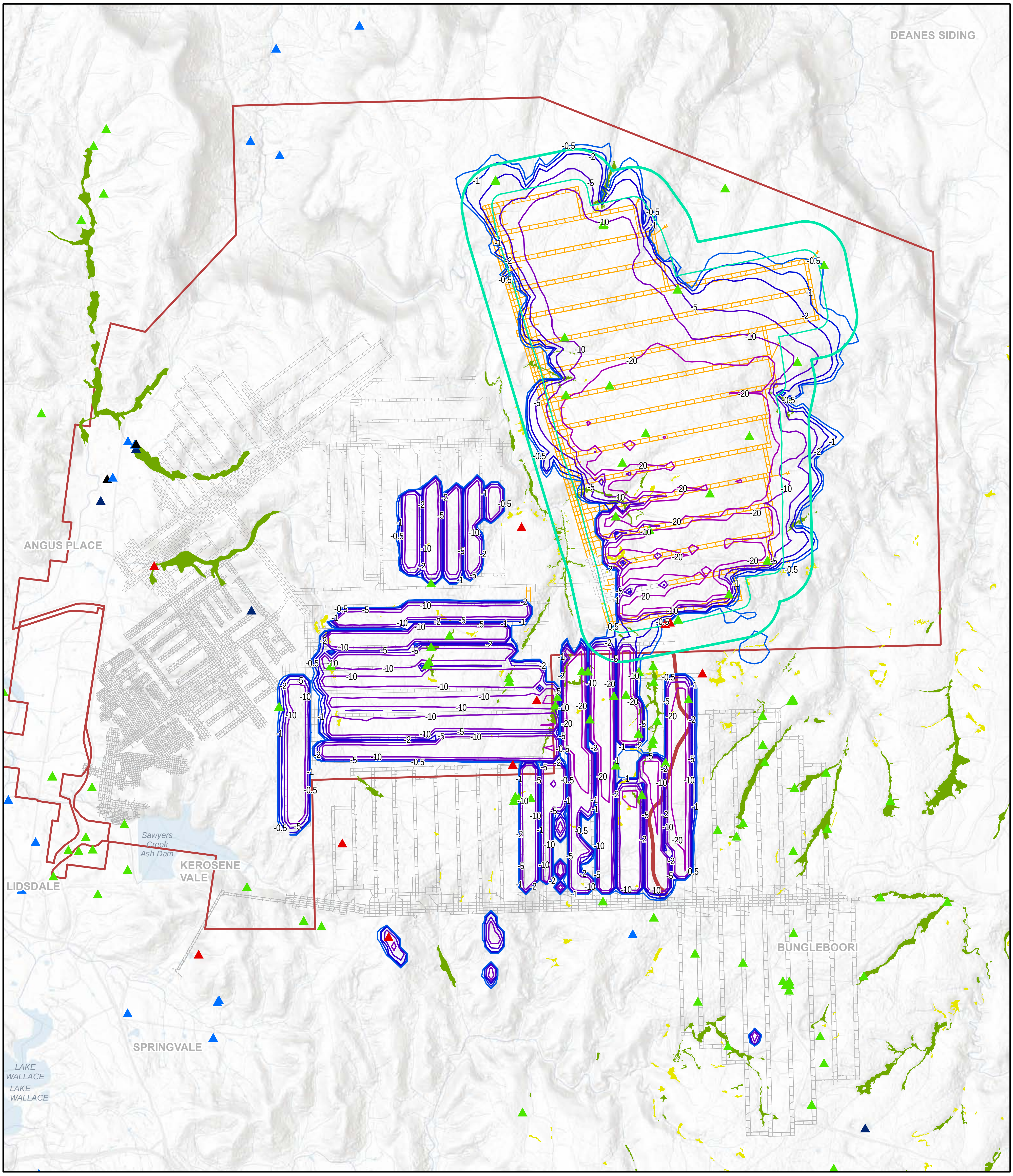
Figure 5.10: Predicted Drawdown at End of Mining – Bankswall Sandstone



Drawdown contour [m]
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- -20
- -10
- -5
- -2
- -1
- -0.5

Groundwater Works Use
- Commercial and Industrial
- Monitoring
- Dewatering
- Irrigation
- Water Supply
- Other
- Unknown

Infrastructure
- Proposed Workings
- Existing Workings

Project Area
- Project Area

APE Study Areas
- 26.5 degree AoD
- 600m Study Area

Swamps
- Hanging
- Shrub

Hydrology
- Water Areas

GDA 1994 MGA Zone 56

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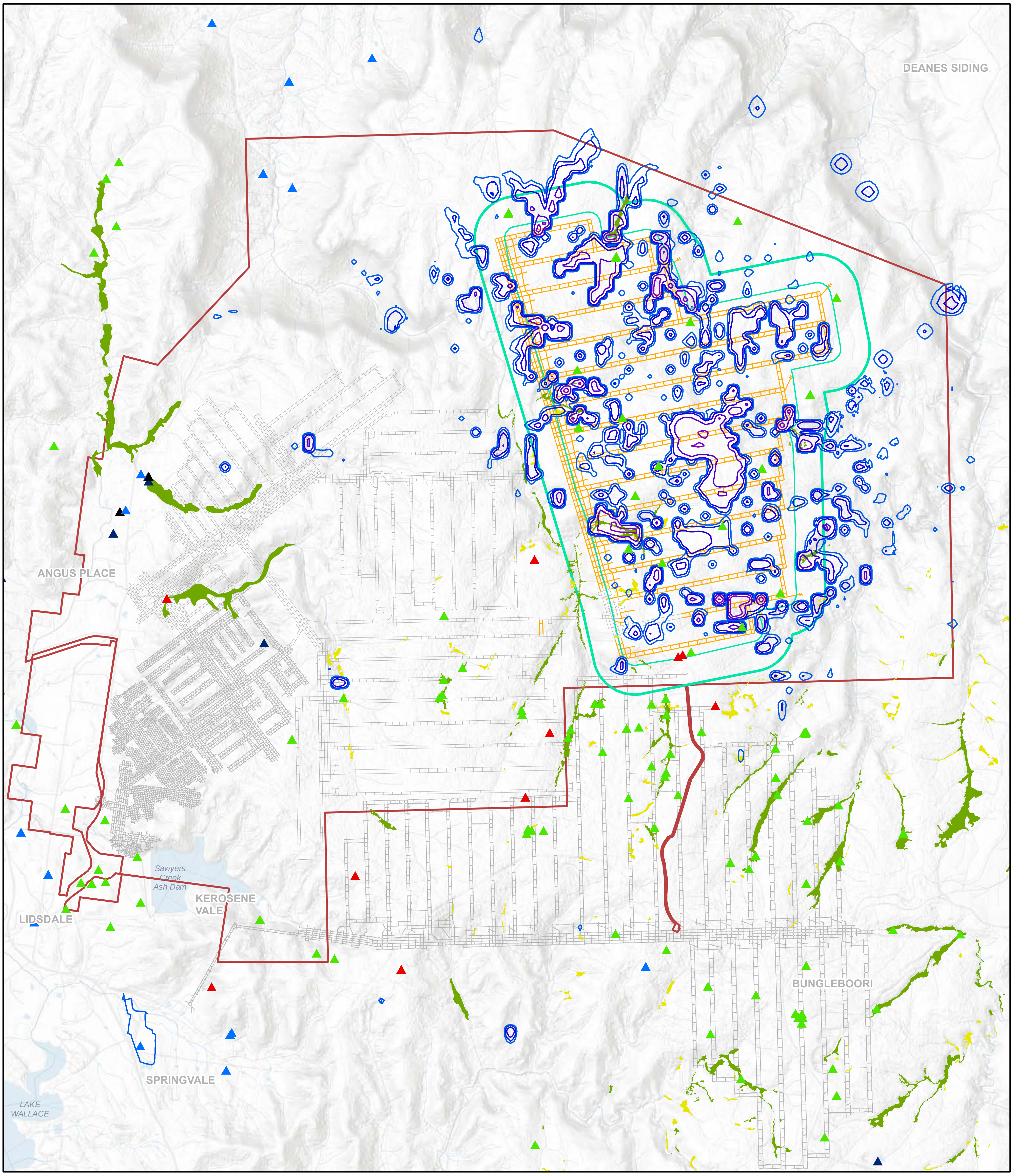
Figure 5.11: Predicted Drawdown at End of Mining – Uppermost Watertable



Drawdown contour [m]
- -50
- -20
- -10
- -5
- -2
- -1
- -0.5

Groundwater Works Use
- Commercial and Industrial
- Monitoring
- Dewatering
- Irrigation
- Water Supply
- Other
- Unknown

Infrastructure
- Proposed Workings
- Existing Workings

Project Area
- Project Area

APE Study Areas
- 26.5 degree AoD
- 600m Study Area

Swamps
- Hanging
- Shrub

Hydrology
- Water Areas

GDA 1994 MGA Zone 56

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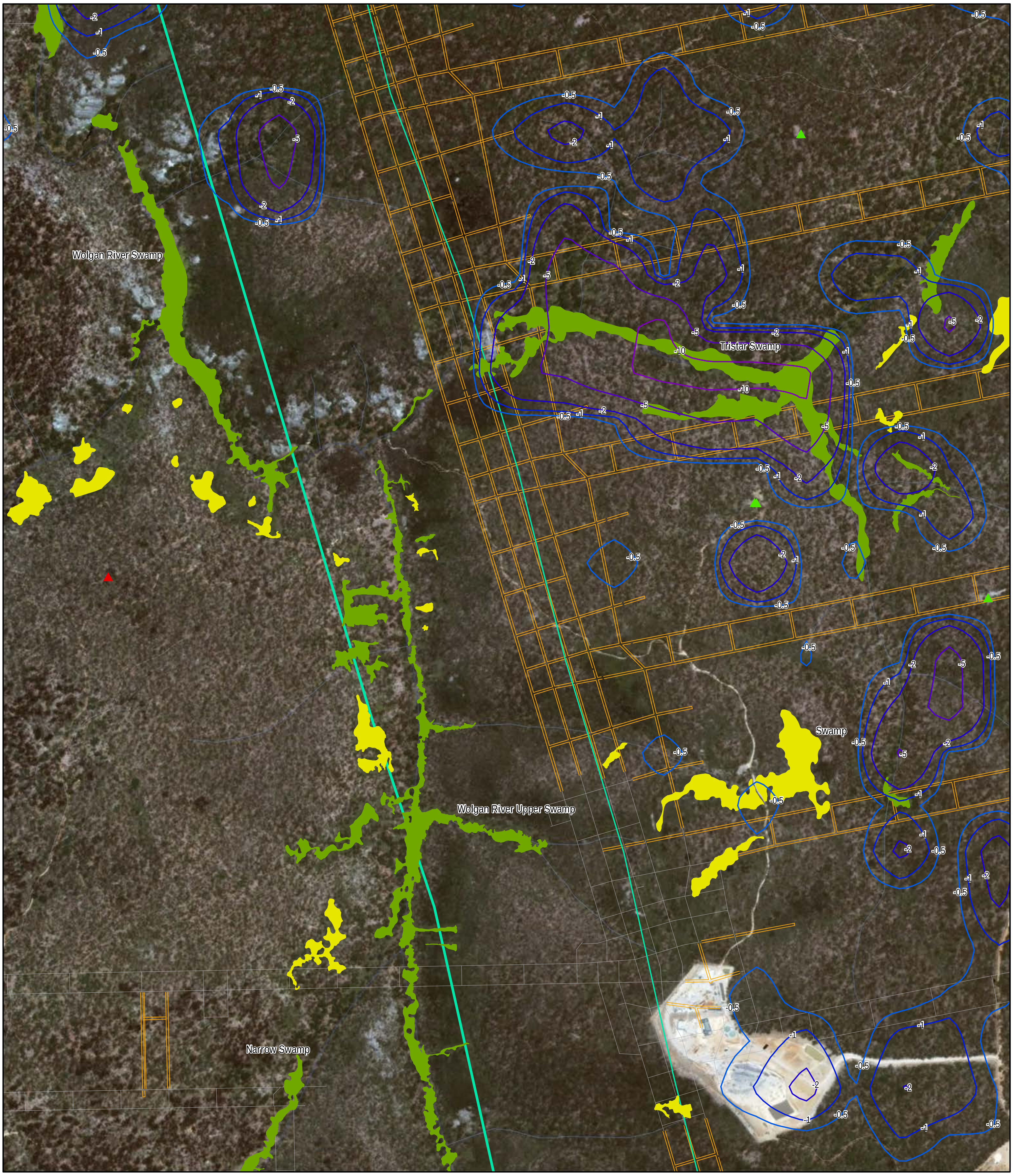
Figure 5.12: Predicted Drawdown at End of Mining – Wolgan River and Tri Star Swamps



Drawdown contour [m]
- -50
- -20
- -10
- -5
- -2
- -1
- -0.5

Groundwater Works Use
- Commercial and Industrial
- Monitoring
- Dewatering
- Irrigation
- Water Supply
- Other
- Unknown

Infrastructure
- Proposed Workings
- Existing Workings

Project Area
- Project Area

APE Study Areas
- 26.5 degree AoD
- 600m Study Area

Hydrology
- Water Areas
- Stream Order 1 - 2
- Stream Order 3 - 6

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Kilometres

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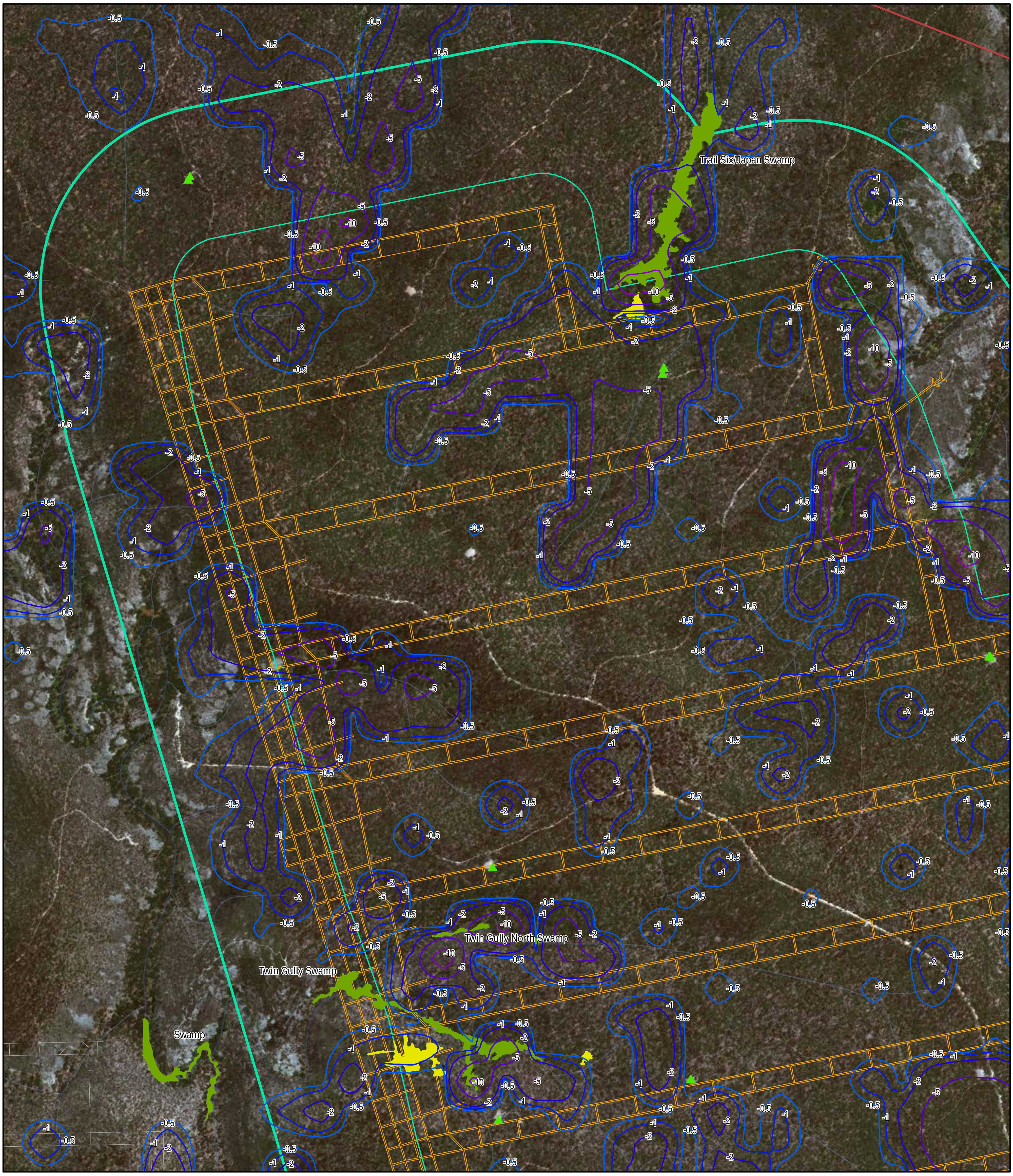
Figure 5.13: Predicted Drawdown at End of Mining – Twin Gully and Trail Six Swamps



Drawdown contour [m]
- -50
- -20
- -10
- -5
- -2
- -1
- -0.5

Groundwater Works Use
- Commercial and Industrial
- Monitoring
- Dewatering
- Irrigation
- Water Supply
- Other
- Unknown

Infrastructure
- Proposed Workings
- Existing Workings

Project Area
- Project Area

APE Study Areas
- 26.5 degree AoD
- 600m Study Area

Hydrology
- Water Areas
- Stream Order 1 - 2
- Stream Order 3 - 6

GDA 1994 MGA Zone 56

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Kilometres

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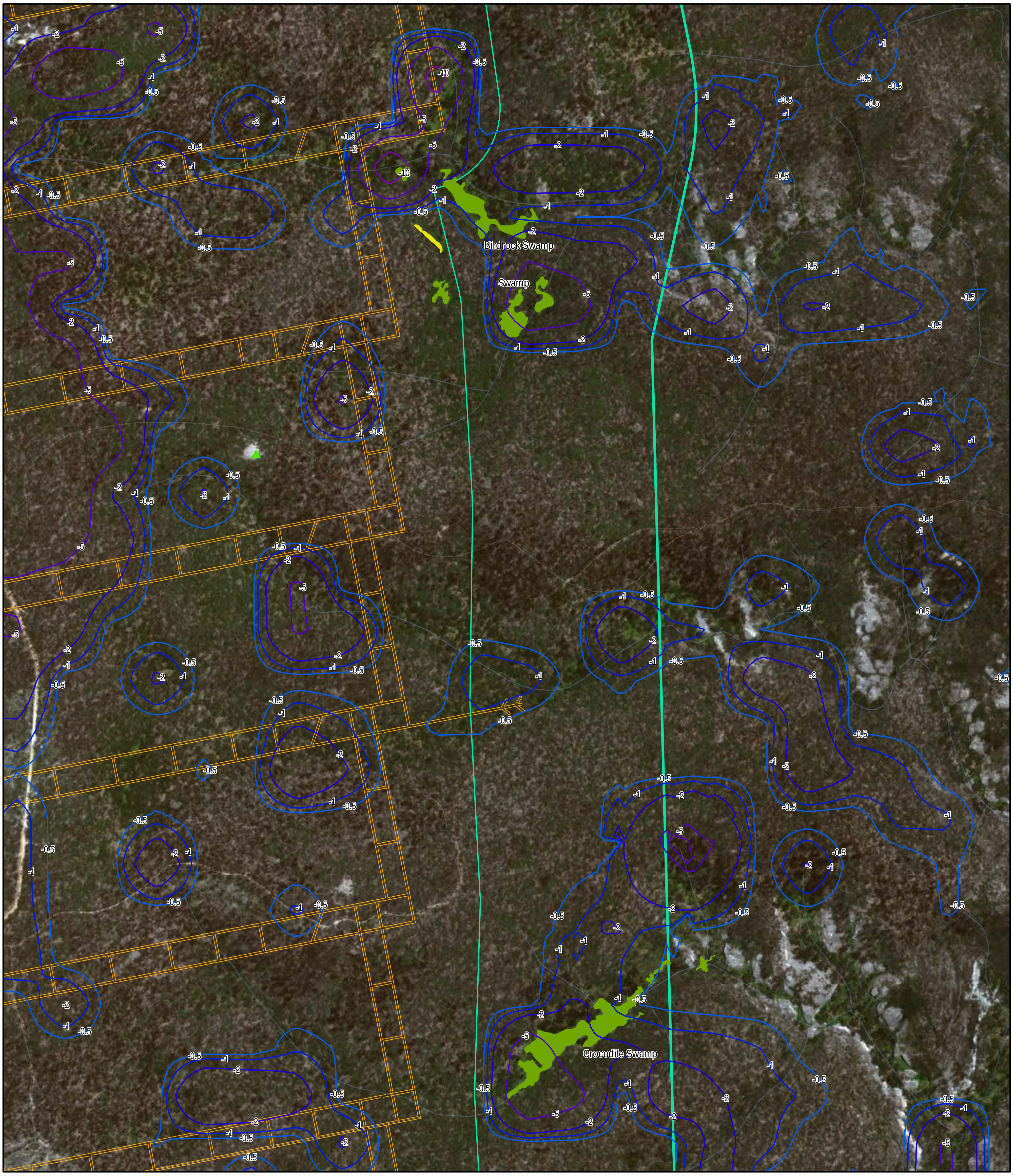
Figure 5.14: Predicted Drawdown at End of Mining – Birds Rock and Crocodile Swamps



Drawdown contour [m]
- -50
- -20
- -10
- -5
- -2
- -1
- -0.5

Groundwater Works Use
- Commercial and Industrial
- Monitoring
- Dewatering
- Irrigation
- Water Supply
- Other
- Unknown

Infrastructure
- Proposed Workings
- Existing Workings

Project Area
- Project Area

APE Study Areas
- 26.5 degree AoD
- 600m Study Area

Hydrology
- Water Areas
- Stream Order 1 - 2
- Stream Order 3 - 6

GDA 1994 MGA Zone 56

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Kilometres

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5.4.2.1 Tri Star and Twin Gully Swamps

The maximum predicted water table decline beneath Tri Star Swamp is 10m for the 10th percentile drawdown, and 5m for the 90th percentile drawdown. The maximum predicted water table decline beneath Twin Gully Swamp is 10m for the 10th percentile drawdown, with up to 5m drawdown predicted for the 90th percentile decline.

Water table declines of this magnitude at Tri Star Swamp are likely to result in a corresponding decline of swamp water levels leading to the drying or partial drying of the swamps. Predicted baseflow impacts are discussed in Section 5.4.6.

5.4.2.2 Wolgan River Swamps and Trail Six Swamps

The maximum predicted water table decline beneath Trail Six Swamp is 10m for the 10th percentile drawdown, with up only 0.5m for the 90th percentile decline.

No significant drawdown is predicted at Wolgan River Swamp or Wolgan River Upper Swamp.

Water level declines at Trail Six Swamp have potential to result in a corresponding decline of swamp water levels leading to the drying or partial drying of the swamps. Predicted baseflow impacts are discussed in Section 5.4.6.

5.4.2.3 Birds Rock Swamp and Crocodile Swamp

The maximum predicted water table decline beneath both Birds Rock Swamp and Crocodile Swamp is up to 5m for the 10th percentile drawdown, with drawdown of the order of 2m predicted for most of the swamp area. For the 90th percentile decline, the predicted drawdown is generally less than 0.5m at Birds Rock and Crocodile Swamps with some areas of up to 1m drawdown predicted.

Water level declines of this magnitude have potential to result in a corresponding decline of swamp water levels leading to the drying or partial drying of the swamps. Predicted baseflow impacts are discussed in Section 5.4.6.

5.4.2.4 Wolgan River

No significant water table decline is predicted beneath the Wolgan River. Predicted baseflow impacts are discussed in Section 5.4.6.

5.4.2.5 Long Swamp and Coxs River

No drawdown is predicted in the vicinity of the pit top or Long Swamp and Coxs River.

5.4.3 Post Mining

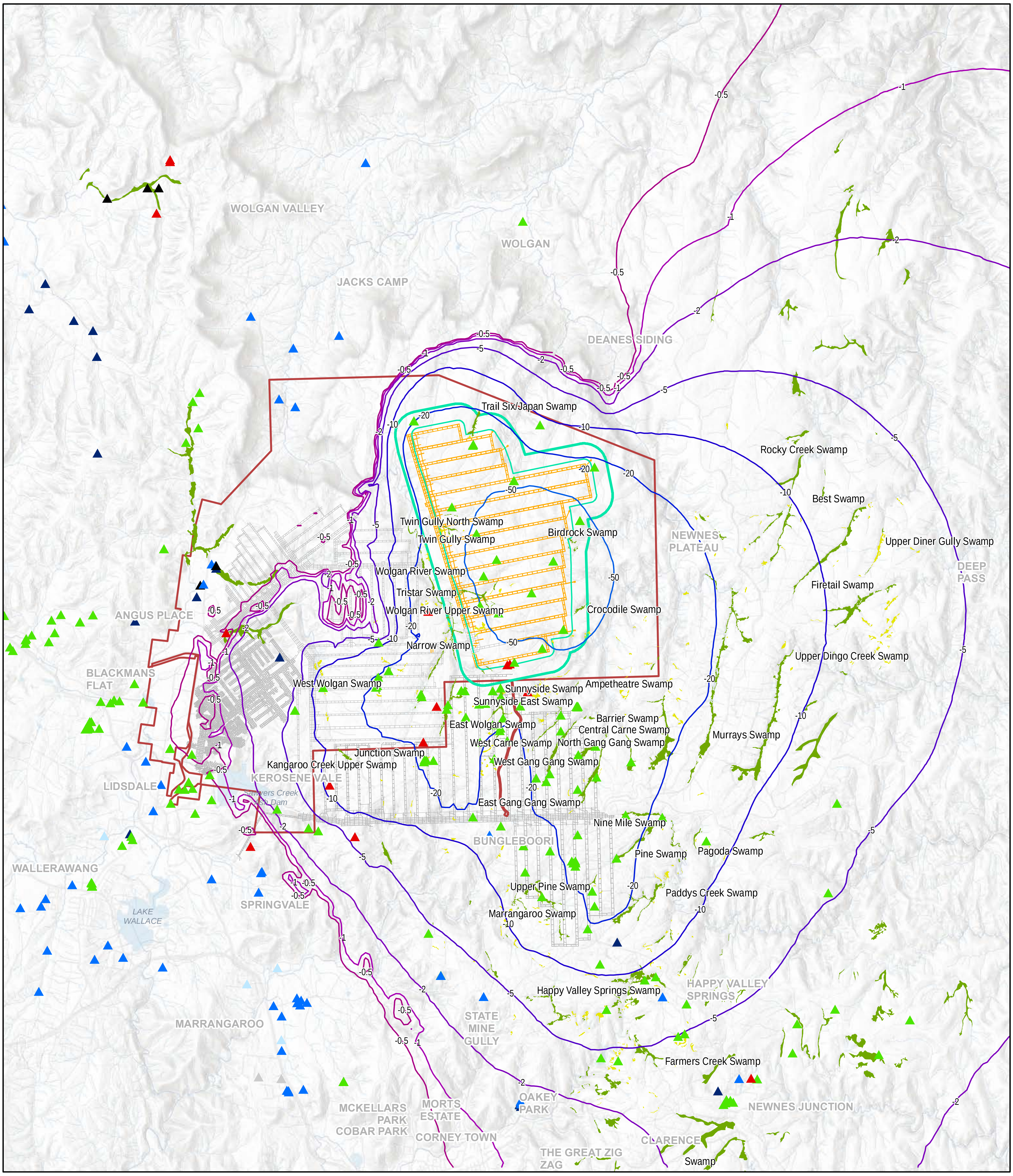
At the time of writing, groundwater level recovery predictions, or residual groundwater drawdown, was only available to 2091, 38 years post mining. More detailed groundwater and mine void recovery scenarios will be undertaken as part of detailed mine closure planning.

At 38 years post mining, depressurisation within the Lithgow Seam is predicted to have propagated further than at end of mining. Predicted drawdown for the 10th percentile water level decline is shown of Figure 5.15.

Drawdown has propagated further to the northeast, east and southeast, with the 2m drawdown contour extending to the eastern model boundary.

At 38 years post mining there is no significant increase in the extent of drawdown at the uppermost water table, there is also no significant recovery. Residual drawdown at 38 Year post mining is presented on Figure 5.15 for the Lithgow Seam and Figure 5.16 for the uppermost water table.

Figure 5.15: Residual Drawdown at 38 Years Post Mining – Lithgow Seam



Drawdown contour [m]
- -50
- -20
- -10
- -5
- -2
- -1
- -0.5

Groundwater Works Use
- Commercial and Industrial
- Monitoring
- Dewatering
- Irrigation
- Water Supply
- Other
- Unknown

Infrastructure
- Proposed Workings
- Existing Workings

Project Area
- Project Area

APE Study Areas
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Hydrology
- Water Areas

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JACOBS

Angus Place Amended Project

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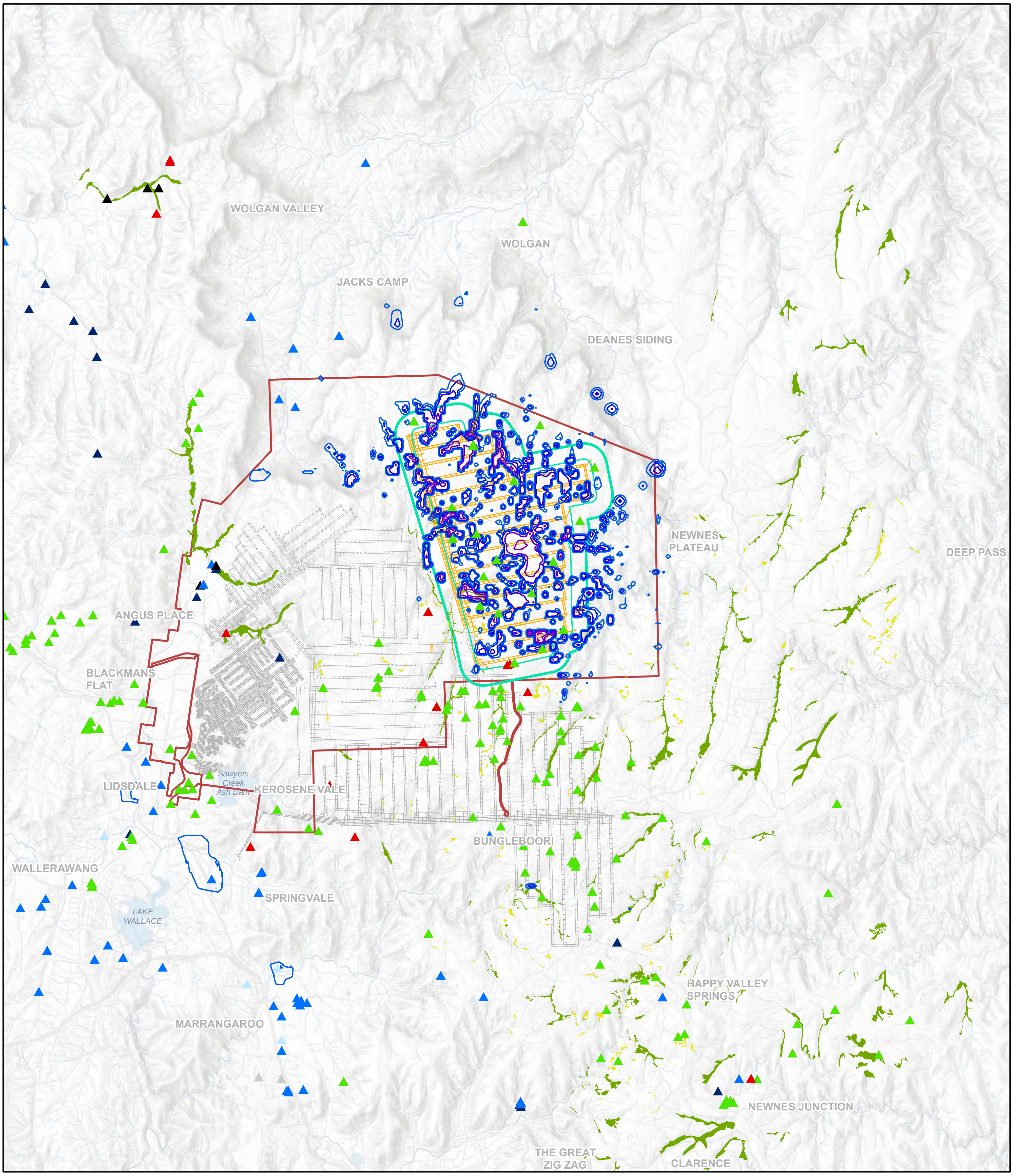
Figure 5.16: Residual Drawdown at 38 Years Post Mining – Uppermost Water Table



Drawdown contour [m]

- -50
- -20
- -10
- -5
- -2
- -1
- -0.5

Groundwater Works Use

- Commercial and Industrial
- Monitoring
- Dewatering
- Irrigation
- Water Supply
- Other
- Unknown

Infrastructure

- Proposed Workings
- Existing Workings

Project Area

- Project Area

APE Study Areas

- 26.5 degree AoD
- 600m Study Area

Hydrology

- Water Areas

GDA 1994 MGA Zone 56

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Kilometres

JACOBS

Data Sources - Centennial Angus Place Pty Ltd: Project Area, Infrastructure (2019); NSW Government Public Data: Roads, Hydrology, Placenames; Bureau of Meteorology: Groundwater Works; JBS&G (2019a): Drawdown Contours; ESRI ArcGIS Image Service: World Elevation Terrain, World Topographic Map. Imagery.

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5.4.4 Predicted Impacts to Groundwater Users

The predicted 10th percentile decline in water level in the Lithgow Seam has been used as a proxy for the maximum potential water level decline during mining and at 38 years post mining. Groundwater users, for water supply purposes, within the 0.5m drawdown contour are noted on Table 5.5.

No impacts are predicted to groundwater users in the Wolgan Valley or Coxs River Valley.

Table 5.5: Predicted Drawdown at Groundwater Works - End of Mining

Bore ID	Purpose	Location	Comment
GW109337	Water Supply - test hole	Newnes Plateau Springvale Mine lease	5m drawdown EOM Test bore - decommissioned
GW042618	Commercial and Industrial - bore	Newnes Plateau south of Springvale – Abandoned Quarry	0.5 to 1 m drawdown in Lithgow Seam at end of mining increasing to 15m at 38 years post mining. Less than 0.5m drawdown above MYC. 29m deep – unlikely to be impacted.
GW101985	Water supply - bore	Newnes Plateau south of Springvale – Motocross Track	Less than 0.5m drawdown in Lithgow Seam at end of mining, increasing to 7-8m at 38 years post mining. Less than 0.5m drawdown above MYC Bore 30m deep – unlikely to be impacted
GW100718	Water supply - bore	Newnes Plateau south of Springvale Mine lease	0.5 to 1 m drawdown in Lithgow Seam at end of mining increasing to 3m at 38 years post mining. Less than 0.5m drawdown above MYC. 15m deep – unlikely to be impacted.
GW109336	Water supply – test hole	Newnes Plateau south of Springvale Mine lease	0.5m drawdown in Lithgow Seam increasing to 3-4m post mining Negligible drawdown above MYC. 15m deep – unlikely to be impacted
GW030862	Commercial and Industrial - bore	Angus Place Bord and Pillar in Project Application Area	Predicted drawdown 2-4m. Dewatering service bore 146m deep
GW106646	Commercial and Industrial - bore	Hanson Quarry near Clarence Colliery	Less than 0.5m drawdown in Lithgow Seam at end of mining, increasing to 3-4m at 38 years post mining Negligible drawdown above MYC. Bore 30m deep – unlikely to be impacted.
GW105734	Water Supply - bore	Clarence Colliery	Less than 0.5m drawdown at end of mining 3-4m drawdown in Lithgow Seam at 38 years post mining 0.5 – 1m drawdown in Katoomba Seam. Bore 120m deep – unlikely to be impacted.
GW105433 GW105434 GW105435 GW103224 GW072919 GW072919	Water Supply and Commercial and Industrial - bores	At or near Lithgow Valley Springs	Less than 0.5m drawdown in Lithgow Seam at end of mining, increasing to 1-2m drawdown at 38 years post mining. Negligible drawdown above MYC. Bores 8 to 72m deep – unlikely to be impacted.

5.4.5 Predicted Impacts to GDEs

No significant water level decline is predicted at GDEs other than THPSS overlying the mining area. Declines in surface water flow are discussed in the Surface Water Impact Assessment.

5.4.6 Baseflow Impacts

Predicted baseflow impacts, calculated as the net difference in groundwater contribution to baseflow between the null case and the proposed case are presented as follows. It is noted that for surface water licencing issues, relative change in groundwater contribution to swamps and creeks is incorporated into the Swamp Water Balance Model and water access licencing requirements for reduced surface water flows are reported in the Surface Water Impact Assessment.

Predicted changes to baseflow are presented on Figure 5.17 to Figure 5.24. Most negative baseflow changes are summarised on Table 5.6. Baseflow reductions are based on the 10th and 90th percentile water level change predictions, however, for baseflow, due to the computational method, the sense of magnitude is reversed. For baseflow the 10th percentile is the least change and the 90th percentile is the greatest change.

For comparison, results for the calibrated model, SIM0, are also included. SIM0 would be considered to be the base case scenario in deterministic groundwater modelling.

The predicted baseflow changes for individual swamps, include the entire contributing catchment. Predicted baseflow changes for Wolgan River and Carne Creek include the all reaches and contributing catchments above that point. Baseflow changes reported for Wolgan River Swamps are for node WR05A located midway between Wolgan River Swamp and Wolgan River Upper Swamp (JBS&G, 2019b), and incorporate all baseflow losses from contributing catchments above that point.

It is noted that for several of the prediction scenarios a positive baseflow impact is predicted. The mechanism for this occurring in the groundwater model is through the material property changes in the subsidence profile, with enhanced horizontal hydraulic conductivity allowing greater lateral transmission of groundwater to seepage faces. While similar responses were predicted in the 2014 EIS (CSIRO, 2013), in practice this effect has not been observed in the monitoring data (flow or water level). It is not clear if this is due the prevailing drying climate masking the effect or if it does not eventuate in reality.

Table 5.6: Predicted Baseflow Impacts

Swamp / Water Course	Mining (kL/day)			Post Mining (kL/day)		
	10th	SIM0	90th	10th	SIM0	90th
Tri Star Swamp	-30.4	-88.8	-143.4	-40.8	-108.8	-169.0
Twin Gully Swamp	-0.4	-6.1	-25.5	0	-19	-49.6
Wolgan River Swamps (WR05a)	0	-249.6	-564.8	-8.6	-110.6	-185.4
Trail Six Swamp	0	-0.2	-28.8	0	-16.4	-56.6
Birds Rock Swamp	-6.6	-35.0	-49.5	-9.6	-37.6	-49.6
Crocodile Swamp	0	-0.4	-10.6	0	0	-8.7
Wolgan River	-0.2	-274.0	-670.6	0	-141.4	-295.6
Carne Creek	0	-64.8	-366.2	0	-290.8	-604.6

5.4.6.1 Tri Star Swamp and Twin Gully Swamp

The maximum predicted baseflow losses for Tri Star Swamp during mining are 88.8 kL/day for SIM0 and 143.4 kL/day for the 90th percentile. Baseflow losses increase slightly post mining to 108.8 kL/day for SIM0 and 169 kL/day for the 90th percentile.

The maximum predicted baseflow losses for Twin Gully Swamp during mining are 6.1 kL/day for SIM0 and 25.5 kL/day for the 90th percentile. Baseflow losses increase slightly post mining to 19 kL/day for SIM0 and 49.6 kL/day for the 90th percentile. For the 10th percentile and SIM0, predicted impacts during mining are predominantly positive.

The reduced predicted impacts at Twin Gully compared to Tri Star Swamp are attributed to the greater depth of cover at Twin Gully.

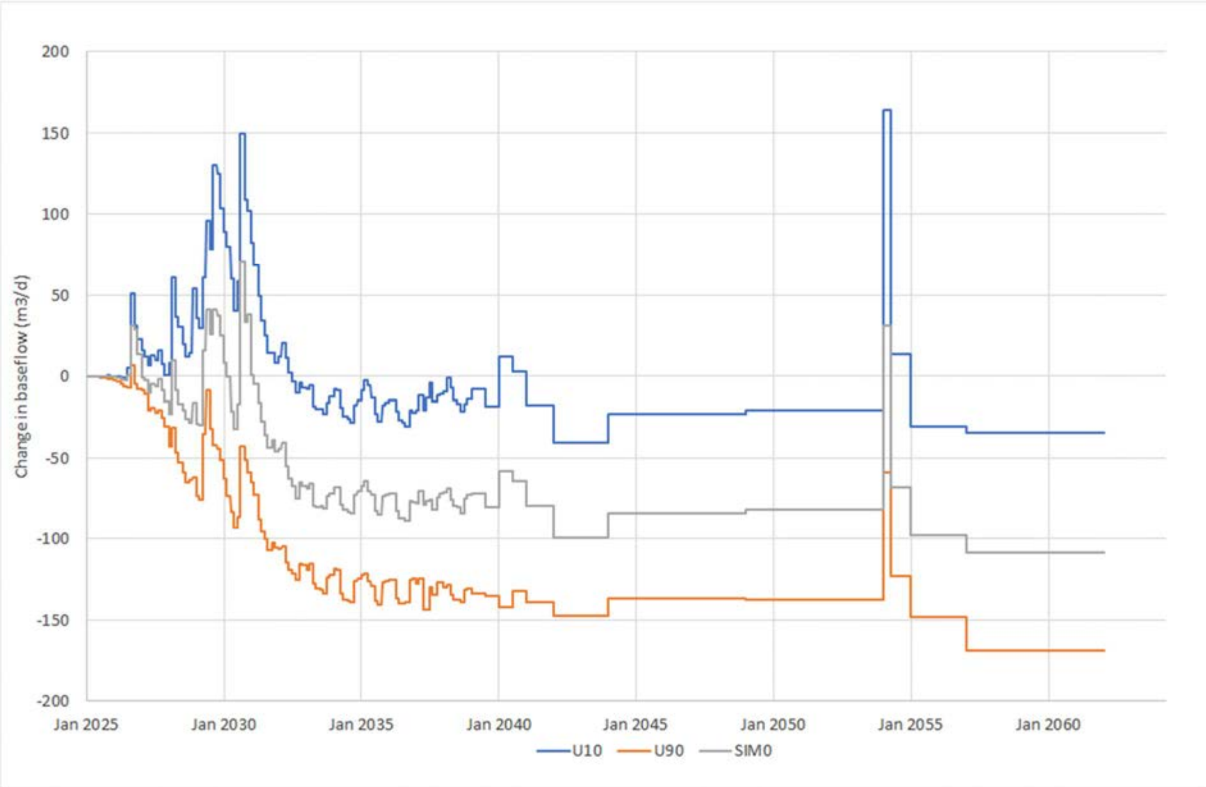

Figure 5.17: Predicted Baseflow Impacts – Tri Star Swamp

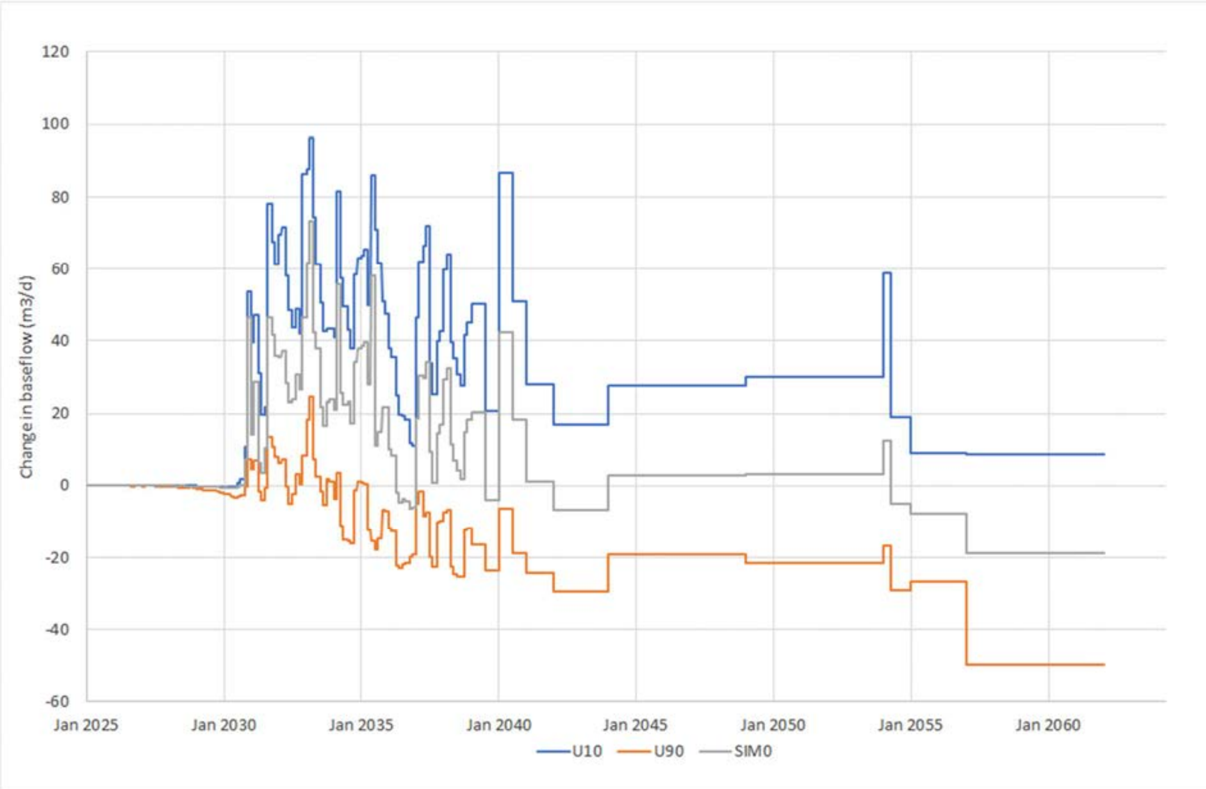

Figure 5.18: Predicted Baseflow Impacts – Twin Gully Swamp

5.4.6.2 Wolgan River Swamps and Trail Six Swamp

The maximum predicted baseflow losses at the location of the Wolgan River Swamps during mining are 249 kL/day for SIM0 and 565 kL/day for the 90th percentile. Predicted baseflow losses decrease substantially post mining to 111 kL/day for SIM0 and 185 kL/day for the 90th percentile. It is noted that this predicted baseflow reduction is cumulative of all upstream contributing catchments.

The maximum predicted baseflow losses for Trail Six Swamp during mining are 0.2 kL/day for SIM0 and 28.8 kL/day for the 90th percentile. Predicted baseflow losses increase slightly post mining to 16.4 kL/day for SIM0 and 56.6 kL/day for the 90th percentile

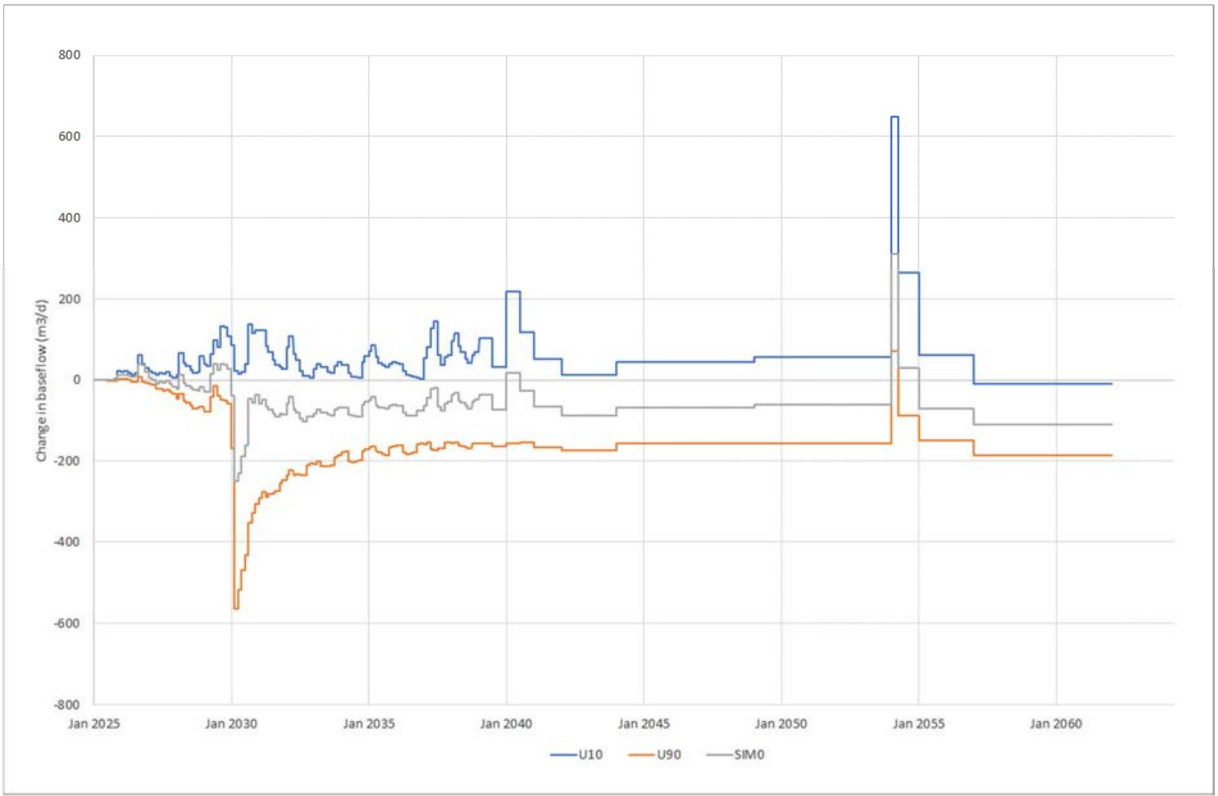

Figure 5.19: Predicted Baseflow Impacts – Wolgan River Swamps (WR05a)

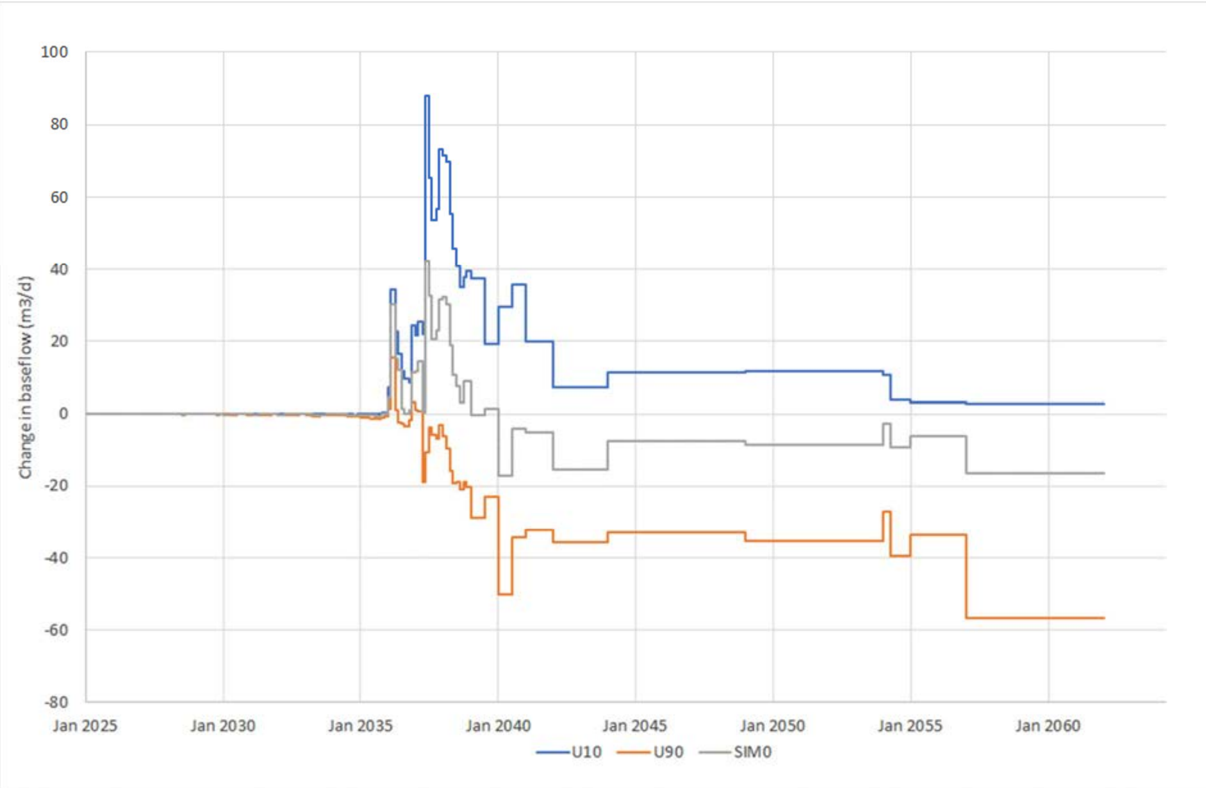

Figure 5.20: Predicted Baseflow Impacts – Trail Six Swamp

5.4.6.3 Birds Rock Swamp and Crocodile Swamp

The maximum predicted baseflow losses for Birds Rock Swamp during mining are 36.6 kL/day for SIM0 and 49.5 kL/day for the 90th percentile. Baseflow losses remain relatively consistent post mining with maximum of 37.6 kL/day for SIM0 and 49.6 kL/day for the 90th percentile.

The maximum predicted baseflow losses for Crocodile Swamp during mining are 0.41 kL/day for SIM0 and 10.6 kL/day for the 90th percentile. For SIM0, the majority of predicted changes are positive. Baseflow losses reduce post mining with a long-term take of 2.8 kL/day for the 90th percentile and predicted gains for SIM0.

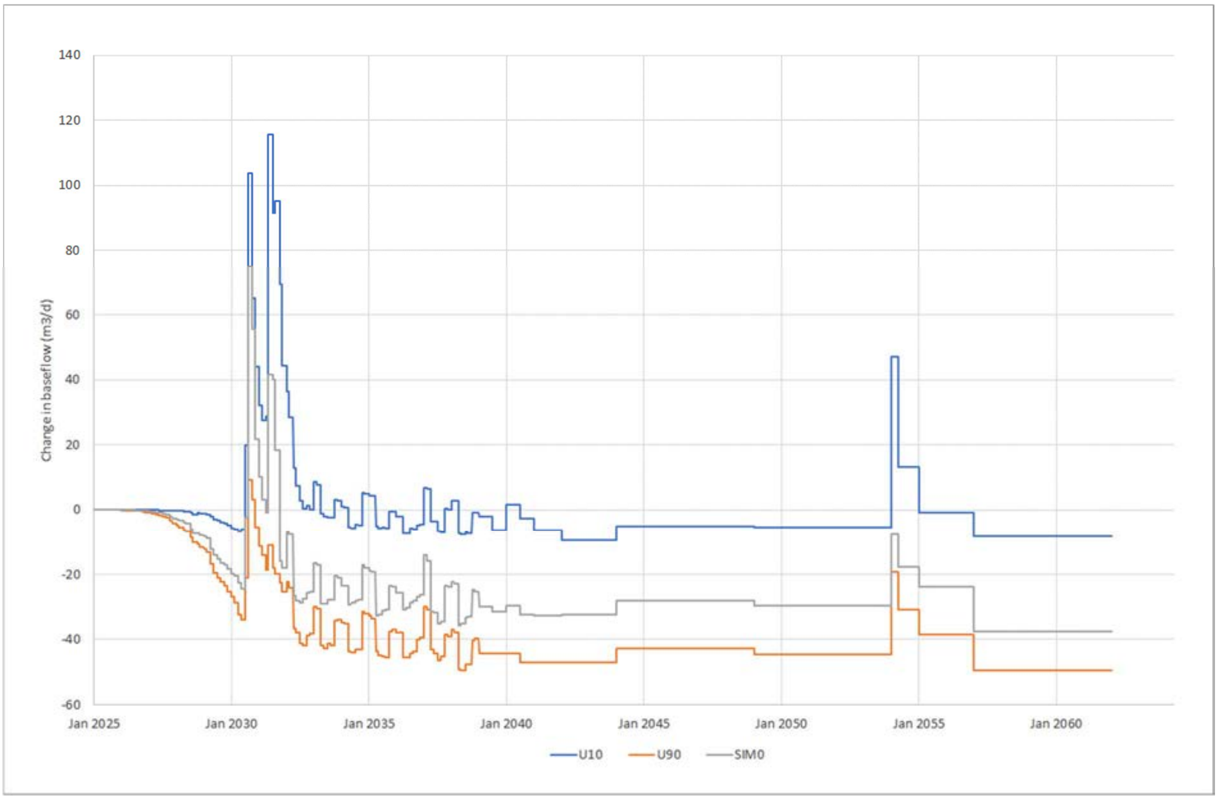

Figure 5.21: Predicted Baseflow Impacts – Birds Rock Swamp

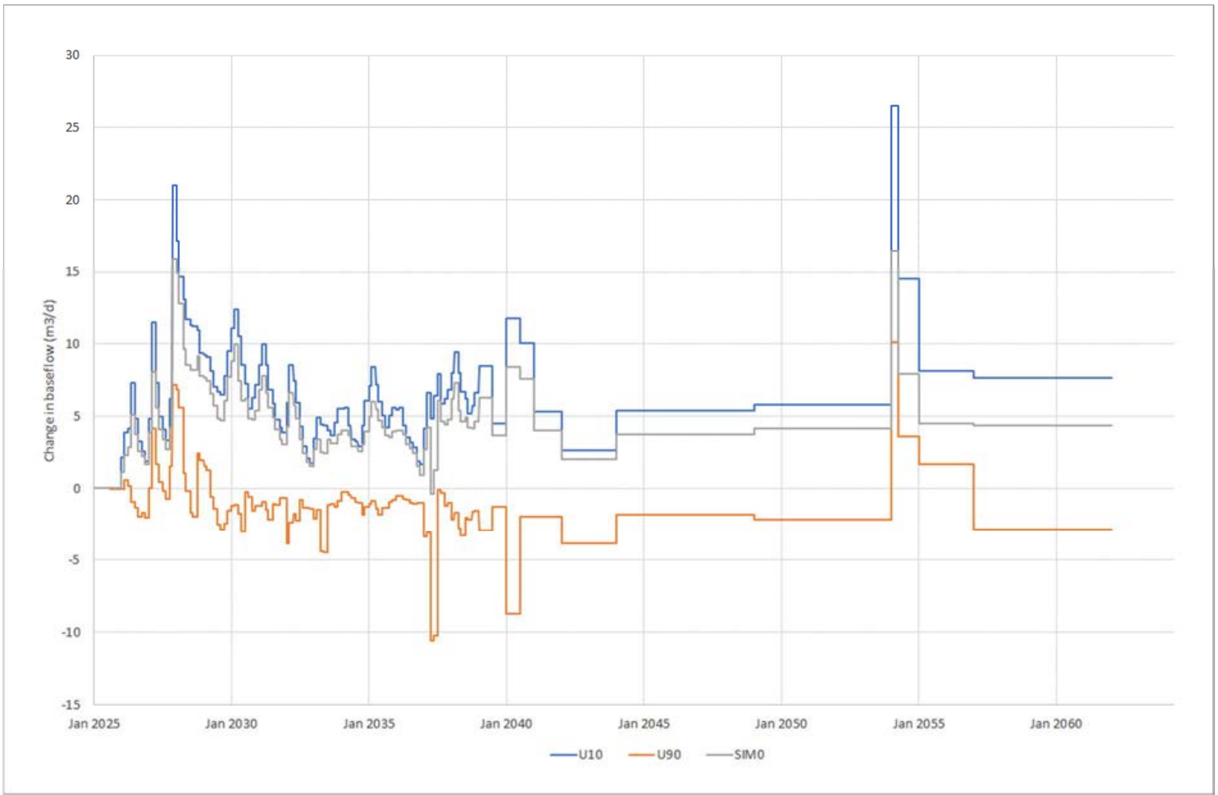

Figure 5.22: Predicted Baseflow Impacts – Crocodile Swamp

5.4.6.4 Wolgan River and Carne Creek

The maximum predicted baseflow losses for the Wolgan River during mining are 274 kL/day for SIM0 and 670 kL/day for the 90th percentile. Baseflow losses decrease post mining to 141 kL/day for SIM0 and 296 kL/day for the 90th percentile.

The maximum predicted reduction is in February 2030 and coincides with the completion of LW1006. For subsequent longwalls the Wolgan River steps further away from the mining area.

The maximum predicted baseflow losses for Carne Creek during mining are 65 kL/day for SIM0 and 366 kL/day for the 90th percentile. Baseflow losses increase post mining to 290 kL/day for SIM0 and 605 kL/day for the 90th percentile.

The increase post mining, compared to the Wolgan River, which shows reduced impacts post mining, is due to the mine being located up dip from Carne Creek. The depressurisation of the formations and the reduced through flow and seepage to Carne Creek will be a long-term impact.

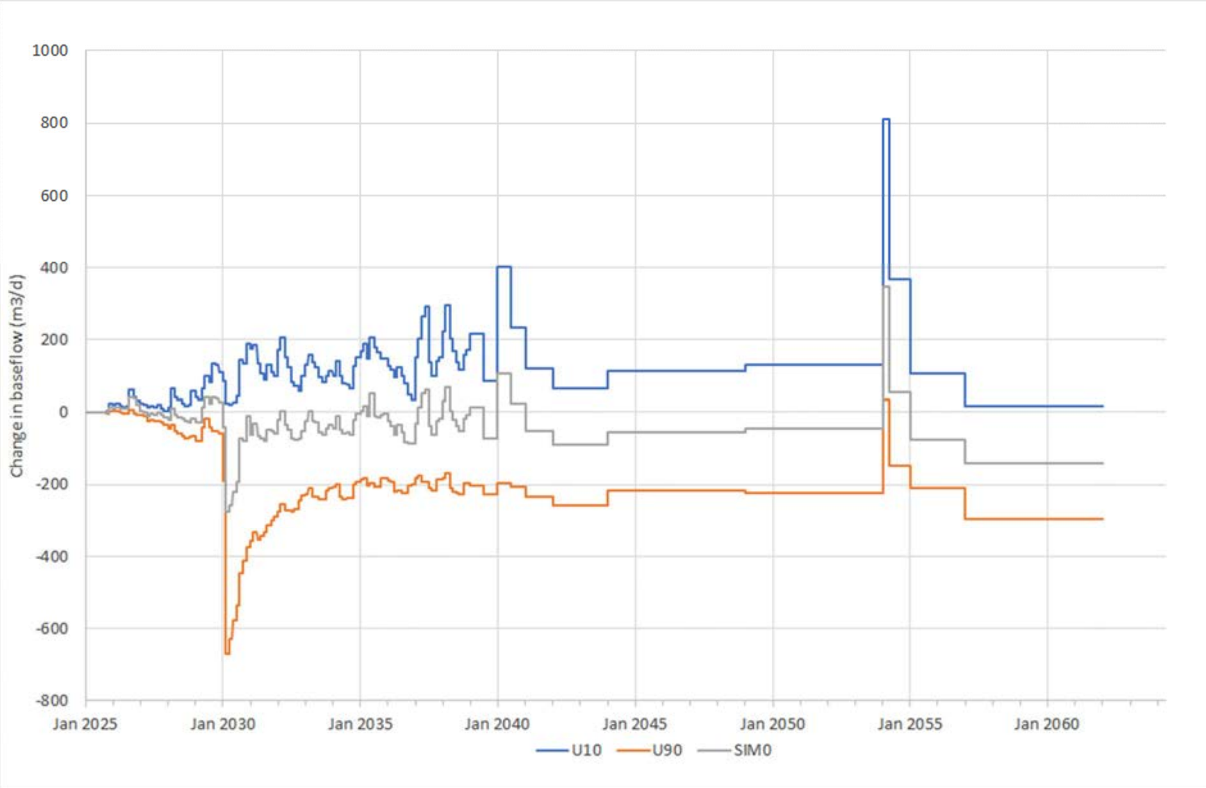

Figure 5.23: Predicted Baseflow Impacts – Wolgan River (above Carne Creek confluence)

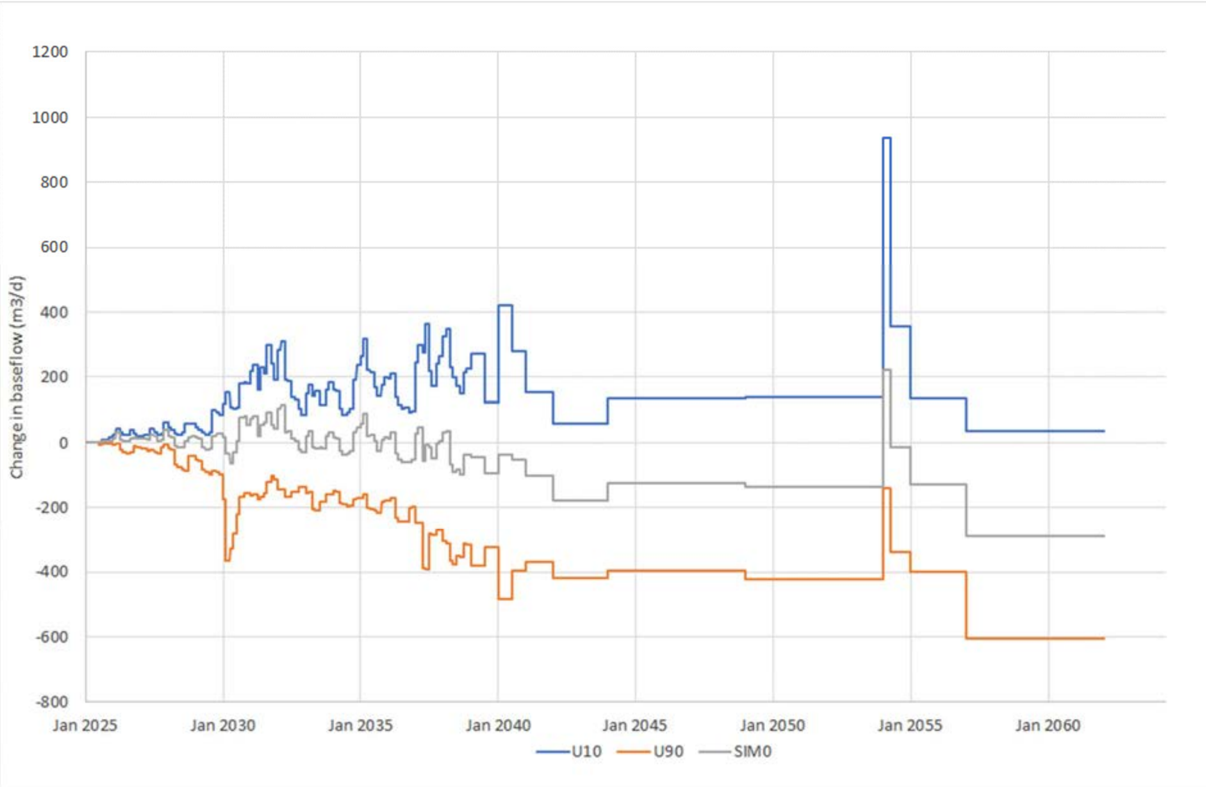

Figure 5.24: Predicted Baseflow Impacts – Carne Creek (above Wolgan River confluence)

5.4.7 Climate Change Scenarios

For the climate change simulations, the NARCliM dataset was utilised to obtain a 'Lowest Cumulative Rainfall, Higher Cumulative Evapotranspiration' scenario as well as a 'Highest Cumulative Rainfall, Lower Cumulative Evapotranspiration' scenario (JBS&G, 2019 and Appendix G). The median rainfall and evapotranspiration datasets used in the predicted scenarios, were updated with a High Rainfall and Low Rainfall version in place of the median version.

Detailed discussion of climate change scenarios with respect to water level drawdown and reduction in surface flows (groundwater contribution to baseflow) are provided in the Hydrogeological Model Report.

The climate change analysis, based on the NARCliM dataset, indicates that model results are consistent in both a High Rainfall and Low Rainfall environment with that simulated for median rainfall conditions. That is to say, the model results are relatively insensitive to climate change, as the bulk of the mine inflows are derived from storage, with only minor contribution from recharge.

5.4.8 Cumulative Impact Considerations

Potential cumulative impacts in relation to the APMEP for groundwater have been assessed in the Hydrogeological Model (JBS&G, 2019a and Appendix G) as follows:

- A Proposed Case, based on the APMEP and extension of existing mining operations at Angus Place Colliery into the 1000 Panel Area, also includes maintaining Springvale Mine in a dewatered state through to 2053.
- A Null Case, based on cessation of mining at Angus Place Colliery, and the existing and approved operations at Springvale at the end of 2029.
- Potential influences from Clarence Colliery are also included.

The adopted approach considers the potential changes to groundwater contribution to surface water and exchange between groundwater sources due to surrounding existing and approved operations before assessing the proposed changes due to the extension of mining at Angus Place Colliery into the 1000 Panel Area. The adopted approach assumes all changes to groundwater contribution to surface water and exchange between groundwater sources are due to the Amended Project, inclusive of changes associated with the extension of duration of dewatering at Springvale Mine.

5.5 Mine Closure

It is proposed that dewatering pumps will be kept running at Angus Place and Springvale Mine after the completion of mining to deliver water to the Springvale Water Treatment Project. The pumps will be switched off at the end of 2053.

CSIRO (2017) undertook an assessment of potential mine void recovery and seepage from sealed portals at Springvale (898.6mAHD), Angus Place (912.3mAHD), and the connected and abandoned Newcom Colliery (900.2mAHD). Key findings were as follows:

- Groundwater potential (as heads of water above the portal elevations) were assessed at 100m head from Springvale and 60m head for Angus Place. The assessment assumed no interconnection between the Springvale and Angus Place workings.
- Following the cessation of pumping, void water pressures would rapidly rise to 50m of head within 5 to 10 years at Springvale, and then slowly rise to a maximum of 100m over the following 100 years.
- At Angus Place a portal seal would experience positive pressure from groundwater 12 years after pumping has ceased. The pressure would rise to 40m after 40 years and then slowly rise to 60m over the following 200 years.
- The seepage at the sealed portals at the maximum potential heads was estimated at 0.3 ML/day for Angus Place and 0.5 ML/day for Springvale.

A detailed investigation and mine closure plan will be prepared within 5 years of the end of extraction at Angus Place as is required under standard conditions of consent.

5.6 Groundwater Quality

Groundwater monitoring at Angus Place and Springvale Mine has not identified any water quality impacts to groundwater as a result of mining and accordingly, no future impacts to groundwater are anticipated during operation.

Following mine closure, there is potential for groundwater seepage to develop in the vicinity of the sealed portals. Water quality will notionally be commensurate with current mine inflows as summarised on Table 4.6. There is also potential for a component of acid generation within the mine voids and contributing overlying unsaturated formations. The potential for this will be assessed and managed at the mine closure planning stage.

5.7 Response to IESC Comments

Responses to IESC comments in relation to the Angus Place Extension Project EIS are provide as follows.

IESC01) Requirement to characterise existing surface water, groundwater and ecological conditions for the majority of Temperate Highland Peat Swamps on Sandstone (THPSS).

> Since the time of Angus Place Mine Extension Project, significant additional investigation has been undertaken on the THPSS at both Angus Place Colliery and Springvale Mine.
>
> Groundwater monitoring data, including soil moisture, at Tri-Star, Twin Gully and Trail Six Swamps is presented in this report. Surface water flow data is presented in the Surface Water Impact Assessment (Jacobs, 2019) and the Swamp Water Balance Model report (JBS&G, 2019).
>
> Ecological assessment is presented in the Ecological Impact Assessment.

IESC02) Seasonal surface water flow and an assessment, or estimation, of the baseflow component of the Coxs River.

> Quarterly stress periods have been adopted in the groundwater model to incorporate seasonal variation. As presented in the Hydrogeological Model Report (JBS&G, 2019a), historical climate data was used during the calibration period and NARCliM based climate data was used for the prediction period.
>
> Modelled contribution of groundwater to surface water flow was implemented in the groundwater model through inclusion of all surface watercourses and seepage fluxes where particular layers terminate as an outcrop in cliffsides.
>
> The relative change to contribution of groundwater to surface water flow was then assessed using the Swamp Water Balance Model and is presented in the Surface water Impact Assessment (Jacobs, 2019).

IESC03) Inclusion of all swamps in the groundwater model.

> As presented in the Hydrogeological Model Report (JBS&G, 2019 and Appendix G), all THPSS swamps in the vicinity of the mining area have been included in the groundwater model.

IESC04) Finer scaled, site specific models, informed by a conceptualisation of the hydrology and hydrogeology, would be needed to have confidence in the predictions of groundwater impacts to individual swamps.

> Site specific groundwater models were investigated during development of the Swamp Water Balance Model. It was found, however, that a regional groundwater model was necessary due to the scale of changes due to mining. Accordingly, finer scale modelling was achieved through the Swamp Water Balance Model, which received output from the regional groundwater model.
>
> Further detail is presented in the Swamp Water Balance Model report (JBS&G, 2019b), which is appended to the Surface Water Impact Assessment.

IESC05) Water quality impact estimations for the Coxs River need to consider the increased discharge volumes to Coxs River resulting from reduced demand from the Wallerawang Power Station.

This aspect was addressed at the time through the Regional Water Quality Impact Assessment Model (RWQIAM). In any regard, in accordance with Angus Place Colliery Modification 5 (JBS&G, 2018), Angus Place Mine Extension Project: Amended Project will become a nil discharge site, with respect to raw or treated mine water, from 1 January 2020.

IESC06) Confidence in groundwater model predictions is limited by a lack of site-specific hydrogeological data and lineament groundwater flow behaviour.

Site-specific hydrogeological data from Springvale Mine and Angus Place Colliery is available and comprises water level and pressure responses at multiple locations. Centennial has conducted a number of investigations into the interaction of the major geological lineaments with groundwater and THPSS (Centennial Coal, 2017 and 2018). That data is presented in Section 4.5.

The updated groundwater model considers the role of lineaments through heterogeneity informed by the use of Pilot Points. As noted above, in an earlier version of the groundwater model, representation of lineaments using hydraulic values that were piece-wise constant was not successful. Adoption of a Pilot Point methodology, where heterogeneity was incorporated, was found to be necessary to achieve model calibration. This is confirmed by parameter sensitivity analysis (identifiability) which indicates that horizontal and vertical distribution of parameter values was important. i.e. there were particular layers at certain locations where Pilot Points were sensitive, not all layers.

With respect to hydraulic data, the entire groundwater monitoring network at Springvale Mine, Angus Place Colliery and at Clarence Colliery is included in the groundwater model. Overall, a good fit to observed groundwater elevation and water table levels was achieved, especially with respect to, now observed, impacts to THPSS such as at Gang Gang Swamp at Springvale Mine. Accordingly, the updated model provides an improved prediction compared to the COSFLOW model.

Lastly, the fit to observed mine dewatering rates is also considered to be good. Because of the duration of mining at Angus Place Colliery, since 1979, considerable confidence can be placed on observed dewatering rates insofar as long-term experience.

Predictive uncertainty analysis, incorporating the stochastic methodology identified in the Explanatory Note prepared by the IESC (2018b), has also been successfully deployed in the updated groundwater model.

5.8 Neutral or Beneficial Impact

During mining the Project will meet the requirements of the State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011 for neutral or beneficial effect on water quality for a continuing development.

From 2020, Angus Place will cease discharge of mine water (raw or treated) to the Coxs River catchment. From 2020 all mine inflows from existing workings will be transferred to the Springvale Water Treatment Project for desalination and beneficial reuse at the Mount Piper Power Station.

Following mine closure and cessation of pumping in 2053, potential seepages resulting from mine void water level recovery may not meet the requirement for a neutral or beneficial effect on water quality. A detailed assessment of potential seepage volumes, water quality and mitigation and management measures will be undertaken at the mine closure planning stage.

5.9 AIP Minimal Impact Considerations

The AIP minimal impact considerations for highly productive porous rock aquifers are outlined in Section 2.2.1.2. Table 5.7 presents a summary of the AIP Minimal Impact Considerations. A detailed assessment against the AIP minimal impacts considerations, along with a completed AIP framework checklist, is provided in Appendix H.

In general, with the exception of predicted water table declines at THPSS, the APMEP would meet with the Level 1 Minimal Impact Considerations for highly productive, porous rock aquifers.

Table 5.7: AIP Minimal Impact Considerations

Level 1 Minimal Impact Consideration	Assessment
Water table - Level 1 Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 metres from any: high priority groundwater dependent ecosystem or high priority culturally significant site listed in the schedule of the relevant water sharing plan. OR A maximum of a 2m water table decline cumulatively at any water supply work.	Level 1 – does not meet. Water level decline greater than a 10% cumulative variation in the water table is predicted at THPSS, a high priority groundwater dependent ecosystem. No significant water table declines are anticipated at any water supply works.
Water table - Level 2 If more than 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m from any: (a) high priority GDE; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan then appropriate studies (including the hydrogeology, ecological condition and cultural function) will be required to demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or culturally significant site. If more than 2m decline cumulatively at any water supply work, then make good provisions should apply.	The predicted water level decline (Section 5.4.2.1) is based on the current understanding of the groundwater systems supporting THPSS and the replication of subsidence impacts in the hydrogeological model. If the predicted water level declines eventuate and have a detrimental impact on swamp health and ecosystem functionality, Centennial Angus Place intend to offset those impacts through the use of the environmental offset facility of the EPBC Act. An assessment of potential offsetting liabilities is provided in the Biodiversity Assessment RPS (2019).
Water pressure - Level 1 A cumulative pressure head decline of not more than a 2m decline, at any water supply work.	Level 1 – acceptable. No significant pressure declines are anticipated at any water supply works.
Water quality - Level 1 Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.	Level 1 – acceptable. No detrimental change in water quality is anticipated.

6. Water Access Licence Requirements

This section summarises the groundwater water access licencing requirements only. Surface water access licence requirements due to incident take of surface water via reduction in baseflow are discussed in the Surface Water Impact Assessment (Jacobs, 2019).

Groundwater sources relevant to the Project are discussed in Section 2.2.1.1 and presented on Figure 2.1.

The approach adopted to determining groundwater licensable take, as presented in the Hydrogeological Model Report (JBS&G, 2019 and Appendix G), was to correlate the stacked drain with the water source in which they were mapped as well as the change to exchange between groundwater sources. The calculated licensable take from the Stacked Drain cells was then balanced to account for predicted in change in baseflow to surface water. That is, any predicted baseflow reduction, that would require a surface water access licence, was deducted from the total groundwater take from the underlying groundwater source, such that the total licensable take associated with mine dewatering matched with the total predicted inflows.

As presented in JBS&G (2019b), during calibration of the SAPSWBM a factor of 20% was applied to outflow from the groundwater model to surface water, in order to fit manual gauging observations in Twin Gully and Tri-Star Swamps. The balance of seepage is assumed to be taken up as soil moisture and lost to evapotranspiration, or directly evaporated at the seepage face. Accordingly, that 20% whole-of-model calibration factor was also used during calculation of the licensing requirement with respect to surface water contribution.

Although Springvale Mine is also being largely maintained in a dewatered state through to December 2053, for the sake of simplicity, all changes to surface water, as relevant, and changes to the exchange between groundwater sources are attributed to the Amended Project for licensing purposes.

The calculated water access licence requirements presented on Table 6.1 are from model runs undertaken using the calibrated parameters (SIM0) and have been apportioned per licencing water year (July through to June).

Groundwater take from the Sydney Basin Coxs River Groundwater Source, increases rapidly to 1,099 ML in 2030/2031 and then remains relatively stable through to the completion of mining 2039/2040. Groundwater take then declines during the post mining period.

Groundwater take from the Sydney Basin Richmond Groundwater Source, is relatively consistent throughout mining with a maximum of 6,761 ML in 2037/2038. Groundwater take then declines through the post mining period.

Table 6.1: Licensable Take (Groundwater): Angus Place Colliery including 1000 Panel Area (ML/year)

Water Year	Sydney Basin Coxs River Groundwater Source	Sydney Basin Richmond Groundwater Source
Mining		
2025/2026	0	5614
2026/2027	0	5525
2027/2028	0	4684
2028/2029	0	4576
2029/2030	357	5089
2030/2031	1099	6068
2031/2032	1096	5964
2032/2033	1056	5545
2033/2034	1043	5442

Water Year	Sydney Basin Coxs River Groundwater Source	Sydney Basin Richmond Groundwater Source
2034/2035	1031	5538
2035/2036	1025	5758
2036/2037	998	6068
2037/2038	1016	6761
2038/2039	1022	6523
Post Mining		
2039/2040	1045	6378
2040/2041	1034	6148
2041/2042	932	5414
2042/2043	932	5414
2043/2044	905	5175
2044/2045	905	5175
2045/2046	905	5175
2046/2047	905	5175
2047/2048	905	5175
2048/2049	905	5175
2049/2050	888	4724
2050/2051	888	4724
2051/2052	888	4724
2052/2053	888	4724
2053/2054	681	2424

It is noted that Centennial Coal currently holds water access licences over Angus Place Colliery, Springvale Mine and Clarence Colliery to the sum of 9,481 ML/yr in the Sydney Basin Coxs River groundwater source, and 15,139 ML/yr in the Sydney Basin Richmond groundwater source. Management of water access licencing requirements is discussed in the main body of the EIS.

6.1 Water Access Rules

Water sharing plans outline rules for managing water access licences and water supply works. Rules for the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 for groundwater are presented in Table 6.2.

Table 6.2: Project Compliance with Water Access Licence and Water Supply Works Approvals Rules

Rule	Compliant	Comments
Part 8 - Rules for managing access licences		
Part 8 – Division 1 Water allocation account management rules	Yes	Water Access Licences are already held, with sufficient entitlement, to account for predicted groundwater take in any one water year.
Part 8 – Division 2 Daily access rules	N/A	Water supply works are more than 40m from the top of a high bank of a river. As per 36(1) daily access rules do not apply to an aquifer interference activity since that activity cannot 'Cease to Pump'
Part 9 - Rules for water supply work approvals		

Rule	Compliant	Comments
Part 9 – 39 Distance restrictions to minimise interference between water supply works	Yes	Water supply works are: • more than 400m from another work (other access licence) • more than 100m from another work (basic landholder rights) • more than 50m from the property boundary • more than 1000m from another work (local water or major utility access licence) • more than 200m from a Department monitoring piezometer
Part 9 – 40 Rules for water supply works located near contamination sources	N/A	There are no contamination sources in the vicinity of the Project.
Part 9 – 41 Rules for water supply works located near sensitive environmental areas	No	Due to predicted groundwater drawdown at THPSS, it is noted that the Project may not meet the requirement that water supply works are: • at a distance specified by the Minister that is more than 200 metres from a high priority groundwater dependent ecosystem listed in clause 1 of Schedule 4, excluding a water supply work solely for basic landholder rights, if the Minister is satisfied that the water supply work is likely to cause drawdown at the perimeter of that groundwater dependent ecosystem. It is proposed that potential impacts to THPSS be managed via environmental offsets under the EPBC Act (refer to the Biodiversity Assessment, (RPS, 2019) for further detail).
Part 9 – 42 Rules for water supply works located near groundwater dependent culturally significant sites	N/A	There are no groundwater dependent culturally significant sites within the vicinity of the Project.
Part 9 – 44 Rules for water supply works located within distance restrictions	N/A	Not applicable since compliant with Part 9 – Clause 39.

7. Monitoring and Management

7.1 Operational Monitoring

Groundwater monitoring for the APMEP will continue to utilise the existing groundwater and swamp monitoring network. The monitoring network and approach will be similar to that adopted for the current Springvale Mine, developed in consultation with the Springvale Mine Independent Monitoring Panel.

Notionally this would require the following additional monitoring:

- Additional swamp piezometers and soil moisture probes at Trail Six/Japan Swamp, Birds Rock Swamp and Crocodile Swamp;
- The installation of shallow aquifer monitoring bores at Tri Star, Twin Gully, Trail Six, Birds Rock and Crocodile Swamps; and
- The establishment of a flow and water quality monitoring sites at the bottom end of Trail Six/Japan Swamp, Birds Rock Swamp and Crocodile Swamp.

The existing network of ridge piezometers and VWP at Angus Place is considered suitable for the monitoring of potential impacts. Additional monitoring may be installed to collect data required for operational purposes.

Centennial Angus Place will review the status and use of water supply works that are within the area of predicted groundwater drawdown. Where a potential risk to a water supply work is identified then monitoring at the water supply work will be considered.

7.2 Mine Water Management

Mine inflows may be managed underground as required to address short term spikes in inflow, or for routine or emergency maintenance of dewatering infrastructure. The planned dewatering of the 700 and 800 panel areas is also considered a mine water management issue and will not have any material impact itself outside of daily mine water management. Water from various parts of the mine will be managed and blended such that the water quality meets the contractual requirements of the Springvale Water Treatment Project.

7.3 Development of Mine Closure Plans

A detailed mine closure plan will be developed and submitted for approval within five years prior to the completion of mining. Notionally, closure will include the placing of seals at all mine access ways, and internally within the mine workings, such that flow paths between Springvale Mine, Angus Place and the older Newcom workings are isolated.

Preliminary assessment undertaken by CSIRO (2017) indicates that heads within the workings are likely to recover to approximately 60 to 100m above the mine portal entries (lowest at 898mAHD) within 150 years of closure.

CSIRO (2017) predicted that with seals in place at the portals, leakage of up to 0.3 ML/day for Angus Place and 0.5 ML/day for Springvale Mine was likely to occur. If this were the case, then permanent management and treatment would likely be required. Such treatment might include limestone beds for buffering of the seepage discharge and wetlands for management of discharge waters. Wetlands can provide conditions which favour microbial and chemical reducing processes, as well as an environment for adsorption, ion exchange and sedimentation.

Volumes of potential seepage and its management will be refined and discussed in the detailed mine closure plan.

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Appendix A. Details of Groundwater Works

Appendix B. High Priority GDEs

Appendix C. Monitoring Hydrographs

Appendix D. Soil Moisture Plots

Appendix E. Swamp Piezometer Water Quality Plots

Appendix F. Comprehensive Water Quality

Appendix G. Hydrogeological Model Report

Appendix H. AIP Checklist

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW003756	Bore	Water Supply	Unknown	776106	6305690	55	1/12/1940	55
GW011892	Well	Water Supply	Unknown	232547	6296343	56		5
GW030862	Bore	Commercial and Industrial	Unknown	232011	6305425	56	1/07/1981	146
GW030898	Bore	Commercial and Industrial	Supply Obtained	227255	6310750	56	1/09/1981	232
GW032030	Bore	Irrigation	Unknown	775537	6305706	55	1/04/1969	4
GW039443	Bore	Irrigation	Inclined Hole	231952	6297313	56	1/02/1990	70
GW042618	Bore	Commercial and Industrial	Unknown	240827	6297987	56	1/02/1975	29
GW045638	Bore	Water Supply	Supply Obtained	221353	6311600	56		61
GW045944	Bore open thru rock	Water Supply	Unknown	222830	6296223	56	1/05/1977	78
GW047359	Bore open thru rock	Water Supply	Supply Obtained	775726	6295062	55	1/05/1979	61
GW047572	Bore open thru rock	Irrigation	Unknown	778887	6301601	55	1/03/1980	29
GW047706	Bore open thru rock	Irrigation	Unknown	777764	6301233	55	1/11/1980	23
GW049109	Bore open thru rock	Water Supply	Unknown	778004	6295181	55	1/11/1977	34
GW050247	Bore open thru rock	Water Supply	Unknown	777853	6301631	55	1/02/1980	31
GW050996	Bore open thru rock	Water Supply	Unknown	230232	6299640	56	1/02/1980	46
GW052328	Bore open thru rock	Water Supply	Unknown	776385	6303678	55	1/02/1981	38
GW053046	Bore	Commercial and Industrial	Unknown	229846	6306999	56		59
GW053071	Bore open thru rock	Irrigation	Unknown	227433	6300764	56	1/12/1980	15
GW053081	Bore	Irrigation	Unknown	232055	6295435	56	1/12/1980	19
GW053401	Bore open thru rock	Irrigation	Unknown	778055	6302365	55	1/11/1980	26
GW053598	Excavation	Commercial and Industrial	Unknown	777016	6305818	55	1/06/1981	60
GW053719	Other	Commercial and Industrial	Unknown	228233	6306368	56		60
GW053868	Bore open thru rock	Irrigation	Unknown	777781	6300924	55	1/05/1982	28
GW053949	Bore	Irrigation	Unknown	223094	6319575	56	1/06/1982	24
GW054003	Bore	Irrigation	Supply Obtained	222756	6317808	56	1/04/1981	91

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW054781	Bore	Water Supply	Unknown	232468	6296402	56	1/11/1980	38
GW054873	Bore	Water Supply	Unknown	220800	6306526	56	1/05/1981	46
GW054874	Bore open thru rock	Water Supply	Unknown	220863	6307053	56	1/05/1981	30
GW055053	Bore open thru rock	Water Supply	Unknown	232063	6295158	56	1/07/1981	15
GW055055	Bore open thru rock	Water Supply	Unknown	232064	6296052	56	1/04/1981	21
GW055392	Bore open thru rock	Water Supply	Unknown	774828	6299867	55	1/07/1981	53
GW056349	Bore	Water Supply	Unknown	777146	6304951	55	1/09/1981	37
GW057365	Bore open thru rock	Water Supply	Unknown	232726	6296410	56	1/03/1983	31
GW057376	Bore	Water Supply	Unknown	775788	6297249	55	1/02/1983	37
GW057380	Bore open thru rock	Water Supply	Unknown	225236	6298882	56	1/03/1983	43
GW057387	Bore open thru rock	Unknown	Unknown	776577	6304967	55	1/03/1983	46
GW057399	Bore open thru rock	Water Supply	Unknown	231850	6296324	56	1/03/1983	18
GW057649	Bore	Water Supply	Unknown	225902	6299117	56	1/02/1983	24
GW057658	Bore open thru rock	Water Supply	Unknown	778116	6299958	55	1/02/1983	31
GW058108	Bore open thru rock	Water Supply	Unknown	232570	6296467	56	1/03/1983	31
GW058320	Bore	Unknown	Unknown	779149	6307114	55	1/01/1980	33
GW058554	Bore open thru rock	Water Supply	Unknown	232465	6296526	56	1/09/1982	34
GW058576	Bore	Water Supply	Unknown	225778	6298928	56	1/02/1983	46
GW059086	Bore open thru rock	Water Supply	Supply Obtained	221041	6299965	56	1/08/1980	75
GW059350	Bore	Commercial and Industrial	Unknown	226640	6314217	56	1/02/1983	24
GW059358	Bore	Commercial and Industrial	Unknown	227236	6313278	56	1/02/1983	24
GW059705	Bore	Water Supply	Unknown	220411	6320053	56	1/04/1983	34
GW060112	Bore	Other	Unknown	232058	6294418	56	1/02/1983	31
GW060113	Bore	Other	Unknown	231462	6294463	56	1/02/1983	46
GW060428	Bore open thru rock	Irrigation	Supply Obtained	231162	6296890	56	1/01/1983	15

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW062283	Bore	Commercial and Industrial	Unknown	225466	6314523	56	1/07/1986	60
GW062284	Bore	Commercial and Industrial	Unknown	227140	6313954	56	1/08/1986	90
GW062285	Bore	Commercial and Industrial	Unknown	225888	6315183	56	1/03/1987	92
GW062815	Bore	Water Supply	Unknown	228910	6302103	56	1/11/1983	57
GW064530	Bore	Water Supply	Unknown	224148	6316244	56	1/11/1987	85
GW064531	Bore	Water Supply	Unknown	224820	6316294	56	1/11/1987	49
GW064610	Bore	Water Supply	Unknown	224741	6317247	56	1/11/1987	36
GW064611	Bore	Water Supply	Unknown	224316	6317605	56	1/11/1987	24
GW067586	Bore open thru rock	Water Supply	Unknown	778248	6299386	55	24/01/1989	49
GW067999	Bore open thru rock	Water Supply	Unknown	221253	6300518	56	26/03/1990	53
GW068458	Bore	Water Supply	Unknown	221242	6300530	56	26/03/1990	53
GW072713	Bore	Water Supply	Supply Obtained	228517	6302706	56	26/05/1994	19
GW072919	Bore	Commercial and Industrial	Supply Obtained	238298	6293737	56	24/09/1995	40
GW075089	Bore - Nested (2)	Monitoring	Instrumented	273841	6266651	56	9/10/2008	-
GW075090	Bore - Nested (2)	Monitoring	Instrumented	276031	6269763	56	17/07/2008	-
GW075091	Bore	Monitoring	Instrumented	253584.8	6299982	56	19/07/2008	145
GW075092	Bore - Nested (3)	Monitoring	Instrumented	280437	6262211	56	27/07/2008	-
GW075093	Bore - Nested (4)	Monitoring	Instrumented	279357	6262372	56	19/08/2008	-
GW075095	Bore - Nested (3)	Monitoring	Instrumented	274524	6269003	56	25/09/2008	-
GW075096	Bore - Nested (2)	Monitoring	Instrumented	277872	6271220	56	18/10/2008	-
GW100514	Bore	Water Supply	Unknown	221229	6300410	56	1/01/1982	33
GW100625	Bore	Monitoring	Equipped	236219	6297110	56	29/01/1996	4
GW100626	Bore	Monitoring	Equipped	236218	6297111	56	29/01/1996	12
GW100627	Bore	Monitoring	Equipped	236219	6297110	56	29/01/1996	6
GW100628	Bore	Monitoring	Equipped	236219	6297110	56	29/01/1996	6

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW100629	Bore	Monitoring	Equipped	236219	6297110	56	24/01/1996	6
GW100630	Bore	Monitoring	Equipped	236219	6297110	56	25/01/1996	21
GW100631	Bore	Monitoring	Equipped	236219	6297110	56	24/01/1996	11
GW100632	Bore	Monitoring	Equipped	236219	6297110	56	1/02/1996	11
GW100633	Bore	Monitoring	Unknown	236219	6297110	56	23/01/1996	9
GW100634	Bore	Monitoring	Equipped	236219	6297110	56	24/01/1996	14
GW100635	Bore	Monitoring	Equipped	236219	6297110	56	31/01/1996	16
GW100636	Bore	Monitoring	Equipped	236219	6297110	56	29/01/1996	11
GW100637	Bore	Monitoring	Equipped	236219	6297110	56	19/01/1996	12
GW100638	Bore	Monitoring	Equipped	236219	6297110	56	29/01/1996	6
GW100639	Bore	Monitoring	Equipped	236219	6297110	56	24/01/1996	11
GW100718	Bore	Water Supply	Supply Obtained	236219	6297110	56	29/09/1995	15
GW100967	Bore	Water Supply	Supply Obtained	232631	6294137	56	12/08/1995	50
GW101117	Bore	Water Supply	Supply Obtained	231432	6324186	56	29/10/1996	26
GW101292	Bore	Monitoring	Equipped	233679	6294346	56	18/01/1996	8
GW101293	Bore	Monitoring	Equipped	233679	6294347	56	18/01/1996	6
GW101294	Bore	Monitoring	Equipped	233679	6294347	56	19/01/1996	4
GW101295	Bore	Monitoring	Equipped	233679	6294347	56	19/01/1996	12
GW101296	Bore	Monitoring	Equipped	233679	6294347	56	31/01/1996	23
GW101297	Bore	Monitoring	Equipped	233679	6294347	56	19/01/1996	6
GW101298	Bore	Monitoring	Equipped	233678	6294347	56	22/01/1996	9
GW101299	Bore	Monitoring	Equipped	233679	6294347	56	22/01/1996	4
GW101300	Bore	Monitoring	Equipped	233679	6294346	56	1/02/1996	12
GW101301	Bore	Monitoring	Equipped	233679	6294347	56	23/01/1996	8
GW101302	Bore	Monitoring	Equipped	233679	6294347	56	23/01/1996	9

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW101303	Bore	Monitoring	Equipped	233679	6294347	56	24/01/1996	12
GW101304	Bore	Monitoring	Equipped	233679	6294347	56	19/01/1996	18
GW101305	Bore	Monitoring	Equipped	233679	6294347	56	19/01/1996	15
GW101340	Bore	Monitoring	Equipped	225045	6305599	56	5/09/1996	27
GW101341	Bore	Monitoring	Equipped	224965	6305690	56	5/09/1996	31
GW101342	Bore	Monitoring	Equipped	224586	6305370	56	5/09/1996	29
GW101413	Bore	Water Supply	Supply Obtained	779031	6303157	55	9/01/1998	36
GW101461	Bore	Water Supply	Supply Obtained	228708	6301416	56	8/01/1998	45
GW101752	Bore	Water Supply	Unknown	776893	6304283	55	11/08/1995	53
GW101844	Bore	Water Supply	Unknown	221039	6300127	56	17/06/1983	50
GW101941	Bore	Water Supply	Unknown	232367	6313495	56	14/08/1998	57
GW101985	Bore	Water Supply	Unknown	242017	6296555	56	20/03/1998	30
GW102079	Bore	Water Supply	Unknown	223093	6299654	56	27/01/1999	43
GW102175	Bore	Water Supply	Supply Obtained	223183	6298330	56	10/12/1998	40
GW102225	Bore	Water Supply	Filled	221174	6300328	56	1/02/1991	53
GW102254	Bore	Water Supply	Supply Obtained	221344	6300719	56	1/09/1994	38
GW102327	Bore	Water Supply	Unknown	776376	6303339	55		33
GW102426	Bore	Water Supply	Unknown	231546	6299830	56	14/08/1995	70
GW102427	Bore	Water Supply	Unknown	231521	6299799	56	14/08/1995	68
GW102428	Bore	Water Supply	Unknown	232196	6294113	56	7/01/1992	38
GW102728	Bore	Monitoring	Unknown	244489	6294416	56	28/11/1998	157
GW103032	Bore	Irrigation	Unknown	778347	6301555	55	1/01/1994	58
GW103223	Bore	Commercial and Industrial	Unknown	238309	6293689	56	1890-01-01	11
GW103224	Bore	Commercial and Industrial	Unknown	238275	6293739	56	1890-01-01	8
GW103238	Bore	Water Supply	Unknown	231463	6299287	56	14/08/1995	68

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW104907	Bore	Water Supply	Supply Obtained	233561	6313829	56	1/10/2002	48
GW104958	Bore	Water Supply	Supply Obtained	231259	6314331	56	26/09/2002	56
GW105064	Bore	Commercial and Industrial	Supply Obtained	230354	6307751	56	11/07/2002	104
GW105235	Bore	Water Supply	Supply Obtained	224097	6299210	56	9/02/2003	72
GW105294	Bore	Water Supply	Supply Obtained	230337	6307812	56	1/02/2003	16
GW105295	Bore	Water Supply	Supply Obtained	230239	6307855	56	2/08/2004	16
GW105389	Bore	Water Supply	Unknown	775405	6302474	55	1/05/2003	36
GW105433	Bore	Water Supply	Unknown	238303	6293826	56	1/02/2003	72
GW105434	Bore	Water Supply	Unknown	238319	6293797	56	28/10/2002	72
GW105435	Bore	Water Supply	Unknown	238313	6293762	56	21/11/2002	72
GW105734	Bore	Water Supply	Unknown	244009	6294417	56	1/01/1980	120
GW105801	Bore	Water Supply	Supply Obtained	227528	6297908	56	1/01/2003	37
GW105973	Bore	Unknown	Unknown	230354	6307815	56	24/05/2005	-
GW106243	Bore	Unknown	Unknown	229939	6307312	56	18/07/2005	-
GW106258	Bore	Water Supply	Supply Obtained	222719	6317347	56	12/05/2003	122
GW106259	Bore	Water Supply	Supply Obtained	777440	6301052	55	18/09/2002	72
GW106646	Bore	Commercial and Industrial	Unknown	243458	6294099	56	1/01/1992	30
GW106737	Bore	Water Supply	Supply Obtained	228017	6303098	56	25/11/2004	90
GW107094	Bore	Water Supply	Supply Obtained	776424	6302939	55	8/11/2004	80
GW107329	Bore	Water Supply	Supply Obtained	230020	6307335	56	5/09/2005	48
GW108185	Bore	Monitoring	Unknown	246570	6301612	56	1/08/2004	295
GW108187	Bore	Monitoring	Unknown	245529	6295853	56	4/08/2004	197
GW108320	Excavation	Water Supply	Unknown	241876	6324885	56	1/01/2004	5
GW108505	Bore	Water Supply	Supply Obtained	775647	6295689	55	3/11/2006	50
GW108613	Bore	Water Supply	Supply Obtained	788327	6307462	55	28/07/2004	53

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW108614	Bore	Water Supply	Supply Obtained	776431	6302368	55	30/07/2004	45
GW108881	Bore	Monitoring	Supply Obtained	229567	6311037	56	29/05/2008	21
GW108932	Bore	Monitoring	Unknown	229743	6312099	56	18/06/2008	18
GW108939	Bore	Monitoring	Unknown	229924	6312340	56	19/06/2008	16
GW109018	Bore	Monitoring	Unknown	229888	6311416	56	10/07/2008	12
GW109260	Piezometer	Monitoring	Equipped	231949	6301453	56	29/10/1985	9
GW109261	Piezometer	Monitoring	Equipped	229804	6301350	56	2/11/1985	18
GW109262	Piezometer	Monitoring	Equipped	230234	6301699	56	30/10/1985	17
GW109263	Piezometer	Monitoring	Equipped	230188	6302356	56	25/08/2008	6
GW109264	Piezometer	Monitoring	Equipped	229631	6302172	56	6/11/1985	14
GW109265	Piezometer	Monitoring	Equipped	229380	6301985	56	7/11/1985	15
GW109336	Bore	Water Supply	Test Hole	237342	6296563	56	11/05/2008	320
GW109337	Bore	Water Supply	Test Hole	237489	6300779	56	7/05/2008	400
GW109453	Bore	Monitoring	Test Hole	238362	6316806	56	14/09/2005	50
GW109766	Bore	Monitoring	Unknown	246343	6299274	56	15/12/2006	258
GW109767	Bore	Monitoring	Unknown	242638	6296369	56	1/05/2008	274
GW109842	Bore	Monitoring	Unknown	243605	6293746	56	14/03/2006	72
GW109843	Bore	Monitoring	Unknown	243684	6293873	56	13/03/2006	72
GW109844	Bore	Monitoring	Unknown	243657	6293784	56	14/03/2006	60
GW109845	Bore	Monitoring	Unknown	243780	6293857	56	16/03/2006	42
GW109846	Bore	Monitoring	Unknown	243859	6293798	56	16/03/2006	30
GW110157	Bore	Monitoring	Unknown	227341	6304272	56	14/10/2005	9
GW110158	Bore	Monitoring	Unknown	227594	6304231	56	14/10/2005	9
GW110159	Bore	Monitoring	Unknown	227830	6304284	56	13/10/2005	10
GW110160	Bore	Monitoring	Unknown	228222	6304736	56	15/10/2005	43

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW110161	Bore	Monitoring	Unknown	228450	6304256	56	13/10/2005	28
GW110162	Bore	Monitoring	Unknown	228445	6304252	56	13/10/2005	12
GW110188	Bore	Monitoring	Unknown	248478	6295951	56	6/04/2009	290
GW110190	Bore	Monitoring	Unknown	245407	6295092	56	23/04/2009	199
GW110329	Bore	Water Supply	Unknown	779076	6302271	55	1/01/2006	8
GW110437	Bore	Monitoring	Unknown	227895	6300507	56	9/03/2009	90
GW110480	Bore	Monitoring	Unknown	229530	6301970	56	28/07/2009	10
GW110481	Bore	Monitoring	Unknown	229166	6301607	56	28/07/2009	16
GW110482	Bore	Monitoring	Unknown	229153	6303047	56	29/07/2009	33
GW110483	Bore	Monitoring	Unknown	229149	6303043	56	29/07/2009	21
GW110484	Bore	Monitoring	Unknown	229722	6302886	56	29/07/2009	59
GW110485	Bore	Monitoring	Unknown	229732	6301996	56	17/09/2009	66
GW110520	Bore	Commercial and Industrial	Equipped	228103	6300812	56	8/05/2015	12
GW110704	Bore	Monitoring	Unknown	241550	6296993	56	3/03/2010	2
GW110705	Bore	Monitoring	Unknown	241839	6297077	56	7/12/2009	2
GW110706	Bore	Monitoring	Unknown	242424	6295520	56	7/12/2009	1
GW110707	Bore	Monitoring	Unknown	242590	6295590	56	7/12/2009	2
GW110847	Bore	Water Supply	Unknown	777262	6303431	55	1/01/2007	8
GW110850	Bore	Water Supply	Unknown	776754	6300471	55	12/02/2010	54
GW110861	Bore	Monitoring	Unknown	227055	6303562	56	19/02/2010	24
GW110934	Bore	Water Supply	Supply Obtained	232416	6311964	56	9/07/2010	50
GW110939	Bore	Monitoring	Equipped	237782	6304627	56	5/03/2010	1
GW110940	Bore	Monitoring	Equipped	237791	6304398	56	5/03/2010	1
GW110941	Bore	Monitoring	Equipped	237845	6303838	56	5/03/2010	1
GW110998	Bore	Water Supply	Supply Obtained	225718	6296702	56	6/08/2010	55

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW110999	Bore	Water Supply	Supply Obtained	225943	6297777	56	1/05/2007	55
GW111021	Collector system	Dewatering	Supply Obtained	230615	6306064	56	19/08/2010	360
GW111022	Bore	Dewatering	Supply Obtained	235892	6306623	56	19/08/2010	410
GW111023	Bore	Dewatering	Supply Obtained	236111	6304138	56	30/10/1989	420
GW111024	Bore	Dewatering	Supply Obtained	235764	6303208	56	23/08/2010	378
GW111025	Bore	Dewatering	Supply Obtained	233981	6300737	56	23/08/2010	380
GW111026	Collector system	Dewatering	Supply Obtained	231254	6300484	56	23/08/2010	400
GW111027	Bore	Monitoring	Equipped	226988	6303549	56	23/02/2004	24
GW111028	Bore	Monitoring	Equipped	226945	6303551	56	23/02/2004	24
GW111029	Bore	Monitoring	Equipped	227030	6303584	56	21/02/2010	24
GW111030	Bore	Monitoring	Equipped	227070	6303571	56	20/02/2010	24
GW111203	Bore	Monitoring	Equipped	226800	6306346	56	3/02/2010	84
GW111204	Bore	Monitoring	Equipped	228994	6308259	56	15/03/2010	16
GW111205	Bore	Monitoring	Equipped	226797	6306348	56	1/02/2010	87
GW111206	Bore	Monitoring	Equipped	227132	6306531	56	6/02/2010	39
GW111207	Bore	Monitoring	Equipped	224813	6306516	56	18/02/2010	50
GW111208	Bore	Monitoring	Equipped	228994	6308259	56	8/03/2010	105
GW111317	Bore	Monitoring	Equipped	240851	6294887	56	4/11/2010	229
GW111318	Bore	Monitoring	Equipped	240854	6294885	56	10/11/2010	140
GW111319	Bore	Monitoring	Equipped	240405	6294964	56	6/10/2010	156
GW111334	Bore	Monitoring	Test Hole	227687	6304308	56	14/02/2010	12
GW111338	Bore	Monitoring	Equipped	240546	6296228	56	26/11/2010	215
GW111339	Bore	Monitoring	Equipped	247658	6295043	56	22/09/2010	280
GW111340	Bore	Monitoring	Equipped	246519	6296234	56	9/09/2010	265
GW111358	Bore	Monitoring	Equipped	227122	6299450	56	10/02/2011	6

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW111359	Bore	Monitoring	Equipped	227111	6299452	56	10/02/2011	6
GW111360	Bore	Monitoring	Equipped	227109	6299443	56	10/02/2011	6
GW111471	Bore	Monitoring	Equipped	227094	6303739	56	23/02/2010	24
GW111472	Bore	Monitoring	Equipped	227053	6303741	56	23/02/2010	24
GW111473	Bore	Monitoring	Equipped	227298	6303561	56	23/03/2010	81
GW111535	Bore	Monitoring	Equipped	777602	6305622	55	28/07/2011	15
GW111536	Bore	Monitoring	Equipped	777679	6305661	55	28/07/2011	15
GW111537	Bore	Monitoring	Equipped	777725	6305604	55	27/07/2011	15
GW111587	Bore	Water Supply	Supply Obtained	227926	6297585	56	6/12/2011	80
GW111670	Bore	Water Supply	Supply Obtained	232246	6294107	56	14/03/2012	48
GW111746	Bore	Monitoring	Equipped	226055	6306394	56	17/01/2012	55
GW111747	Bore	Monitoring	Filled	226295	6306539	56	2/12/2011	30
GW111748	Bore	Monitoring	Filled	225986	6305823	56	1/12/2011	30
GW111749	Bore	Monitoring	Abandoned	226139	6306062	56	30/11/2011	58
GW111825	Bore	Monitoring	Equipped	225533	6306000	56	27/01/2012	20
GW111866	Bore	Monitoring	Equipped	238707	6302272	56	23/02/2009	387
GW111867	Bore	Monitoring	Equipped	237392	6304217	56	28/08/2009	422
GW111868	Bore	Monitoring	Equipped	239795	6301971	56	9/09/2009	285
GW111942	Bore	Commercial and Industrial	Supply Obtained	224475	6308667	56	31/03/2007	48
GW111944	Bore	Water Supply	Supply Obtained	234257	6318342	56	29/10/2012	131
GW111964	Bore	Monitoring	Equipped	225389	6305910	56	25/09/2012	2
GW111965	Bore	Monitoring	Equipped	225373	6305876	56	26/09/2012	5
GW111966	Bore	Monitoring	Unknown	225373	6305785	56	25/09/2012	3
GW112383	Bore	Water Supply	Supply Obtained	231996	6312171	56	11/06/2013	120
GW112392	Bore	Water Supply	Supply Obtained	226598	6299487	56	2/10/2012	33

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW112413	Bore	Monitoring	Abandoned	235521	6311605	56	13/07/2011	343
GW112419	Bore	Monitoring	Filled	239853	6308994	56	8/08/2011	445
GW112427	Bore	Monitoring	Filled	238130	6310038	56	22/08/2011	360
GW112429	Bore	Monitoring	Filled	239426	6306145	56	15/09/2011	380
GW112432	Bore	Monitoring	Filled	237064	6310960	56	8/11/2011	342
GW112442	Bore	Monitoring	Equipped	237060	6301251	56	22/07/2002	385
GW112443	Bore	Monitoring	Equipped	237791	6301016	56	25/02/2003	395
GW112444	Bore	Monitoring	Equipped	236025	6302731	56	1/12/2003	396
GW112445	Bore	Monitoring	Equipped	236874	6303862	56	31/05/2004	406
GW112446	Bore	Monitoring	Equipped	237575	6304545	56	25/06/2004	382
GW112447	Bore	Monitoring	Equipped	237573	6303655	56	29/04/2004	412
GW112448	Bore	Monitoring	Equipped	237618	6302778	56	6/07/2004	407
GW112449	Bore	Monitoring	Equipped	239357	6303496	56	3/11/2005	420
GW112450	Bore	Monitoring	Equipped	235903	6298217	56	3/02/2006	264
GW112451	Bore	Monitoring	Equipped	239074	6300367	56	3/02/2006	420
GW112452	Bore	Monitoring	Equipped	240061	6298330	56	15/12/2005	396
GW112453	Bore	Monitoring	Equipped	236846	6304550	56	6/12/2005	384
GW112454	Bore	Monitoring	Equipped	236758	6304554	56	1/01/2006	380
GW112455	Bore	Monitoring	Equipped	237217	6304198	56	1/01/2006	210
GW112457	Bore	Monitoring	Equipped	237245	6303199	56	1/01/2006	305
GW112463	Bore	Monitoring	Unknown	238292	6304150	56	1/01/2006	210
GW112464	Bore	Monitoring	Equipped	237958	6303241	56	1/01/2006	400
GW112465	Bore	Monitoring	Equipped	235781	6302690	56	22/04/2002	9
GW112466	Bore	Monitoring	Equipped	235802	6302753	56	23/04/2002	8
GW112467	Bore	Monitoring	Equipped	235850	6302735	56	23/04/2002	7

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW112468	Bore	Monitoring	Equipped	237766	6303509	56	4/05/2005	2
GW112469	Bore	Monitoring	Equipped	237783	6303571	56	4/05/2005	1
GW112470	Bore	Monitoring	Equipped	239352	6303913	56	5/05/2005	1
GW112471	Bore	Monitoring	Equipped	239382	6303247	56	5/05/2005	1
GW112526	Bore	Dewatering	Supply Obtained	244328	6294427	56	1/01/2011	118
GW112563	Bore	Dewatering	Supply Obtained	238024	6305254	56	22/08/2005	472
GW112564	Bore	Dewatering	Supply Obtained	233318	6302081	56	30/09/2001	380
GW112565	Bore	Dewatering	Supply Obtained	237956	6305229	56	26/07/2005	466
GW112566	Bore	Dewatering	Supply Obtained	238492	6304522	56	14/09/2009	470
GW112719	Bore	Monitoring	Equipped	238425	6299811	56	2/02/2009	396
GW112720	Bore	Monitoring	Equipped	238385	6300497	56	12/02/2009	375
GW112721	Bore	Monitoring	Equipped	239798	6300792	56	20/01/2009	393
GW112722	Bore	Monitoring	Equipped	240180	6299311	56	20/01/2009	396
GW112845	Bore	Monitoring	Equipped	238977	6302179	56	12/10/2011	1
GW112846	Bore	Monitoring	Equipped	239070	6302377	56	12/10/2011	1
GW112847	Bore	Monitoring	Equipped	239814	6302877	56	12/10/2004	1
GW112848	Bore	Monitoring	Equipped	240263	6303097	56	12/10/2011	1
GW112849	Bore	Monitoring	Equipped	240285	6302294	56	12/10/2011	1
GW112850	Bore	Monitoring	Equipped	241193	6302693	56	2/11/2011	1
GW112851	Bore	Monitoring	Equipped	241045	6301305	56	13/10/2011	1
GW112852	Bore	Monitoring	Equipped	240809	6300174	56	2/11/2011	1
GW112853	Bore	Monitoring	Equipped	242008	6301246	56	13/10/2011	1
GW112854	Bore	Monitoring	Equipped	238860	6299169	56	2/11/2011	1
GW112897	Bore	Monitoring	Equipped	227111	6299528	56	2/05/2011	5
GW112898	Bore	Monitoring	Equipped	227101	6299529	56	2/05/2011	5

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW112899	Bore	Monitoring	Equipped	227093	6299540	56	2/05/2011	5
GW113101	Bore	Monitoring	Test Hole	239788	6304124	56	12/06/2013	432
GW113102	Bore	Monitoring	Test Hole	239765	6304133	56	12/06/2013	432
GW113103	Bore	Monitoring	Test Hole	239801	6304137	56	12/06/2013	432
GW113104	Bore	Monitoring	Test Hole	239782	6304149	56	12/06/2013	432
GW113486	Bore	Monitoring	Equipped	233152	6304633	56	14/01/2014	2
GW113487	Bore	Monitoring	Equipped	234527	6304641	56	5/05/2005	2
GW113488	Bore	Monitoring	Equipped	234566	6304686	56	5/05/2005	3
GW113489	Bore	Monitoring	Equipped	234591	6304901	56	20/12/2005	3
GW113490	Bore	Monitoring	Equipped	235719	6304396	56	3/05/2005	3
GW113491	Bore	Monitoring	Equipped	235709	6304459	56	4/05/2005	3
GW113492	Bore	Monitoring	Equipped	236375	6304064	56	3/05/2005	3
GW113493	Bore	Monitoring	Equipped	236409	6304181	56	3/05/2005	1
GW113494	Bore	Monitoring	Equipped	234859	6305069	56	23/02/2006	2
GW114247	Bore	Monitoring	Equipped	239736	6300099	56	25/06/2012	433
GW114248	Bore	Monitoring	Equipped	239645	6300103	56	1/08/2012	426
GW114249	Bore	Monitoring	Equipped	239744	6300048	56	27/08/2012	294
GW114250	Bore	Monitoring	Equipped	239687	6300048	56	21/08/2012	130
GW114251	Bore	Monitoring	Equipped	239732	6299966	56	19/03/2014	130
GW114270	Bore	Monitoring	Equipped	238873	6305658	56	12/02/2012	343
GW114271	Bore	Monitoring	Equipped	239426	6306145	56	13/07/2011	343
GW114272	Bore	Monitoring	Equipped	239163	6307934	56	27/02/2012	445
GW114273	Bore	Monitoring	Equipped	239426	6306145	56	8/08/2011	445
GW114274	Bore	Monitoring	Equipped	239163	6307934	56	22/08/2011	360
GW114275	Bore	Monitoring	Equipped	239856	6308995	56	1/05/2012	360

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW114276	Bore	Monitoring	Equipped	236510	6309349	56	17/12/2011	380
GW114277	Bore	Monitoring	Equipped	238135	6310037	56	15/04/2011	380
GW114278	Bore	Monitoring	Equipped	240235	6310388	56	7/02/2012	390
GW114279	Bore	Monitoring	Equipped	237069	6310980	56	24/10/2011	390
GW114280	Bore	Monitoring	Equipped	237069	6310980	56	8/11/2011	342
GW114281	Bore	Monitoring	Equipped	238814	6311489	56	5/12/2011	342
GW114282	Bore	Monitoring	Equipped	235516	6311594	56	22/02/2012	110
GW114283	Bore	Monitoring	Equipped	234593	6305817	56	22/02/2012	75
GW114284	Bore	Monitoring	Equipped	232410	6304043	56	9/02/2012	110
GW114285	Bore	Monitoring	Equipped	239426	6306145	56	22/02/2012	110
GW114286	Bore	Monitoring	Equipped	232410	6304043	56	19/12/2011	50
GW114299	Bore	Monitoring	Equipped	237243	6306778	56	31/03/2010	347
GW114300	Bore	Monitoring	Equipped	237247	6306777	56	28/04/2010	40
GW114301	Bore	Monitoring	Equipped	238143	6305296	56	3/05/2010	419
GW114302	Bore	Monitoring	Equipped	237340	6307548	56	25/05/2010	405
GW114303	Bore	Monitoring	Equipped	237731	6306579	56	20/04/2010	399
GW114304	Bore	Monitoring	Equipped	237676	6307973	56	11/02/2010	423
GW114305	Bore	Monitoring	Equipped	236529	6308525	56	21/12/2009	333
GW114306	Bore	Monitoring	Equipped	237157	6308658	56	16/05/2010	51
GW114307	Bore	Monitoring	Equipped	238596	6307107	56	9/02/2010	54
GW114856	Bore	Monitoring	Equipped	243154	6300630	56	19/11/2014	335
GW114873	Bore	Water Supply	Supply Obtained	232252	6294076	56	30/04/2014	109
GW114938	Bore	Monitoring	Equipped	240377	6297412	56	8/07/2010	259
GW115010	Bore	Monitoring	Equipped	228170	6300662	56	9/05/2015	8
GW115011	Bore	Monitoring	Equipped	228131	6300744	56	13/08/2015	5

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW115052	Bore	Monitoring	Equipped	239687	6300048	56	21/08/2012	130
GW115053	Bore	Monitoring	Equipped	240236	6298926	56	31/08/2012	130
GW115054	Bore	Monitoring	Equipped	233019	6300889	56	1/08/2012	426
GW115055	Bore	Monitoring	Equipped	232764	6300969	56	27/08/2012	294
GW115075	Bore	Monitoring	Equipped	223707	6305932	56	6/06/2012	20
GW115076	Bore	Monitoring	Equipped	223773	6305842	56	4/06/2012	10
GW115077	Bore	Monitoring	Equipped	223711	6305632	56	4/06/2012	11
GW115078	Bore	Monitoring	Equipped	223531	6305476	56	6/06/2012	22
GW115079	Bore	Monitoring	Equipped	223548	6305390	56	8/06/2012	9
GW115080	Bore	Monitoring	Equipped	223464	6305392	56	8/06/2012	5
GW115081	Bore	Monitoring	Equipped	223638	6305332	56	12/06/2012	20
GW115082	Well	Monitoring	Equipped	223442	6305311	56	12/06/2012	7
GW115083	Well	Monitoring	Equipped	223596	6305250	56	12/06/2012	8
GW115084	Well	Monitoring	Equipped	223573	6305177	56	13/06/2012	10
GW115085	Well	Monitoring	Equipped	223400	6305135	56	13/06/2012	6
GW115086	Well	Monitoring	Equipped	223514	6305016	56	13/06/2012	20
GW115087	Well	Monitoring	Equipped	223400	6304924	56	14/06/2012	10
GW115088	Well	Monitoring	Equipped	223425	6304779	56	7/06/2012	4
GW115089	Well	Monitoring	Equipped	223158	6304951	56	7/06/2012	5
GW115090	Well	Monitoring	Equipped	223257	6305425	56	7/06/2012	5
GW800821	Bore	Dewatering	Unknown	229155	6318420	56	9/11/1990	117
GW800822	Bore	Dewatering	Unknown	229155	6318370	56	9/11/1990	117
GW801271	Bore	Water Supply	Supply Obtained	227176	6297536	56	8/06/2000	55
GW801436	Bore	Dewatering	Unknown	228792	6317018	56	4/02/2001	146
GW801861	Bore	Water Supply	Supply Obtained	224280	6315565	56	26/09/2002	72

Bore ID	Type	Purpose	Status	Easting	Northing	Zone	Date completed	Total depth (m)
GW802153	Bore	Water Supply	Supply Obtained	774973	6301258	55	29/07/2004	46
GW802266	Bore	Water Supply	Supply Obtained	779038	6305343	55	21/06/2004	114
GW802429	Bore	Water Supply	Supply Obtained	775813	6297683	55	2/08/2005	44
GW802816	Bore	Water Supply	Supply Obtained	776817	6304350	55	22/03/2004	40
GW802827	Bore	Water Supply	Supply Obtained	223238	6318597	56	28/02/2004	30
GW802856	Bore	Water Supply	Supply Obtained	222503	6321968	56	26/03/2004	60
GW803509	Bore	Monitoring	Filled	774193	6292763	55	3/04/2008	81
GW804298	Bore	Water Supply	Supply Obtained	774110	6308125	55	14/02/2010	37
GW804393	Bore	Commercial and Industrial	Supply Obtained	782725	6313040	55	16/05/2000	27
GW804550	Bore	Water Supply	Supply Obtained	776920	6304210	55	15/05/1989	33
GW804624	Bore	Water Supply	Supply Obtained	778710	6305445	55	29/06/1994	-
GW804731	Bore - Nested (2)	Unknown	Equipped	227508	6317408	56	26/03/2009	-
GW804732	Bore - Nested (2)	Unknown	Equipped	228562	6317684	56	31/03/2009	-
GW804733	Bore - Nested (2)	Unknown	Equipped	228853	6317684	56	4/04/2009	-
GW804772	Bore	Monitoring	Equipped	784590	6312920	55	4/12/2011	74
GW804779	Bore	Monitoring	Equipped	782584	6312510	55	8/12/2011	42
GW805211	Bore	Water Supply	Supply Obtained	228956	6297337	56	24/11/2014	-
GW805415	Bore	Water Supply	Supply Obtained	776848	6303713	55	16/09/2014	30
GW805533	Bore	Water Supply	Supply Obtained	776627	6304379	55	21/09/1994	-

Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011

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Schedule 4 High priority groundwater dependent ecosystems

Note. High priority groundwater dependent ecosystems (GDEs), including high priority cave environment GDEs and high priority karst environment GDEs, are currently under investigation and some of these may be identified during the term of this Plan. The full list of potential GDEs will be identified on the Department's GDE Register and, as a precautionary approach, will be considered in the assessment of any application for a water supply works approval within the Plan area. If verified as high priority GDEs, the Schedule will be amended to include further GDEs.

1 High priority groundwater dependent ecosystems

High priority groundwater dependent ecosystems in these groundwater sources are as specified in Table D and Table E below.

Notes.

1 The approximate location of GDEs listed in Column 1 of Table D is provided as (i) Northings and Eastings in Columns 2 and 3 of Table D, and/or (ii) a location description in Column 4 of Table D.

2 Where a GDE listed in Column 1 of Table D is comprised of numerous individual sites, Northings and Eastings have not been provided in Columns 2 and 3 of Table D.

3 The approximate location of GDEs listed in Column 1 of Table D are shown on the maps in Appendix 2.

Table D—High priority groundwater dependent ecosystems

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
High priority groundwater dependent ecosystem	**Northing (GDA 94)**	**Easting (GDA 94)**	**Location**	**Note.** **Conservation Status at the commencement of this Plan**	**Area (ha)**
Black Springs	732238	6161184	Northwest of Goulburn on the Wollondilly River		
Botany Wetlands **Note.** Botany Wetlands include Lachlan Swamps, Mill Pond, Mill Stream and Engine Pond.	335174	6243804	Estuarine wetland located on the northern shore of Botany Bay, from Gardeners Road Mascot to the Bay. Elevation: 0–12 m ASL.	Part of the Sydney Freshwater Wetlands of the Sydney Basin Bioregion, which is an endangered ecological community listed in the *Threatened Species Conservation Act 1995*.	64.0

Boyd Plateau Bogs **Note.** Boyd Plateau Bogs include Little Dingo Swamp, Wheengee Whungee Swamps, Little Morong Bog and Roly Whalans Swamp.	225872	6241458	Located in shallow headwater valleys on the Boyd Plateau.	Part of the Montane peatlands and swamps of the Sydney Basin Bioregion, which is an endangered ecological community listed in the *Threatened Species Conservation Act 1995*.	
Budderoo National Park and Barren Grounds Nature Reserve heath swamps	286199	6161444	Located approximately 15 km south-west of Robertson.	Part of Budderoo National Park and Barren Grounds Nature Reserve.	1150.0
Coomonderry Swamp	292781	6145133	Large semi-permanent freshwater swamp located north-east of Nowra.	Listed on the Register of the National Estate.	428.896
Coonemia Creek	290114	6128425	Coastal lagoon wetlands, feeder stream for Wollumboolla Lake, located 3 km north of Jervis Bay.	SEPP14 wetlands; part of the Sydney Freshwater Wetlands of the Sydney Basin Bioregion, which is an endangered ecological community listed in the *Threatened Species Conservation Act 1995*.	1.258
Cormorant Beach	262659	6068358	Wetland located south of Bawley Point township between Murramurang Road and Cormorant Beach. Elevation: 0 m ASL. Includes dunal freshwater wetland.	SEPP14 wetland	12.0

Currys Springs	219277	6252369	Located on Great Dividing Range near head of Hollanders River.	0.1
Ferny Spring	227413	6241503	Perennial spring on the head of Little Morong Creek about 1.2 km west by north of Queen Pin Hill.	0.1
Forty Year Spring	339986	6284743	Located 1 km west of Walker Point and about 1.5 km south by east of Junction Hill.	0.1
Kiaramba Spring	221194	6243173	Located on Kiaramba Creek about 1.2 km from where it rises on the northern slopes of Mount Feld.	0.1
Lake Bathurst **Note.** Lake Bathurst includes The Morass.	197570	6116569	Large, shallow permanent freshwater lake located in the southern tablelands at the southernmost extremity of the Nepean-Hawkesbury catchment approximately 1 km east of the Mulwaree River.	490.764
Lanes Yards Spring	221194	6243173	Located near Hollanders River about 3.2 km northeast of Grave Hill.	0.1

Long Swamp	309888	6280497	Located approximately 20 km west of Moss Vale and approximately 7 km west of Tennyson Park in the catchment which flows into the Wollondilly River and Warragamba Dam.		
Longneck Lagoon	305173	6284101	Freshwater lagoon with channels and pools about 2 -3 metres deep with gently sloping margins. Located on the Hawkesbury River floodplain, approximately 8 km north-east of Windsor.	Part of the Freshwater Wetlands on Coastal Floodplains of the Sydney Basin Bioregion, which is an endangered ecological community listed in the *Threatened Species Conservation Act 1995*.	2.930
Macquarie Rivulet Estuary	289098	6172794	Macquarie Rivulet Estuary is located next to Lake Illawarra. Macquarie Rivulet rises near Robertson, drains the eastern edge of the Southern Highlands plateau and part of the Illawarra escarpment, and flows into Lake Illawarra.		1.077
Minnamurra River Estuary **Note.** Minnamurra River Estuary includes the Minnamurra River and its adjacent wetland areas.	293892	6163654	Estuarine wetlands located between the towns of Shellharbour to the north and Kiama to the south.	SEPP14 wetlands	52.729

O'Hares Creek **Note.** O'Hares Creek includes the catchment of O'Hares, Stokes and Four Mile Creeks, downstream to the junction of O'Hares and Stokes Creeks.	305027	6211055	Floodplain wetland located between Appin and Bulli on the Woronora Plateau. Elevation: 100–450 m ASL.		9000.0
Pitt Town Lagoon	300588	6281233	Wetlands located on the Hawkesbury River floodplain immediately adjacent to the southern edge of Pitt Town, 4 km north-east of Windsor.		41.0
Salt Pan Creek	319132	6241847	Estuarine wetland which flows to Georges River, located in the suburbs of Riverwood and Peakhurst.		1.077
Temperate Highland Peat Swamps on Sandstone **Note.** Temperate Highland Peat Swamps on Sandstone includes Blue Mountains Sedge Swamps, Butler's Swamp, Newnes Plateau Swamps, Paddy's River Swamps and Wingecarribee Swamp.			Numerous small wetlands located in the Blue Mountains and Newnes Plateau regions. **Note.** A current list of Temperate Highland Peat Swamps on Sandstone is provided on the Office of Environment and Heritage's website.	Part of the Montane peatlands and swamps of the Sydney Basin Bioregion, which is an endangered ecological community listed in the *Threatened Species Conservation Act 1995*; listed as an endangered ecological community under section 181 of the *Environmental Protection and Biodiversity Conservation Act 1999* (Cth).	

Thirlmere Lakes **Note.** Thirlmere Lakes include Gandangarra, Werri-Berri, Couridjah, Baraba and Nerrigorang Lakes.	272861	6211256	Freshwater lakes located on the edge of the Southern tablelands approximately 10 km south west of Picton.		
Towra Point Estuarine Wetlands	329245	6236488	Located approximately 16 km south of Sydney centre. Towra Point adjoins Kurnell Peninsula forming the southern and eastern boundaries of Botany Bay.	Ramsar estuarine wetlands	638.309
Wollumboola Lake	296160	6130411	Large brackish coastal lake which is intermittently connected to the ocean, located 3 km north of Jervis Bay between Shoalhaven River, Jervis Bay and Beecroft Peninsula.		531.744

Table E—High priority endangered ecological vegetation communities

Column 1	**Column 2**
High priority endangered ecological vegetation community	**Conservation Status at the commencement of this Plan**
Bangalay Sand Forest	Endangered ecological community listed in the *Threatened Species Conservation Act 1995*
Castlereagh Swamp Woodland Community	Endangered ecological community listed in the *Threatened Species Conservation Act 1995*
Cooks River/Castlereagh Ironbark Forest in the Sydney Basin Bioregion	Endangered ecological community listed in the *Threatened Species Conservation Act 1995*
Cumberland Plain Woodland	Critically endangered ecological community listed in the *Threatened Species Conservation Act 1995*
Duffys Forest Ecological Community in the Sydney Basin Bioregion	Endangered ecological community listed in the *Threatened Species Conservation Act 1995*
Eastern Suburbs Banksia Scrub in the Sydney Basin Bioregion	Endangered ecological community listed in the *Threatened Species Conservation Act 1995*

Kurnell Dune Forest in the Sutherland Shire and City of Rockdale	Endangered ecological community listed in the *Threatened Species Conservation Act 1995*
Littoral Rainforest in the Sydney Basin Bioregion	Endangered ecological community listed in the *Threatened Species Conservation Act 1995*
Pittwater Spotted Gum Forest	Endangered ecological community listed in the *Threatened Species Conservation Act 1995*
River-Flat Eucalypt Forest on Coastal Floodplains	Endangered ecological community listed in the *Threatened Species Conservation Act 1995*
Shale Gravel Transition Forest in the Sydney Basin Bioregion	Endangered ecological community listed in the *Threatened Species Conservation Act 1995*
Swamp Oak Floodplain Forest	Endangered ecological community listed in the *Threatened Species Conservation Act 1995*
Swamp Sclerophyll Forest on Coastal Floodplains	Endangered ecological community listed in the *Threatened Species Conservation Act 1995*
Sydney Freshwater Wetlands in the Sydney Basin Bioregion	Endangered ecological community listed in the *Threatened Species Conservation Act 1995*

Note.

The following high priority groundwater dependent ecosystems as specified in Table D are located within the Sydney Freshwater Wetlands in the Sydney Basin Bioregion: Botany Wetlands, Coonemia Creek.

Note.

All high priority endangered ecological vegetation communities in Table E are Endangered Ecological Communities listed in Schedule 1 or Critically Endangered Ecological Communities listed in Schedule 1A of the *Threatened Species Conservation Act 1995* at the commencement of this Plan.

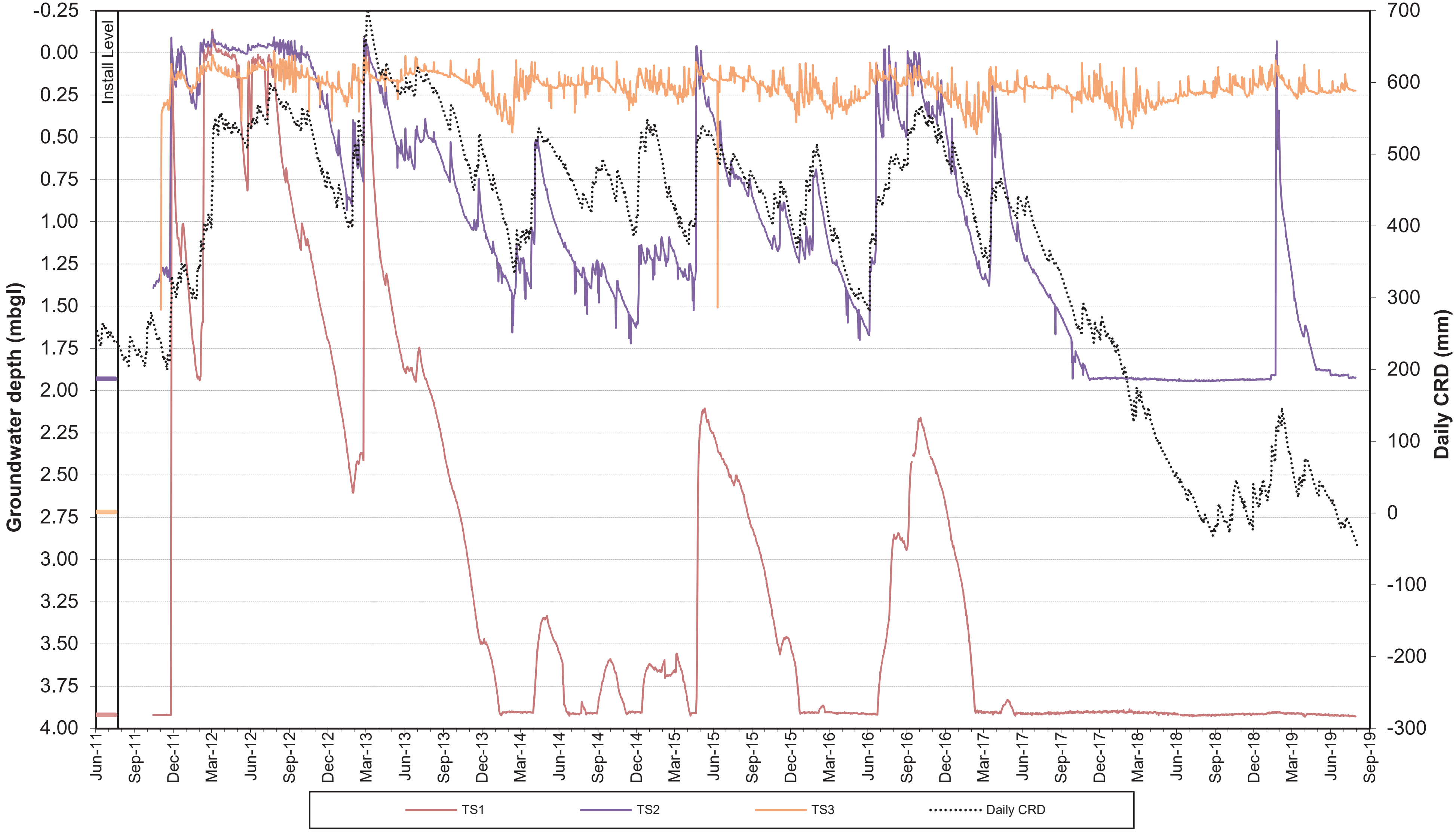
2 High priority karst environment groundwater dependent ecosystems

High priority karst environment groundwater dependent ecosystems in these groundwater sources are as specified in Table F below.

Table F—High priority karst environment groundwater dependent ecosystems

Column 1	**Column 2**
High priority groundwater dependent ecosystem (karst)	**Location**
Bendethera	50 km south-west of Bateman’s Bay
Billys Creek Caves	50 km south-east of Oberon
Bungonia	35 km east of Goulbourn.
Canyonleigh	30 km east of Taralga.
Capertee Valley	14 km south-east of Capertee
Church Creek Caves	50 km south-east of Oberon

Cleatmore (Cheitmore)	45 km west south-west of Bateman's Bay
Colong Caves	50 km south-east of Oberon
Ettrema & Jones Creek	40 km south-west of Nowra
Hollanders River	25 km south-east of Oberon
Jaunter Caves	North-west and west of Tuglow
Jenolan Caves	23 km south-east of Oberon
Jerrara	Bungonia
Limeburners Flat	10 km east of Colong Caves
Little Wombeyan Creek	14 km north of Wombeyan Caves
Mt Fairy	7 km east north-east of Bungendore
Murruin Creek	4.5 km west of Colong Caves
Portland	Portland
Tuglow Caves	30 km south-east of Oberon
Wombeyan Caves	16 km north-east of Taralga
Wyanbene	45 km west south-west of Bateman's Bay



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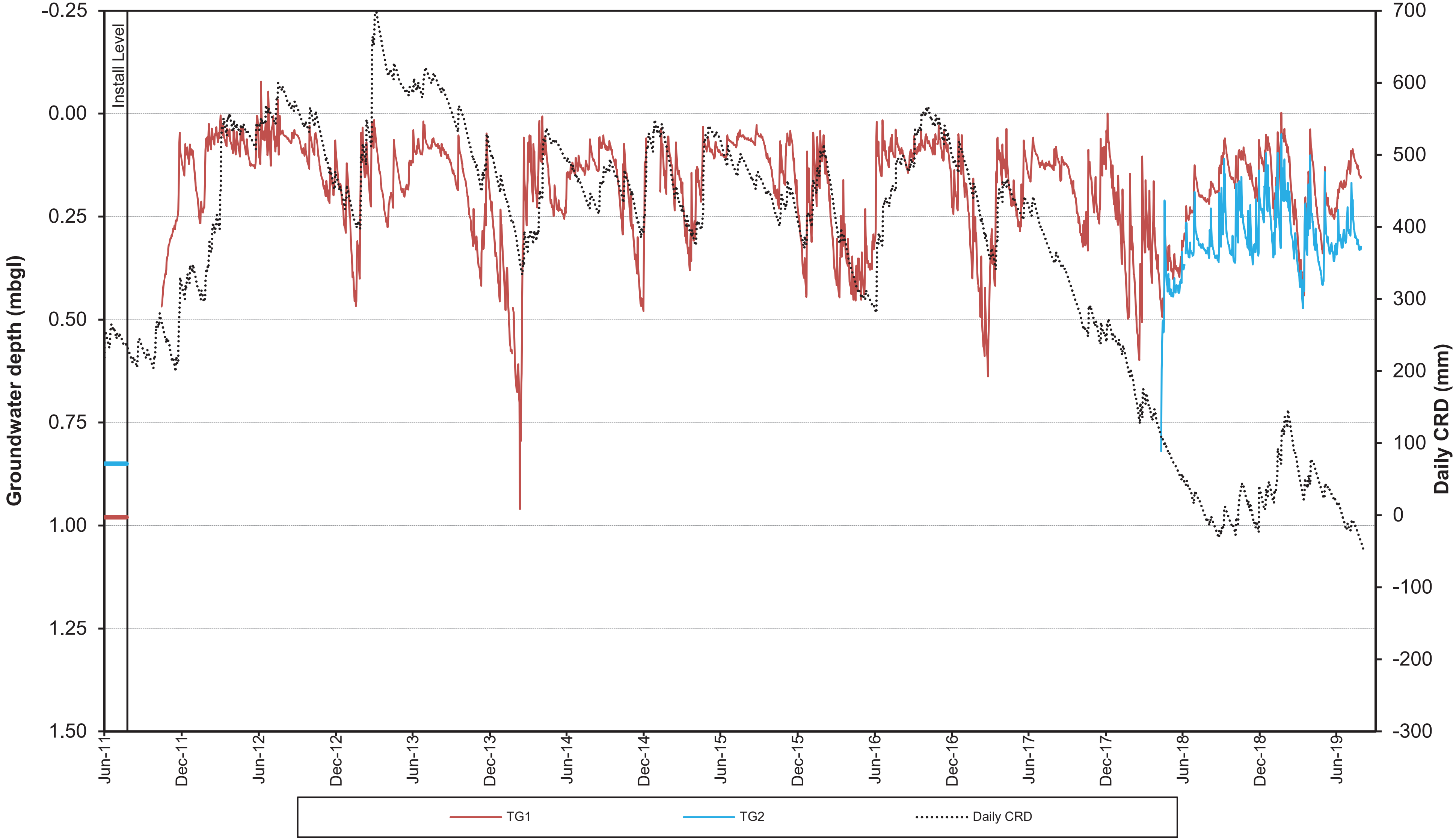
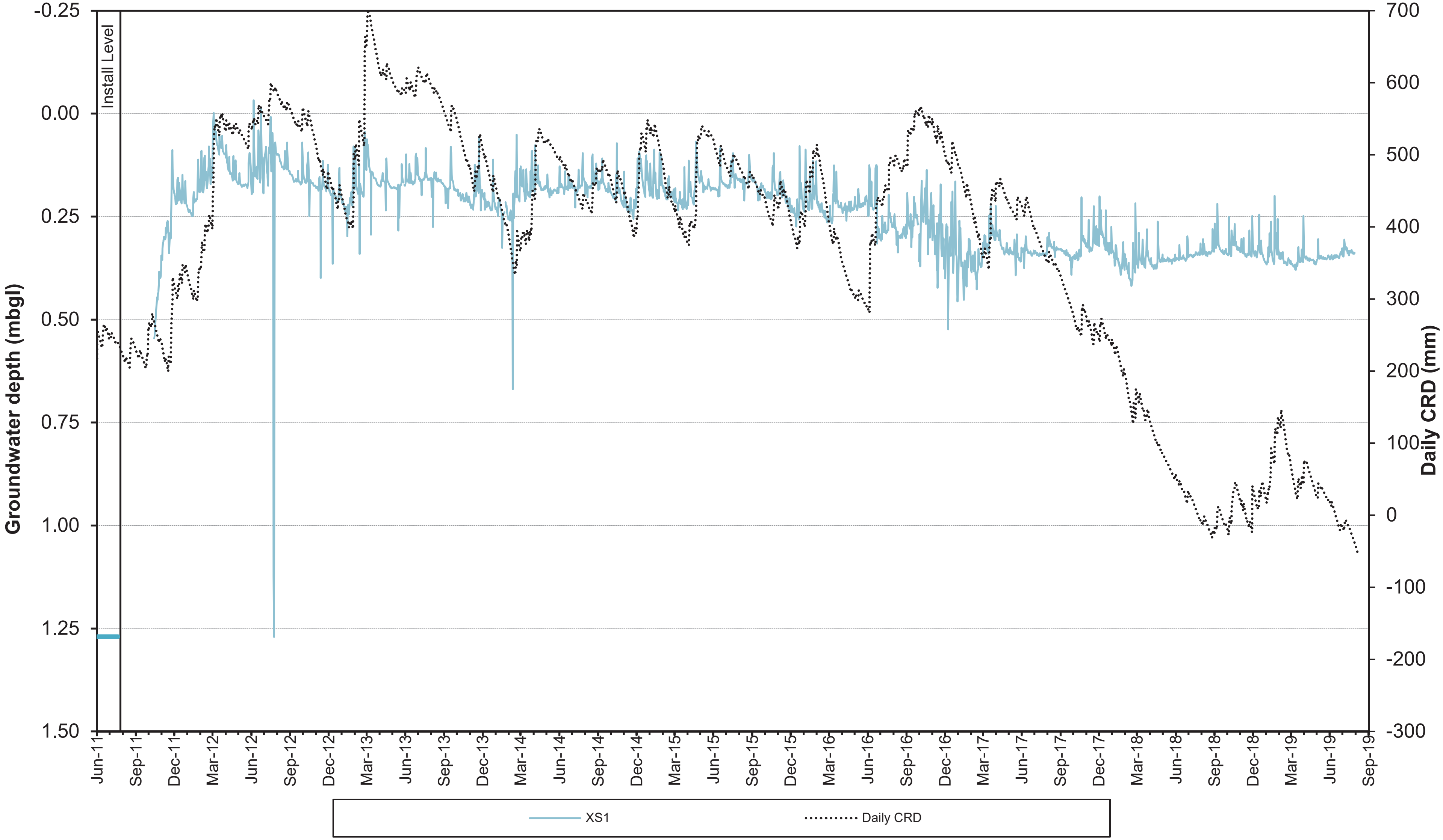
Tristar Swamp Piezometer Hydrographs - Appendix D

J:\IE\Projects\04_Eastern\IA161510\21 Deliverables\Appendices\D\data\[AP_SwampData apr 2019.xlsx]Figure 4_TS-CRD

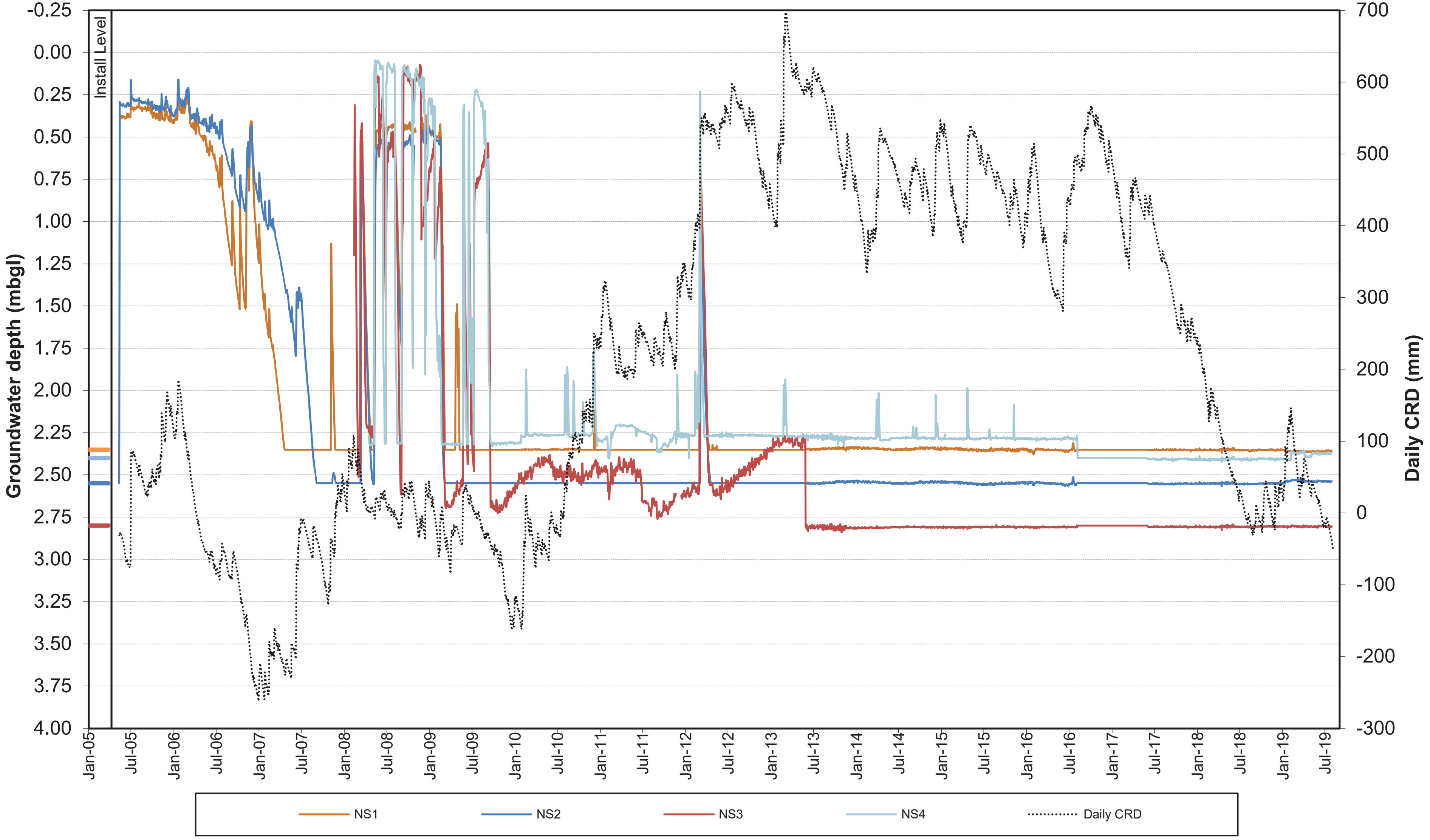


Twin Gully Swamp Piezometer Hydrographs - Appendix D

J:\IE\Projects\04_Eastern\IA161510\21 Deliverables\Appendices\D\data\[AP_SwampData apr 2019.xlsx]Figure 7_TG-CRD

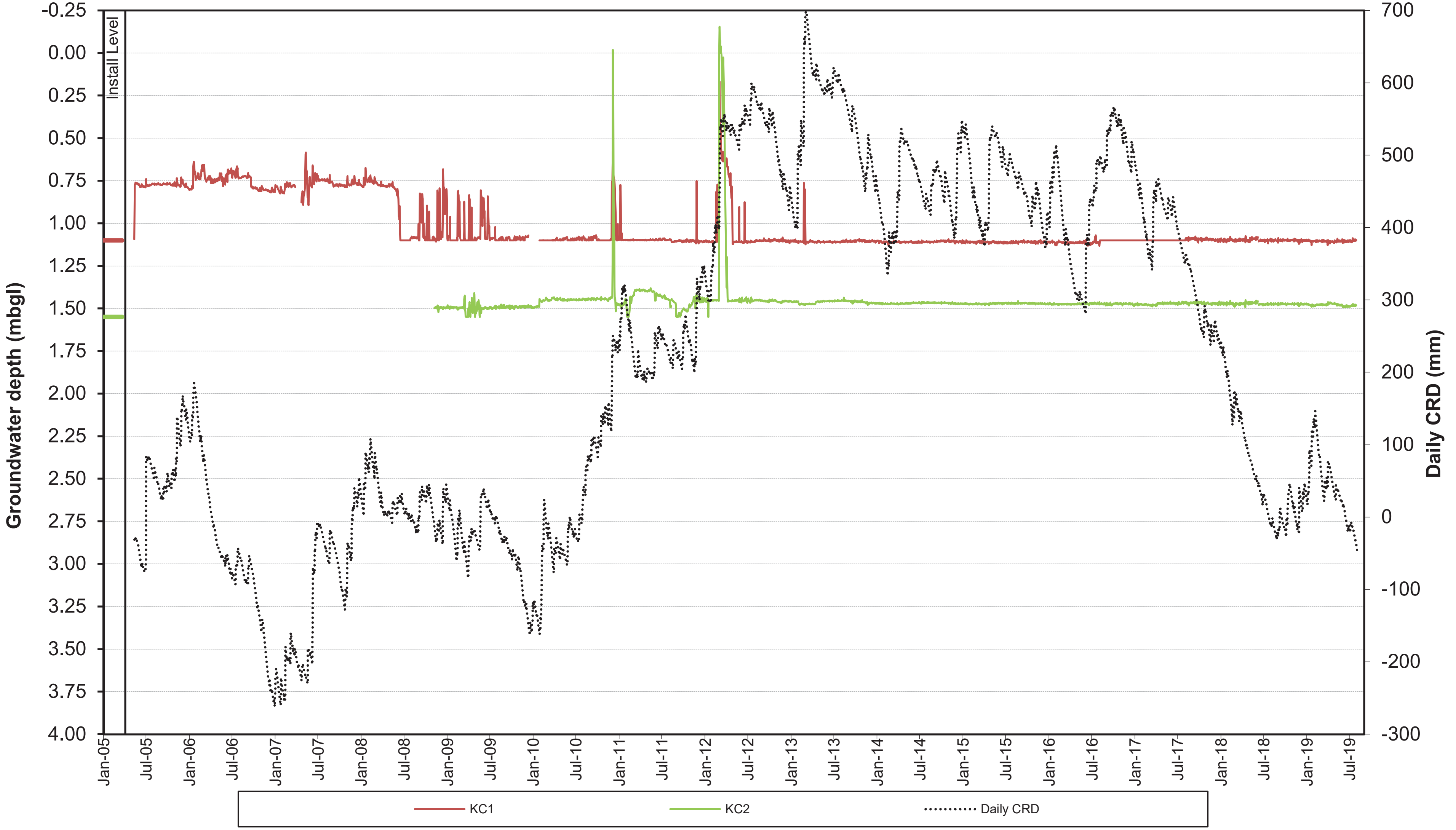


Install Level
Groundwater depth (mbgl)
Daily CRD (mm)
-0.25
0.00
0.25
0.50
0.75
1.00
1.25
1.50
700
600
500
400
300
200
100
0
-100
-200
-300
Jun-11
Sep-11
Dec-11
Mar-12
Jun-12
Sep-12
Dec-12
Mar-13
Jun-13
Sep-13
Dec-13
Mar-14
Jun-14
Sep-14
Dec-14
Mar-15
Jun-15
Sep-15
Dec-15
Mar-16
Jun-16
Sep-16
Dec-16
Mar-17
Jun-17
Sep-17
Dec-17
Mar-18
Jun-18
Sep-18
Dec-18
Mar-19
Jun-19
Sep-19
XS1
Daily CRD

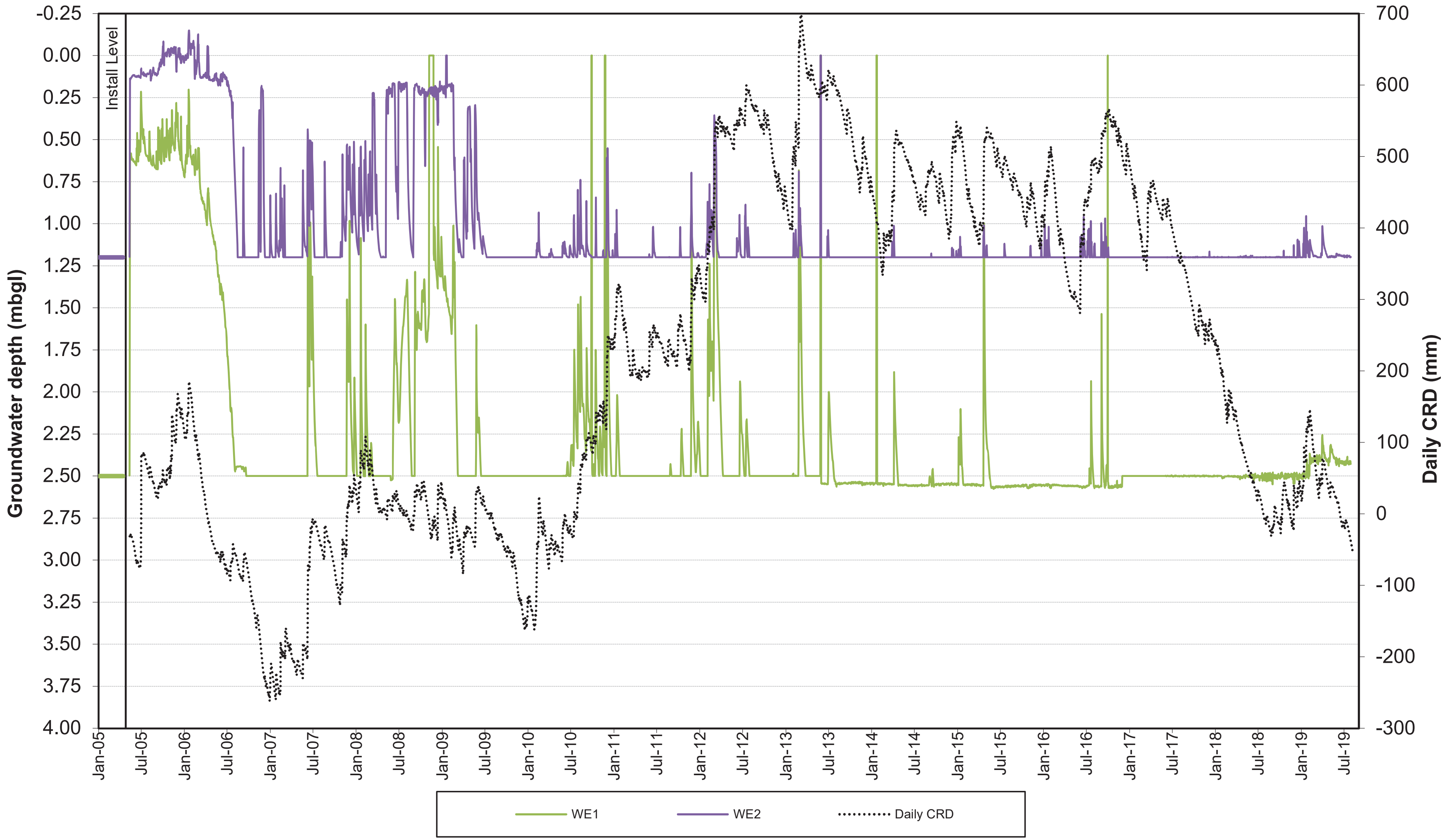


Narrow Swamp Piezometer Hydrographs - Appendix D

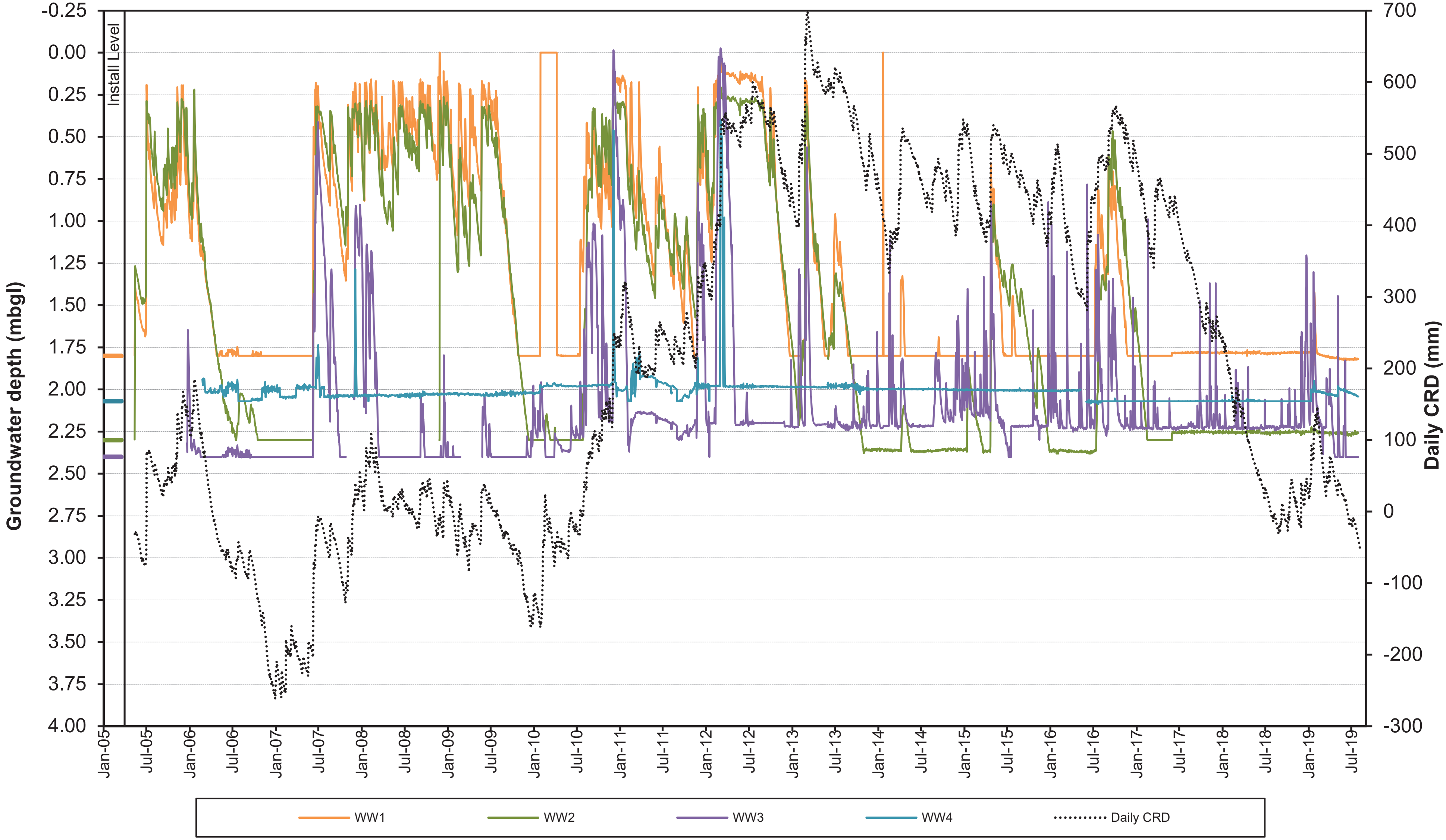
J:\IE\Projects\04_Eastern\IA161510\21 Deliverables\Appendices\D\data\[AP_SwampData apr 2019.xlsx]Figure 8_NS-CRD



Install Level
Groundwater depth (mbgl)
Daily CRD (mm)
-0.25
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
700
600
500
400
300
200
100
0
-100
-200
-300
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14
Jul-14
Jan-15
Jul-15
Jan-16
Jul-16
Jan-17
Jul-17
Jan-18
Jul-18
Jan-19
Jul-19
KC1
KC2
Daily CRD

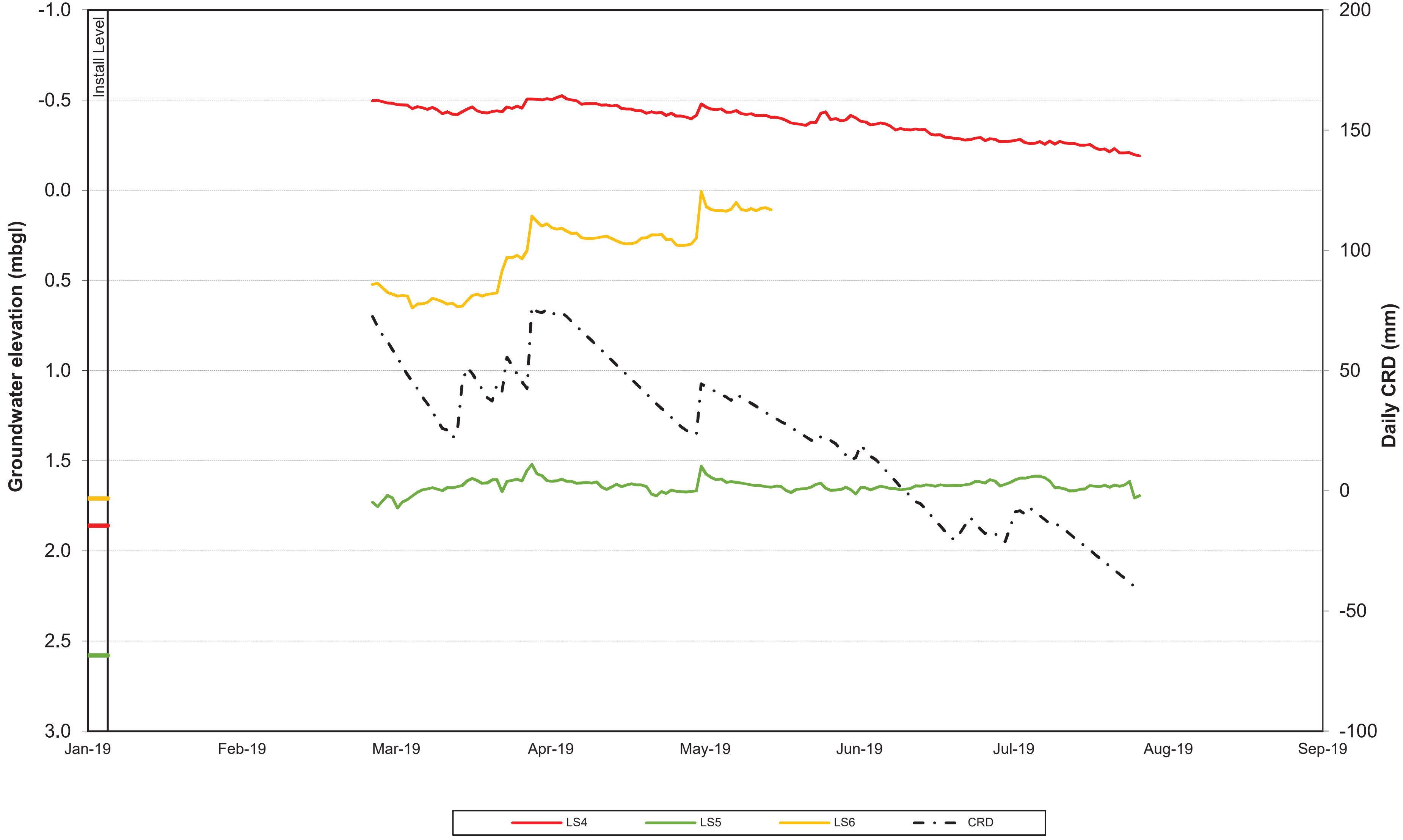


J:\IE\Projects\04_Eastern\IA161510\21 Deliverables\Appendices\D\data\[AP_SwampData apr 2019.xlsx]Figure 9_EW-CRD

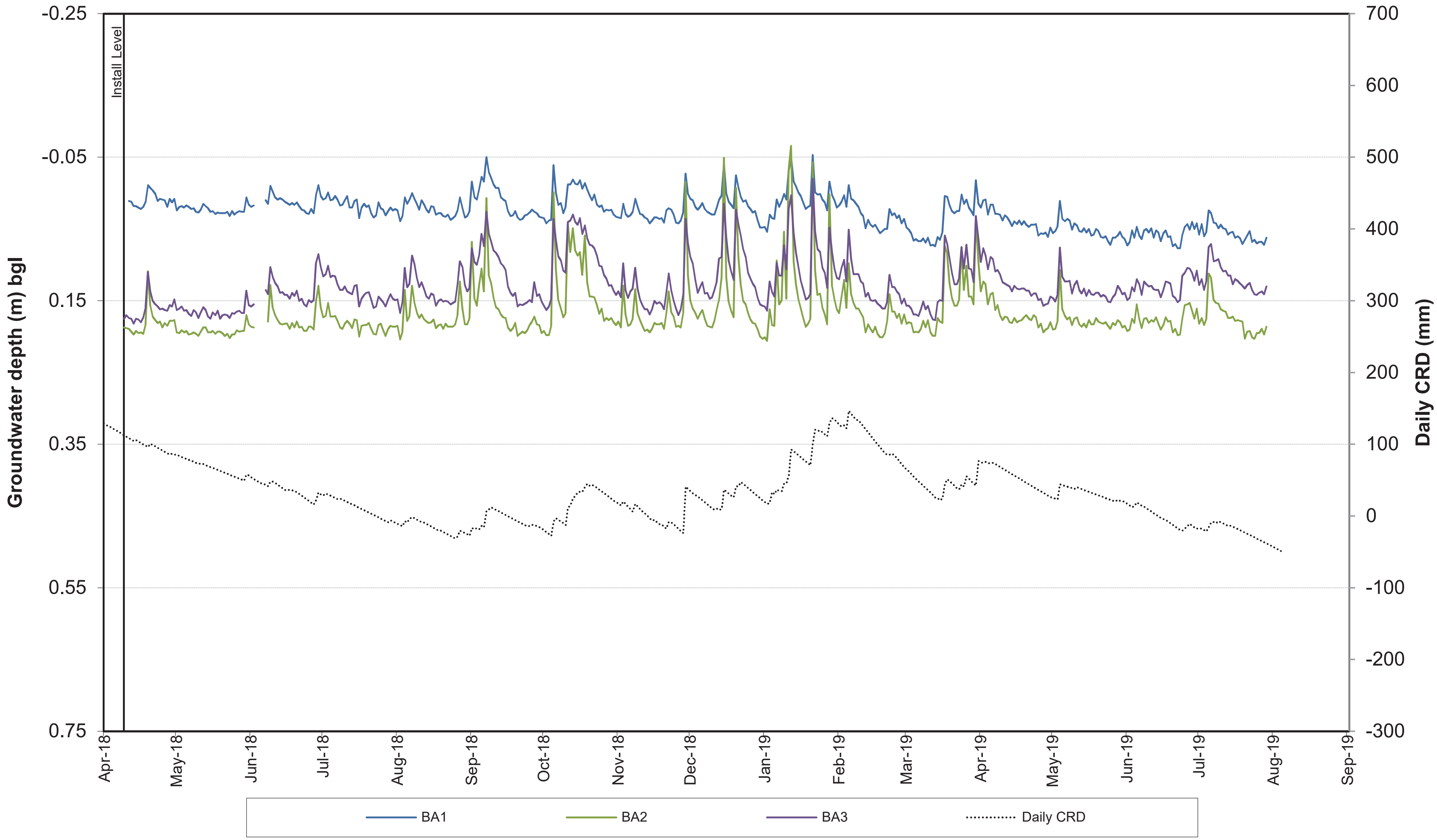


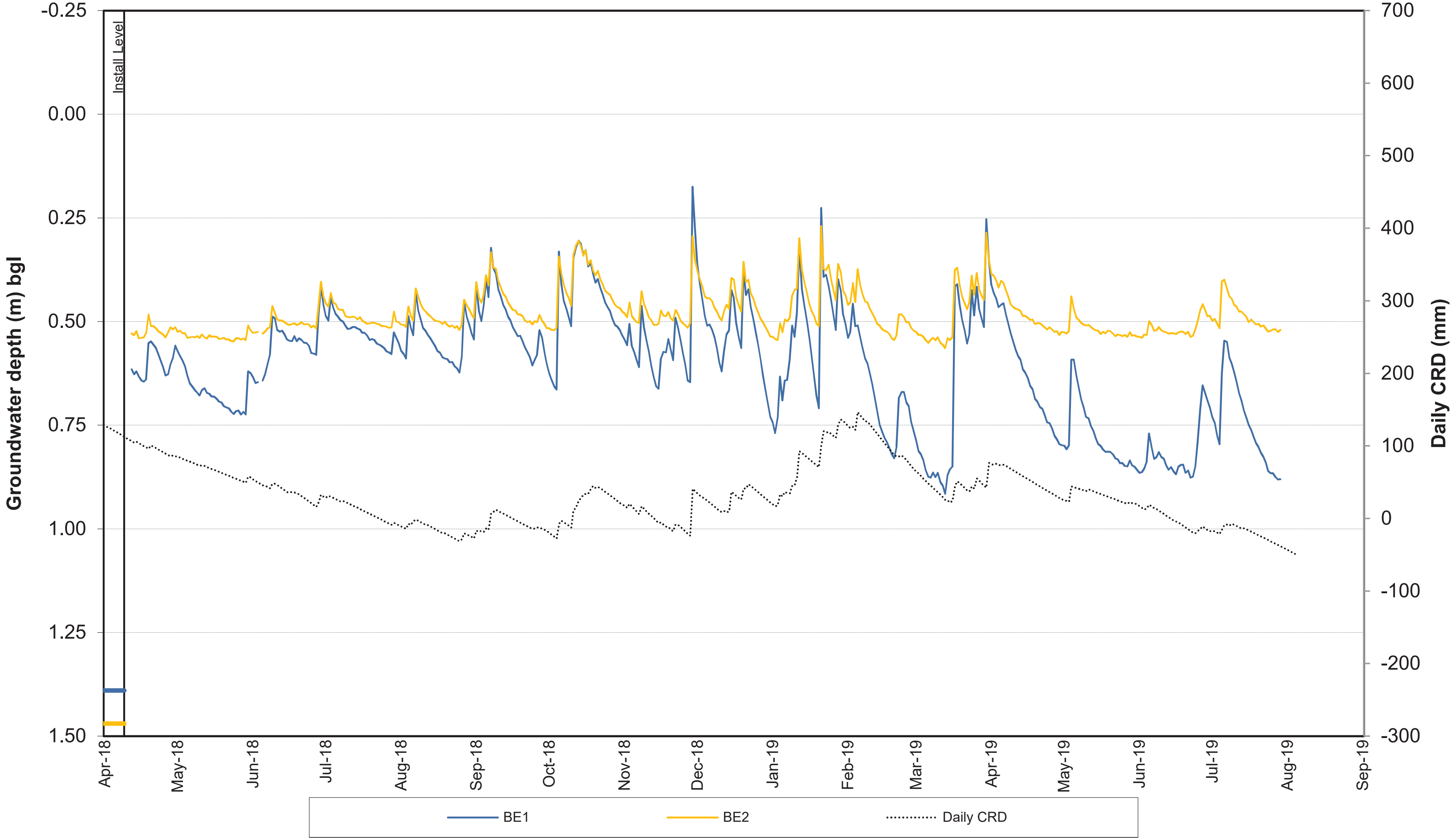
West Wolgan Swamp Piezometer Hydrographs - Appendix D

J:\IE\Projects\04_Eastern\IA161510\21 Deliverables\Appendices\D\data\[AP_SwampData apr 2019.xlsx]Figure 5_WW-CRD

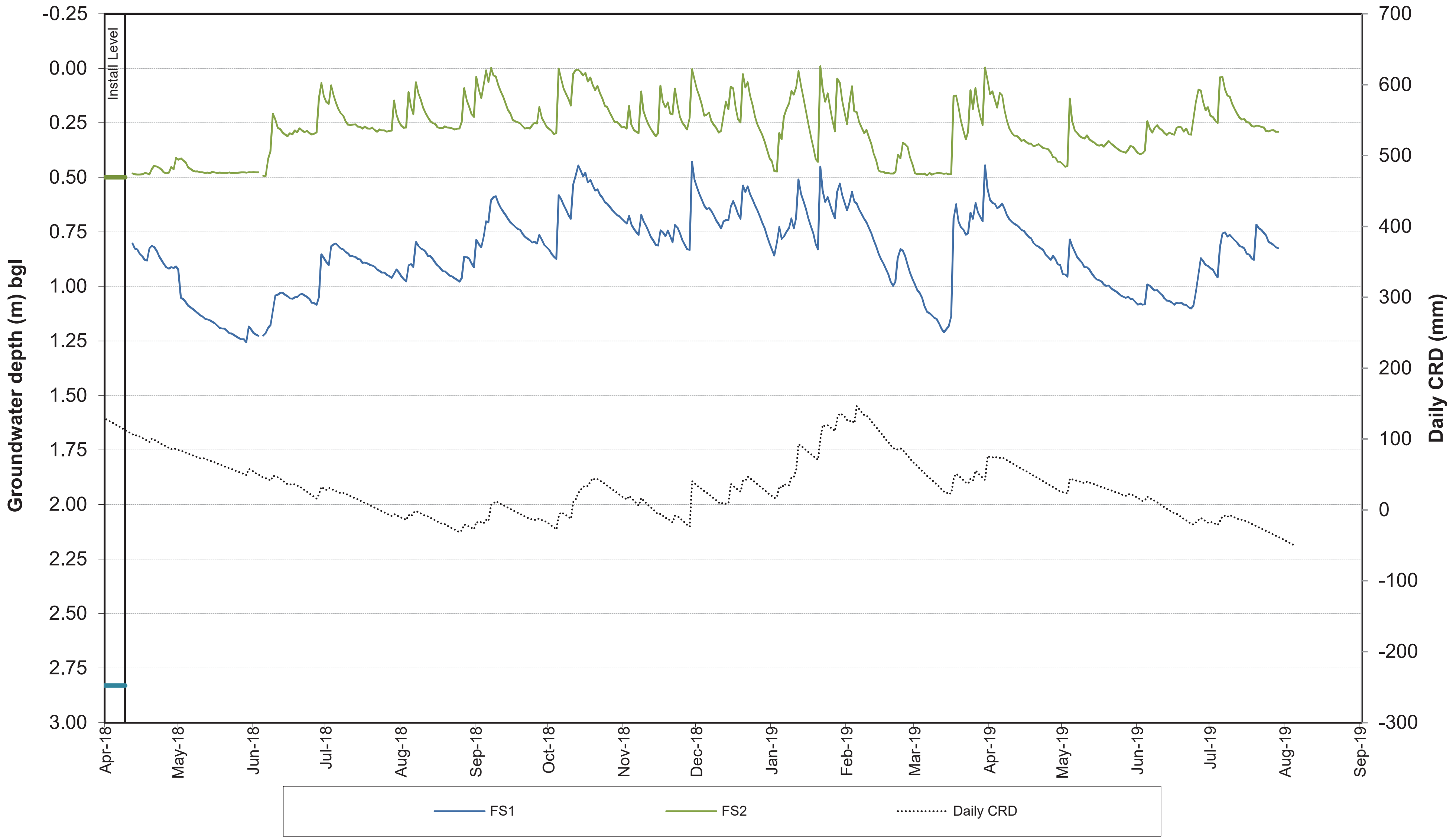


Install Level
Groundwater elevation (mbgl)
Daily CRD (mm)
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
200
150
100
50
0
-50
-100
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Jul-19
Aug-19
Sep-19
LS4
LS5
LS6
CRD

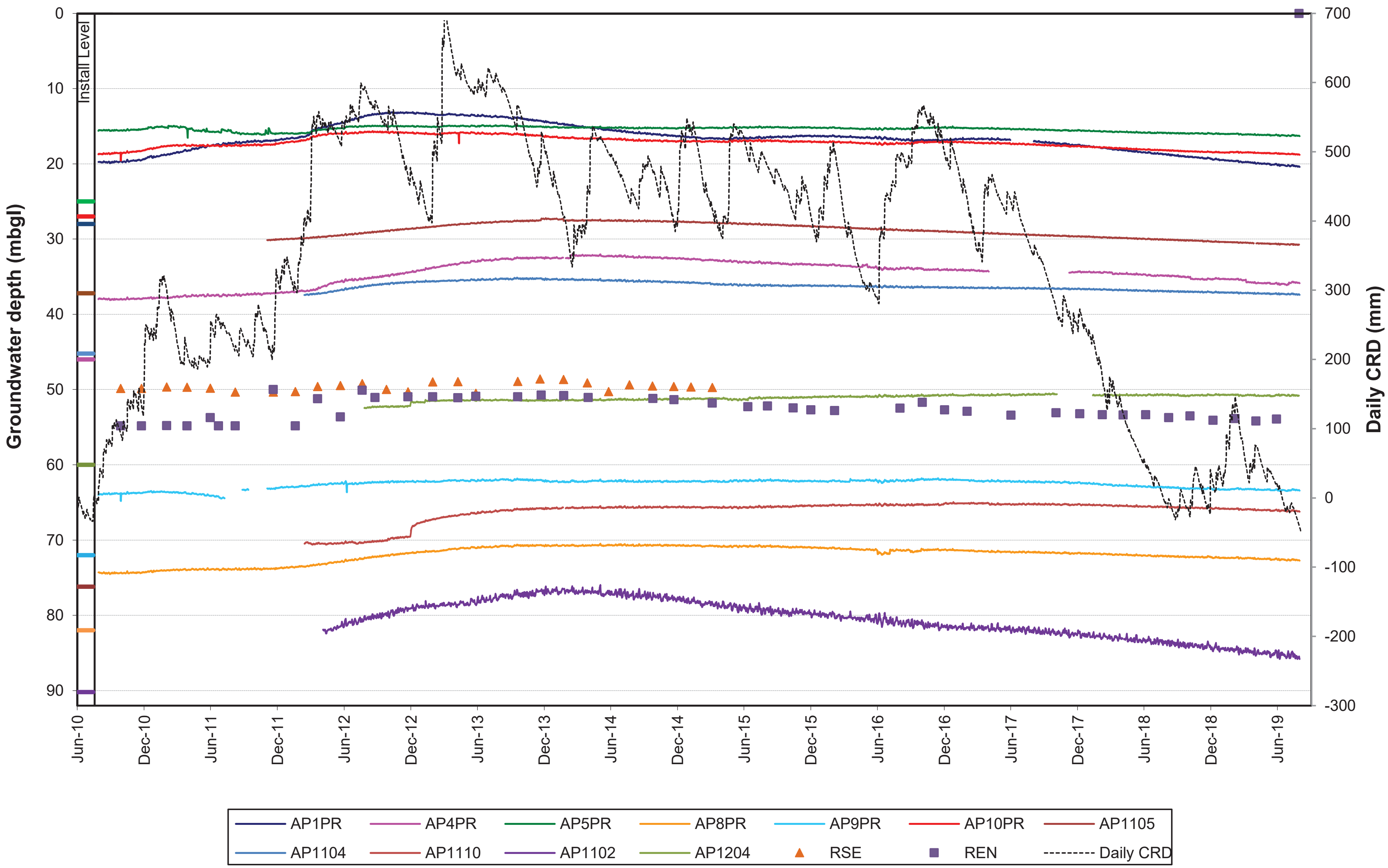

Install Level
Groundwater depth (m) bgl
Daily CRD (mm)
-0.25
-0.05
0.15
0.35
0.55
0.75
700
600
500
400
300
200
100
0
-100
-200
-300
Apr-18
May-18
Jun-18
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Jul-19
Aug-19
Sep-19
BA1
BA2
BA3
Daily CRD



-0.25
0.00
0.25
0.50
0.75
1.00
1.25
1.50
Groundwater depth (m) bgl
700
600
500
400
300
200
100
0
-100
-200
-300
Daily CRD (mm)
Install Level
Apr-18
May-18
Jun-18
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Jul-19
Aug-19
Sep-19
BE1
BE2
Daily CRD



Groundwater depth (m) bgl
Daily CRD (mm)
Install Level
-0.25
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
700
600
500
400
300
200
100
0
-100
-200
-300
Apr-18
May-18
Jun-18
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Jul-19
Aug-19
Sep-19
FS1
FS2
Daily CRD



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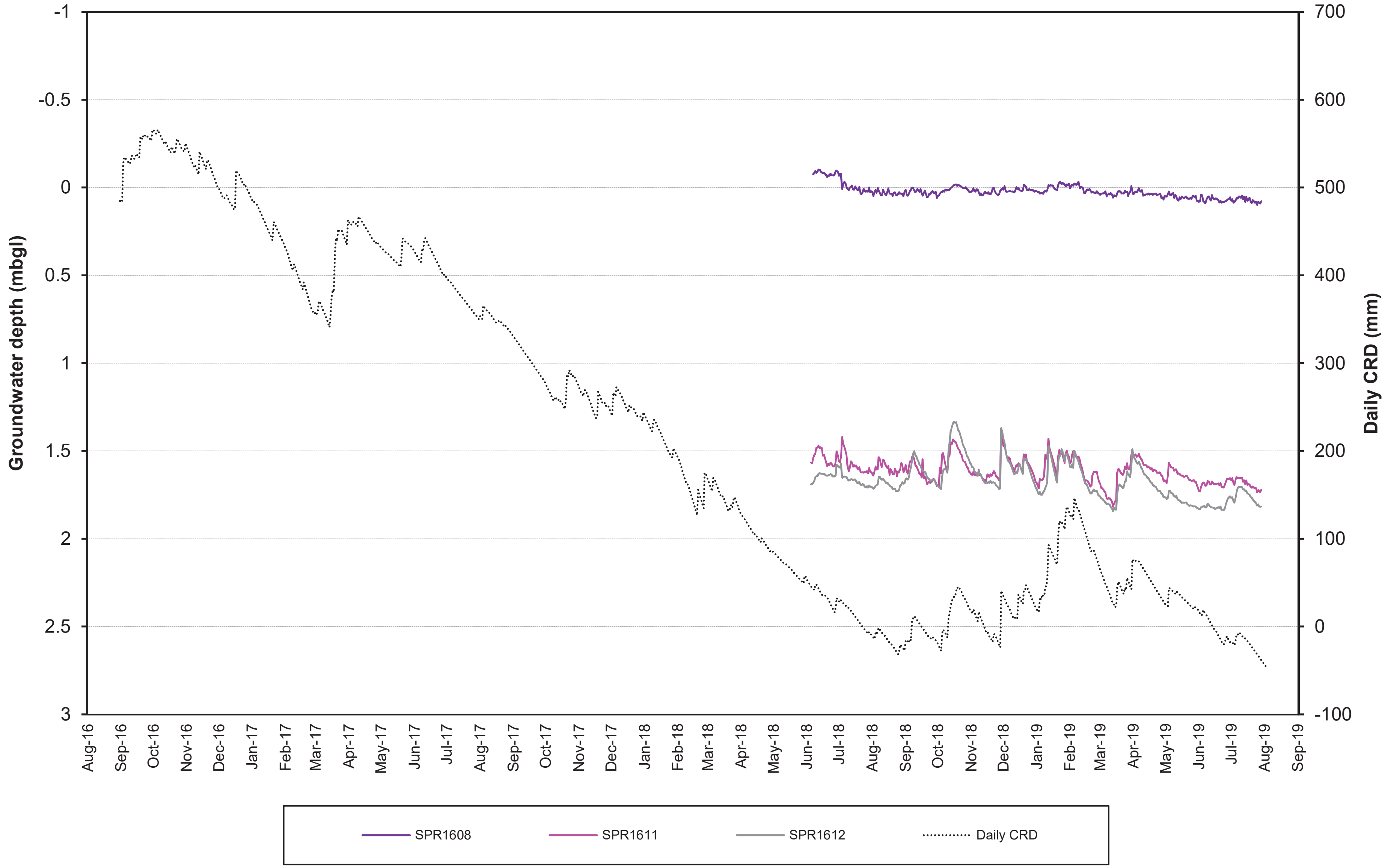
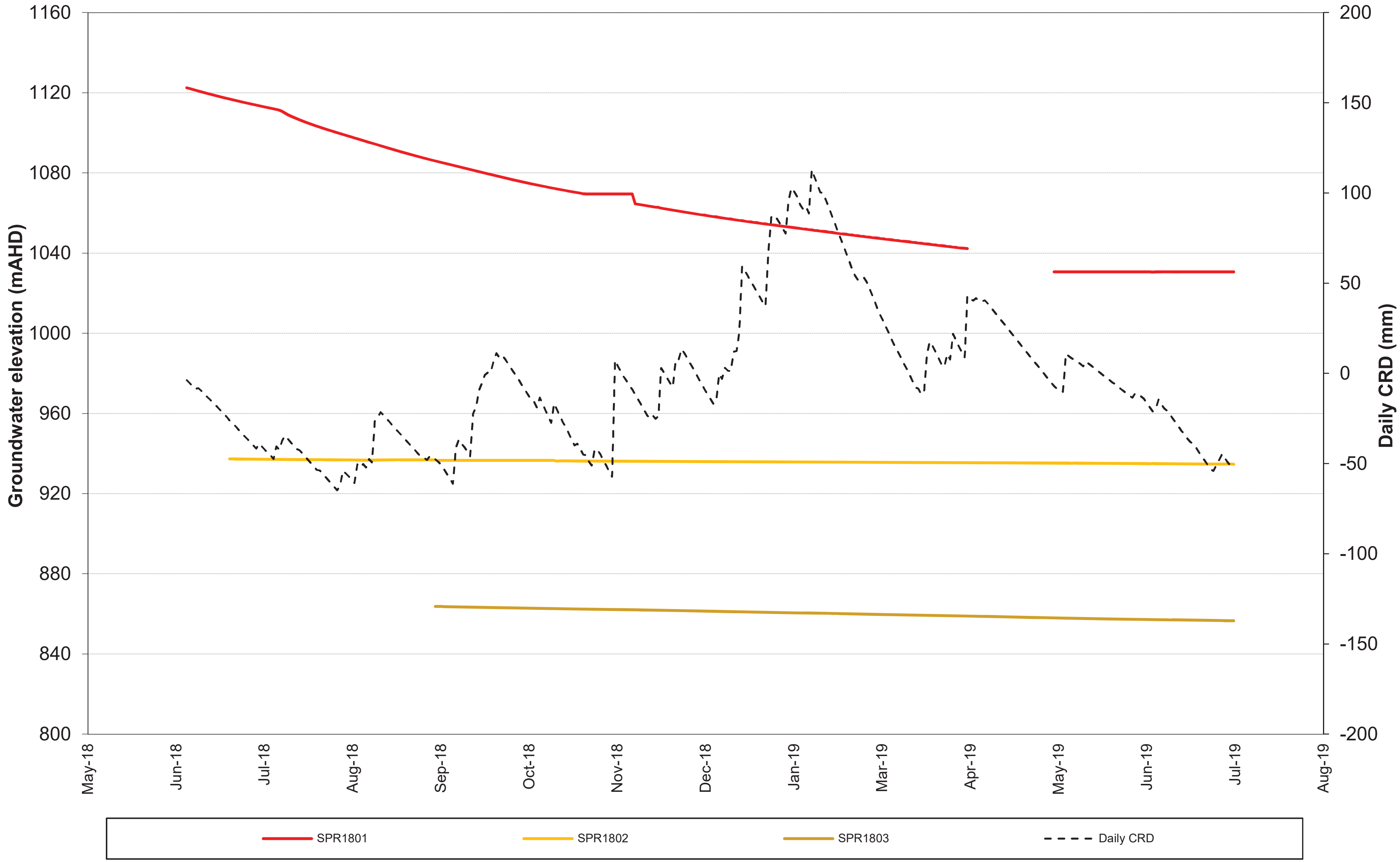
Ridge Piezometer Hydrographs - Appendix D

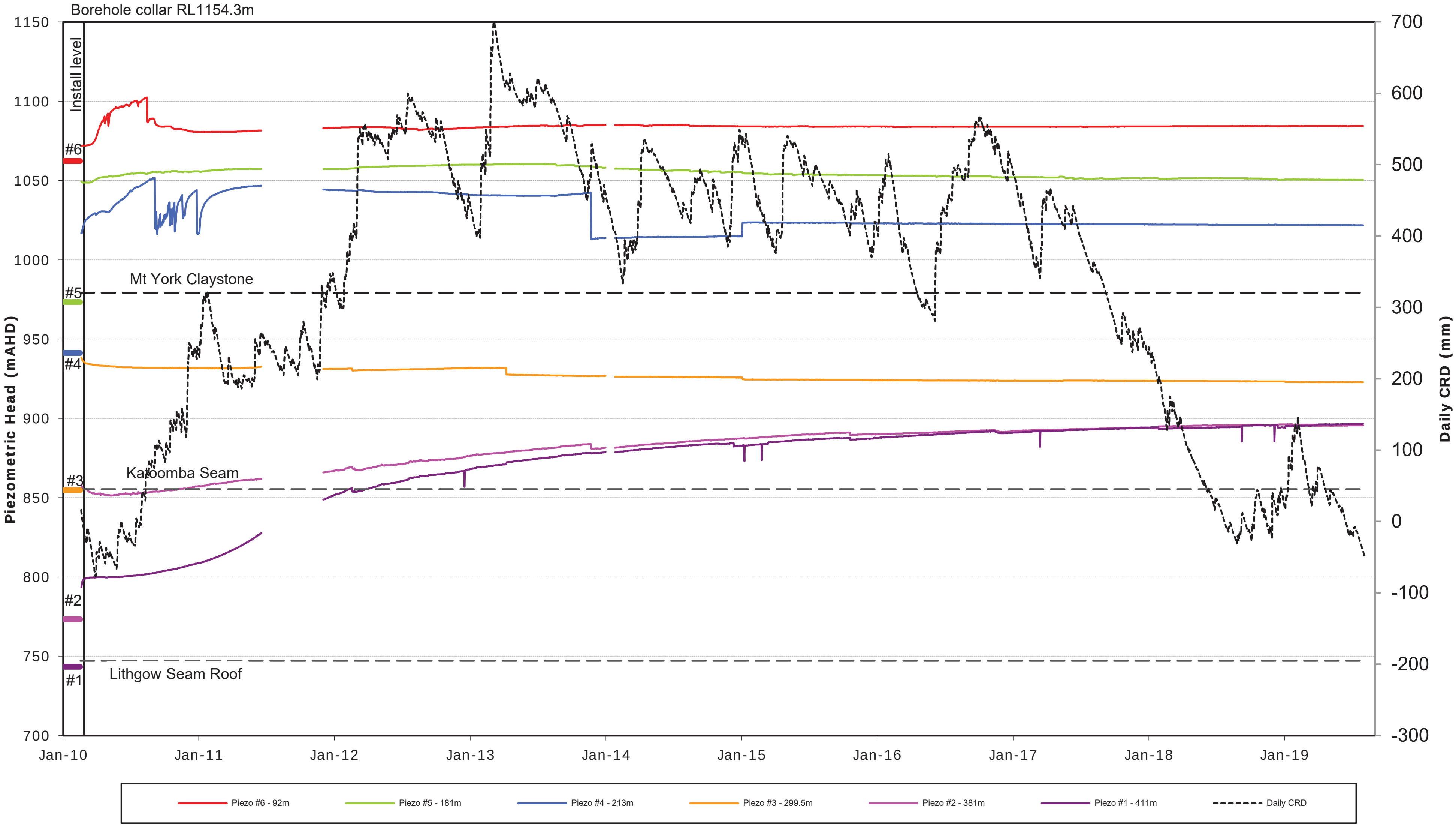
J:\IE\Projects\04_Eastern\IA161510\21 Deliverables\Appendices\D\data\[AP Open Boreholes v4.xlsx]Figure 10_AP Ridge Piezos CRD



Groundwater depth (mbgl)
Daily CRD (mm)
-1
-0.5
0
0.5
1
1.5
2
2.5
3
700
600
500
400
300
200
100
0
-100
Aug-16
Sep-16
Oct-16
Nov-16
Dec-16
Jan-17
Feb-17
Mar-17
Apr-17
May-17
Jun-17
Jul-17
Aug-17
Sep-17
Oct-17
Nov-17
Dec-17
Jan-18
Feb-18
Mar-18
Apr-18
May-18
Jun-18
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Jul-19
Aug-19
Sep-19
SPR1608
SPR1611
SPR1612
Daily CRD

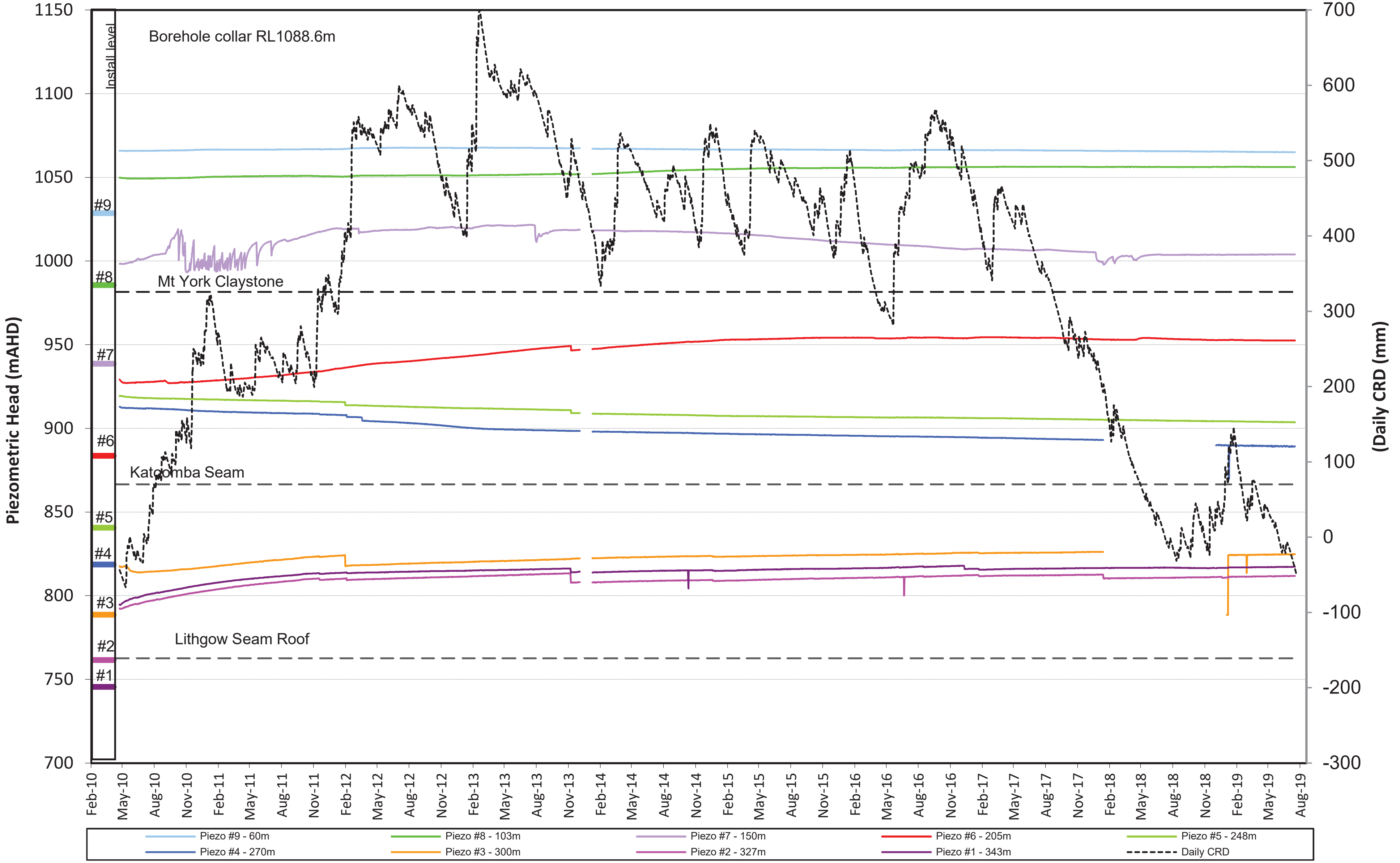


Groundwater elevation (mAHD)
Daily CRD (mm)
1160
1120
1080
1040
1000
960
920
880
840
800
200
150
100
50
0
-50
-100
-150
-200
May-18
Jun-18
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Mar-19
Apr-19
May-19
Jun-19
Jul-19
Aug-19
SPR1801
SPR1802
SPR1803
Daily CRD



AP2PR VWP Hydrographs - Appendix D

J:\IE\Projects\04_Eastern\IA161510\21 Deliverables\Appendices\D\data\[AP2PR.xls]Figure 11 - AP2PR CRD



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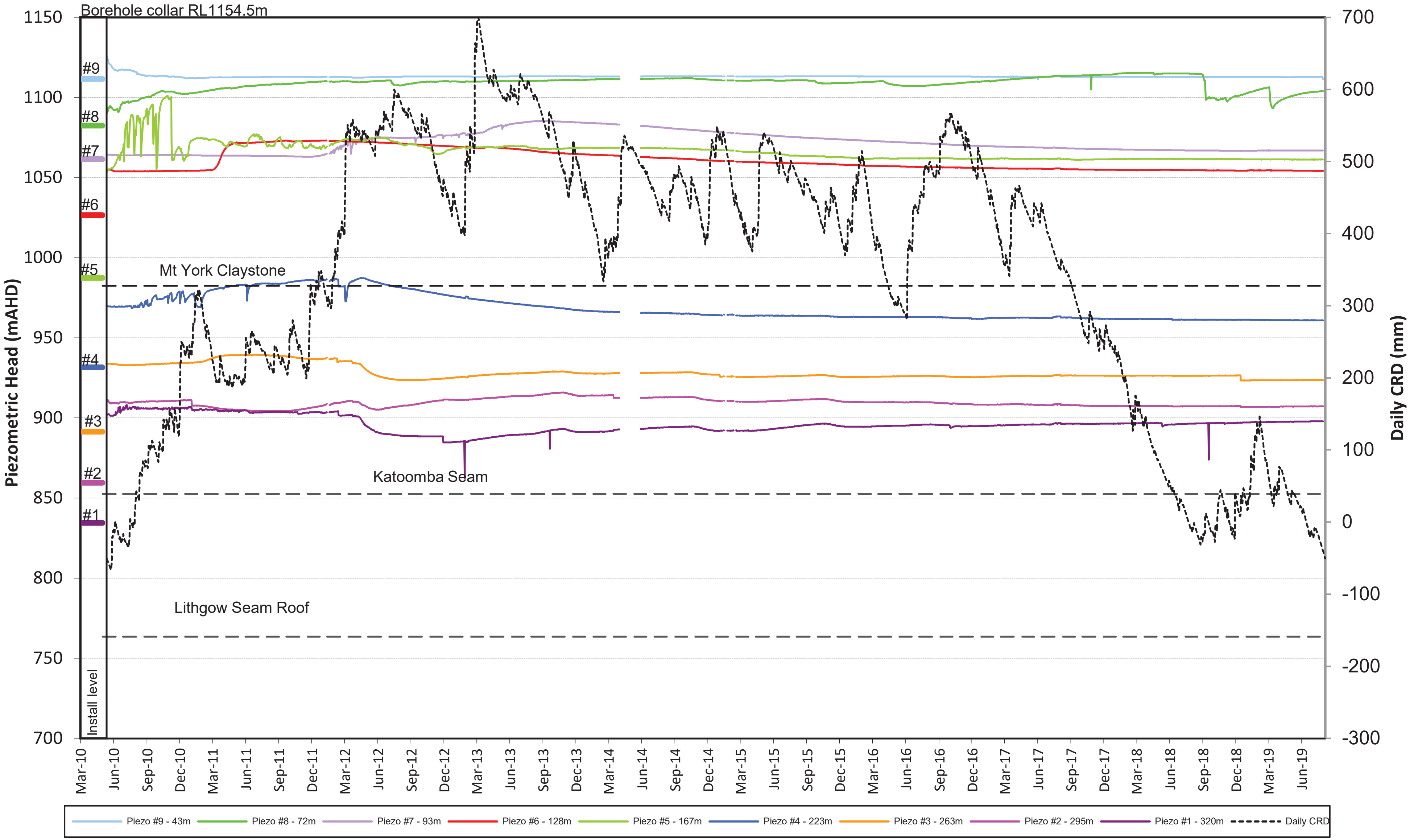
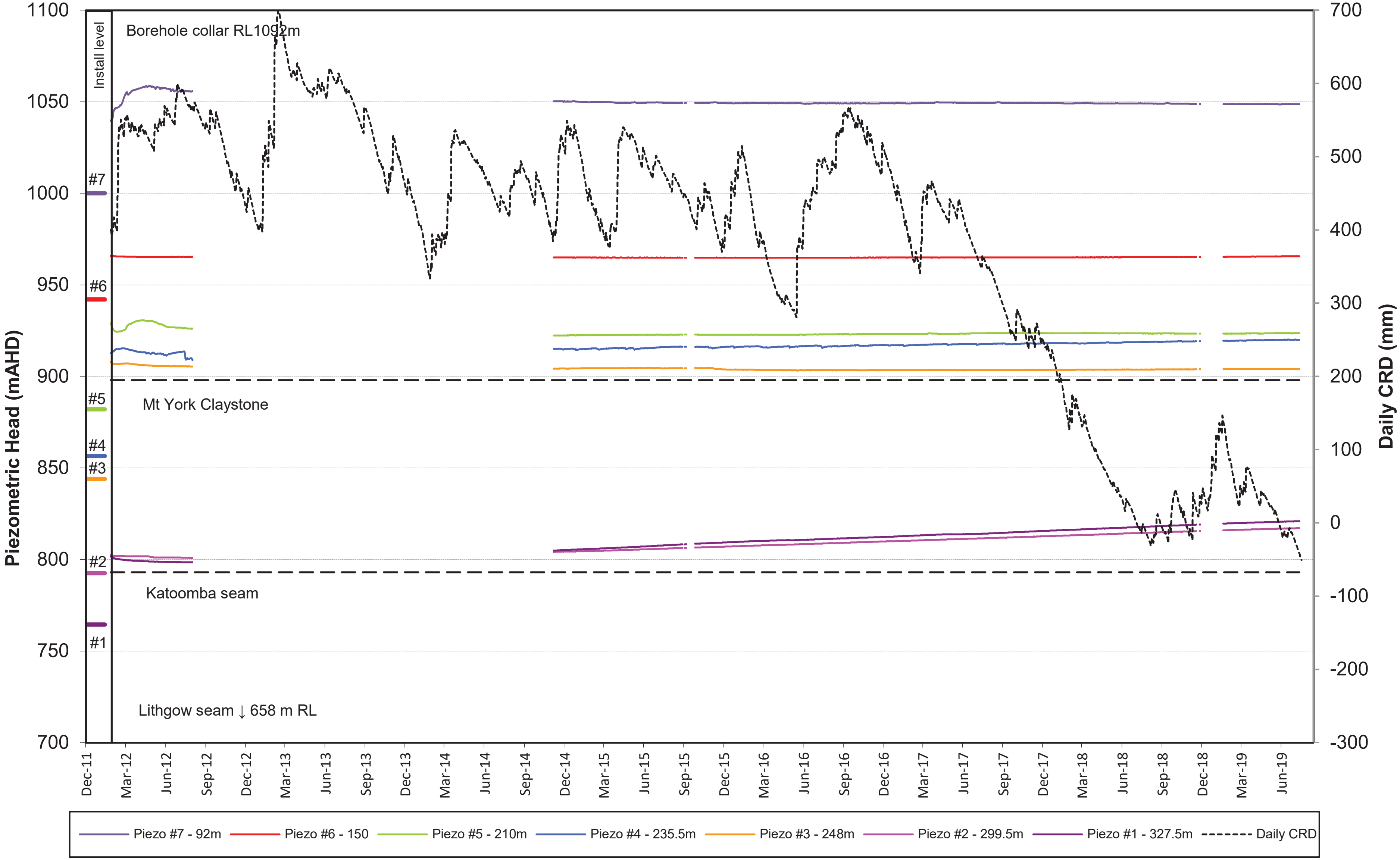
AP10PR VWP Hydrographs - Appendix D

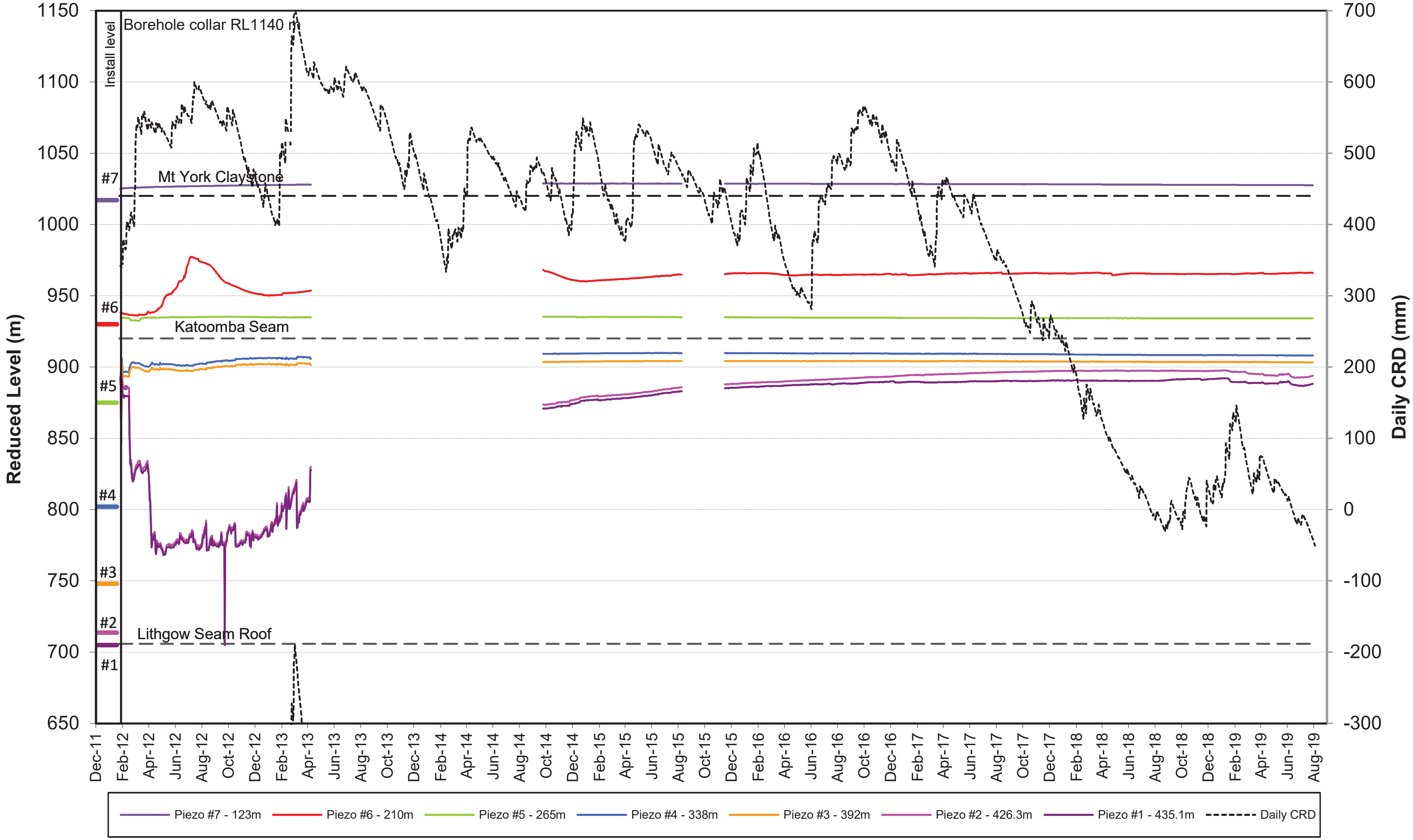
J:\IE\Projects\04_Eastern\IA161510\21 Deliverables\Appendices\D\data\[AP10PR.xls]Figure 12_AP10PR CRD



Borehole collar RL1154.5m
Piezometric Head (mAHD)
Daily CRD (mm)
Mt York Claystone
Katoomba Seam
Lithgow Seam Roof
Install level
#9
#8
#7
#6
#5
#4
#3
#2
#1
1150
1100
1050
1000
950
900
850
800
750
700
-300
-200
-100
0
100
200
300
400
500
600
700
Mar-10 Jun-10 Sep-10 Dec-10 Mar-11 Jun-11 Sep-11 Dec-11 Mar-12 Jun-12 Sep-12 Dec-12 Mar-13 Jun-13 Sep-13 Dec-13 Mar-14 Jun-14 Sep-14 Dec-14 Mar-15 Jun-15 Sep-15 Dec-15 Mar-16 Jun-16 Sep-16 Dec-16 Mar-17 Jun-17 Sep-17 Dec-17 Mar-18 Jun-18 Sep-18 Dec-18 Mar-19 Jun-19
Piezo #9 - 43m
Piezo #8 - 72m
Piezo #7 - 93m
Piezo #6 - 128m
Piezo #5 - 167m
Piezo #4 - 223m
Piezo #3 - 263m
Piezo #2 - 295m
Piezo #1 - 320m
Daily CRD

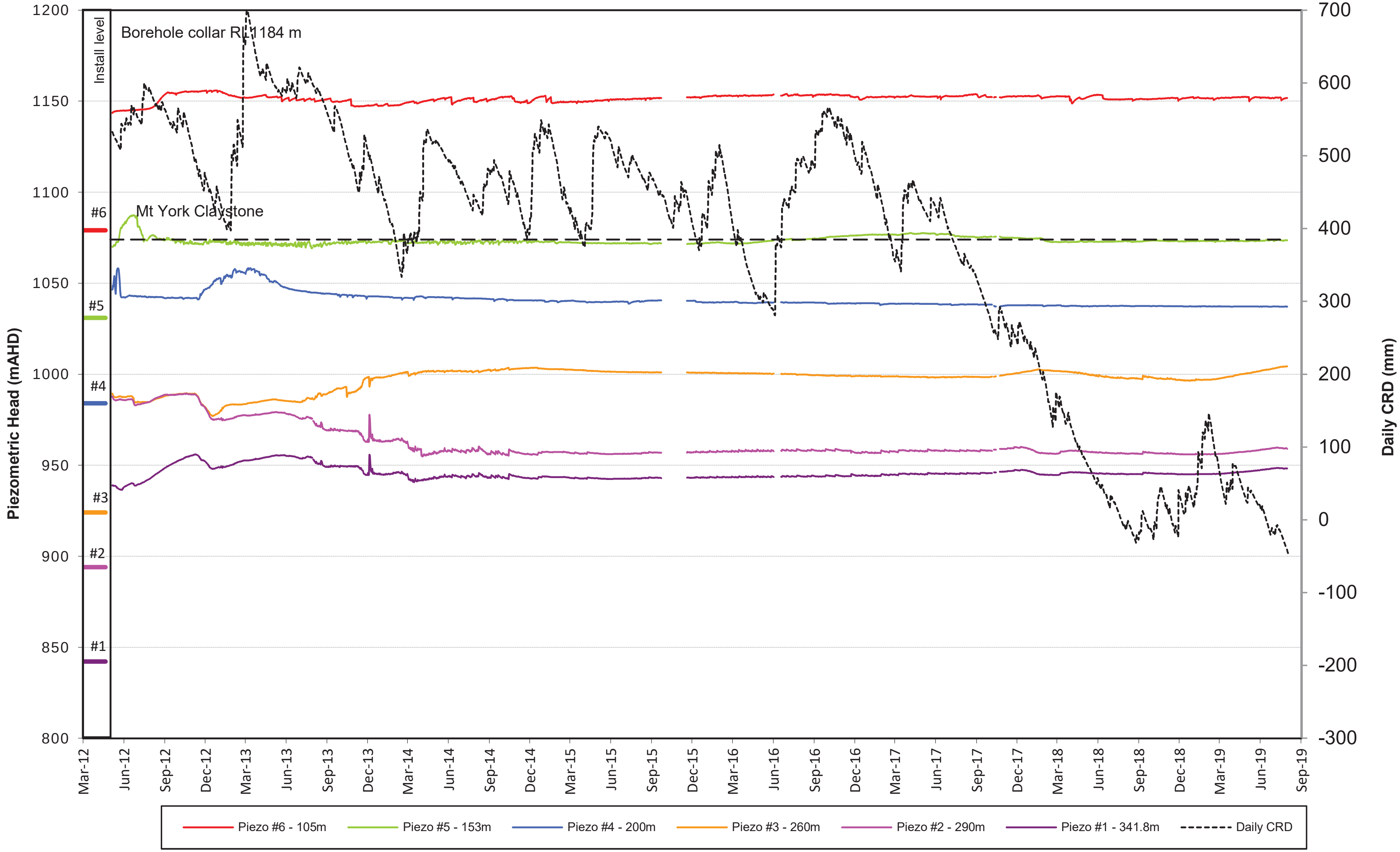


Borehole collar RL1092m
Install level
#7
#6
#5
#4
#3
#2
#1
Mt York Claystone
Katoomba seam
Lithgow seam ↓ 658 m RL
Piezometric Head (mAHD)
Daily CRD (mm)
1100
1050
1000
950
900
850
800
750
700
700
600
500
400
300
200
100
0
-100
-200
-300
Dec-11
Mar-12
Jun-12
Sep-12
Dec-12
Mar-13
Jun-13
Sep-13
Dec-13
Mar-14
Jun-14
Sep-14
Dec-14
Mar-15
Jun-15
Sep-15
Dec-15
Mar-16
Jun-16
Sep-16
Dec-16
Mar-17
Jun-17
Sep-17
Dec-17
Mar-18
Jun-18
Sep-18
Dec-18
Mar-19
Jun-19
Piezo #7 - 92m
Piezo #6 - 150
Piezo #5 - 210m
Piezo #4 - 235.5m
Piezo #3 - 248m
Piezo #2 - 299.5m
Piezo #1 - 327.5m
Daily CRD



AP1102 VWP Hydrographs - Appendix D

J:\IE\Projects\04_Eastern\IA161510\21 Deliverables\Appendices\D\data\[AP1102.xlsx]Figure 15_AP1102_CRD



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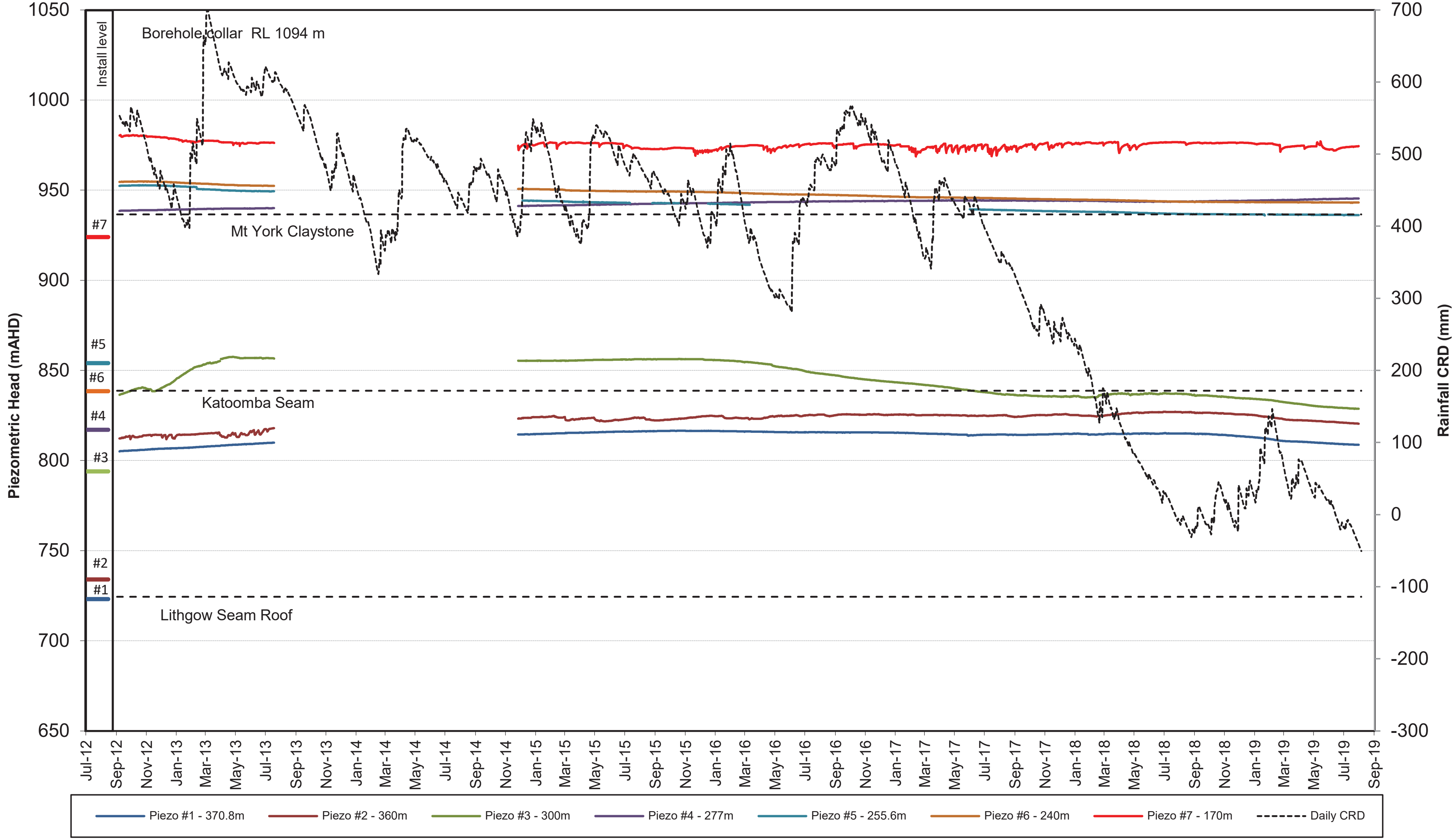
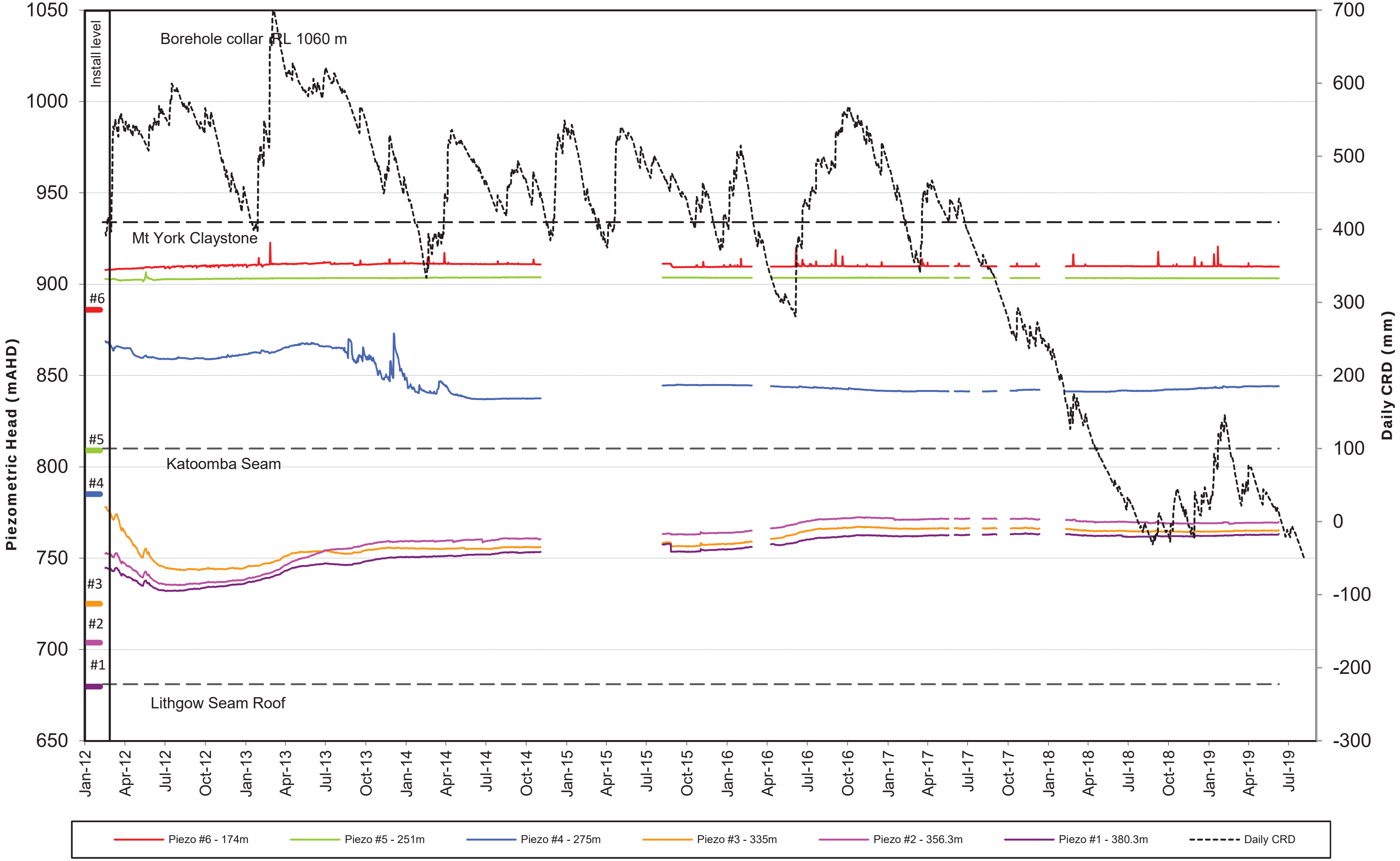
AP1103 VWP Hydrographs - Appendix D

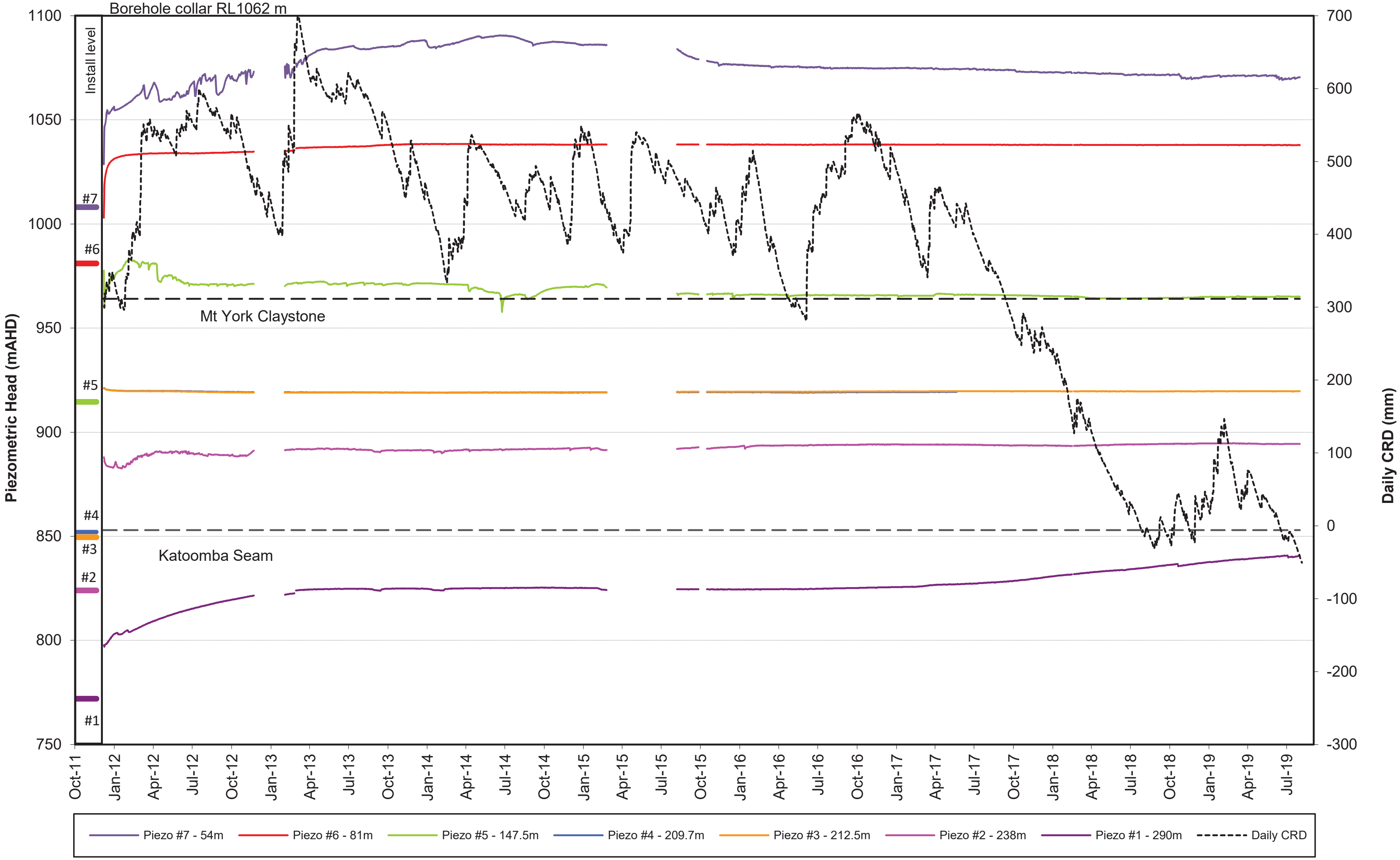
J:\IE\Projects\04_Eastern\IA161510\21 Deliverables\Appendices\D\data\[AP1103.xlsx]Figure 16_AP1103 CRD



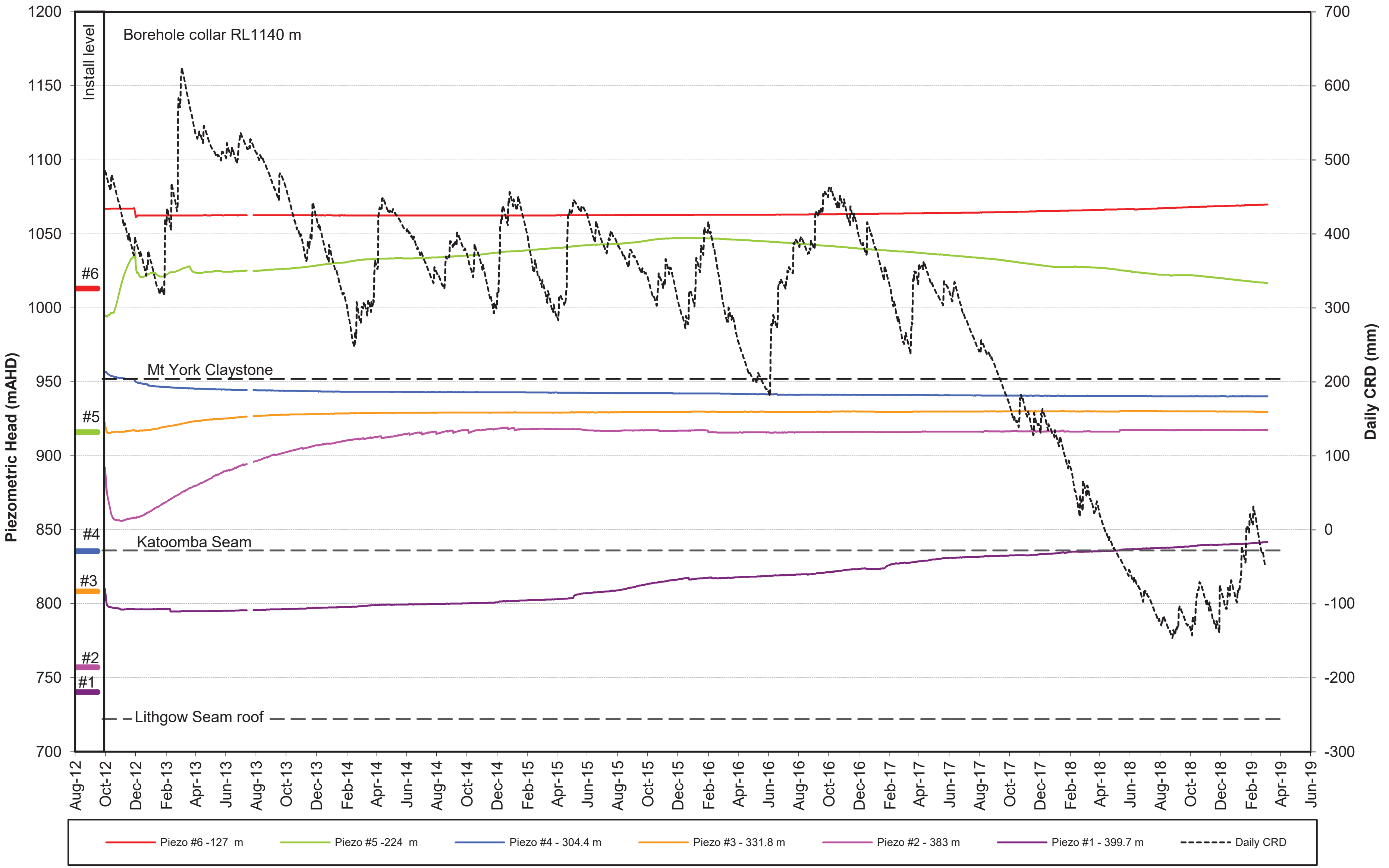
Borehole collar RL 1094 m
Install level
#7
#5
#6
#4
#3
#2
#1
Mt York Claystone
Katoomba Seam
Lithgow Seam Roof
Piezometric Head (mAHD)
Rainfall CRD (mm)
1050
1000
950
900
850
800
750
700
650
700
600
500
400
300
200
100
0
-100
-200
-300
Jul-12
Sep-12
Nov-12
Jan-13
Mar-13
May-13
Jul-13
Sep-13
Nov-13
Jan-14
Mar-14
May-14
Jul-14
Sep-14
Nov-14
Jan-15
Mar-15
May-15
Jul-15
Sep-15
Nov-15
Jan-16
Mar-16
May-16
Jul-16
Sep-16
Nov-16
Jan-17
Mar-17
May-17
Jul-17
Sep-17
Nov-17
Jan-18
Mar-18
May-18
Jul-18
Sep-18
Nov-18
Jan-19
Mar-19
May-19
Jul-19
Sep-19
Piezo #1 - 370.8m
Piezo #2 - 360m
Piezo #3 - 300m
Piezo #4 - 277m
Piezo #5 - 255.6m
Piezo #6 - 240m
Piezo #7 - 170m
Daily CRD



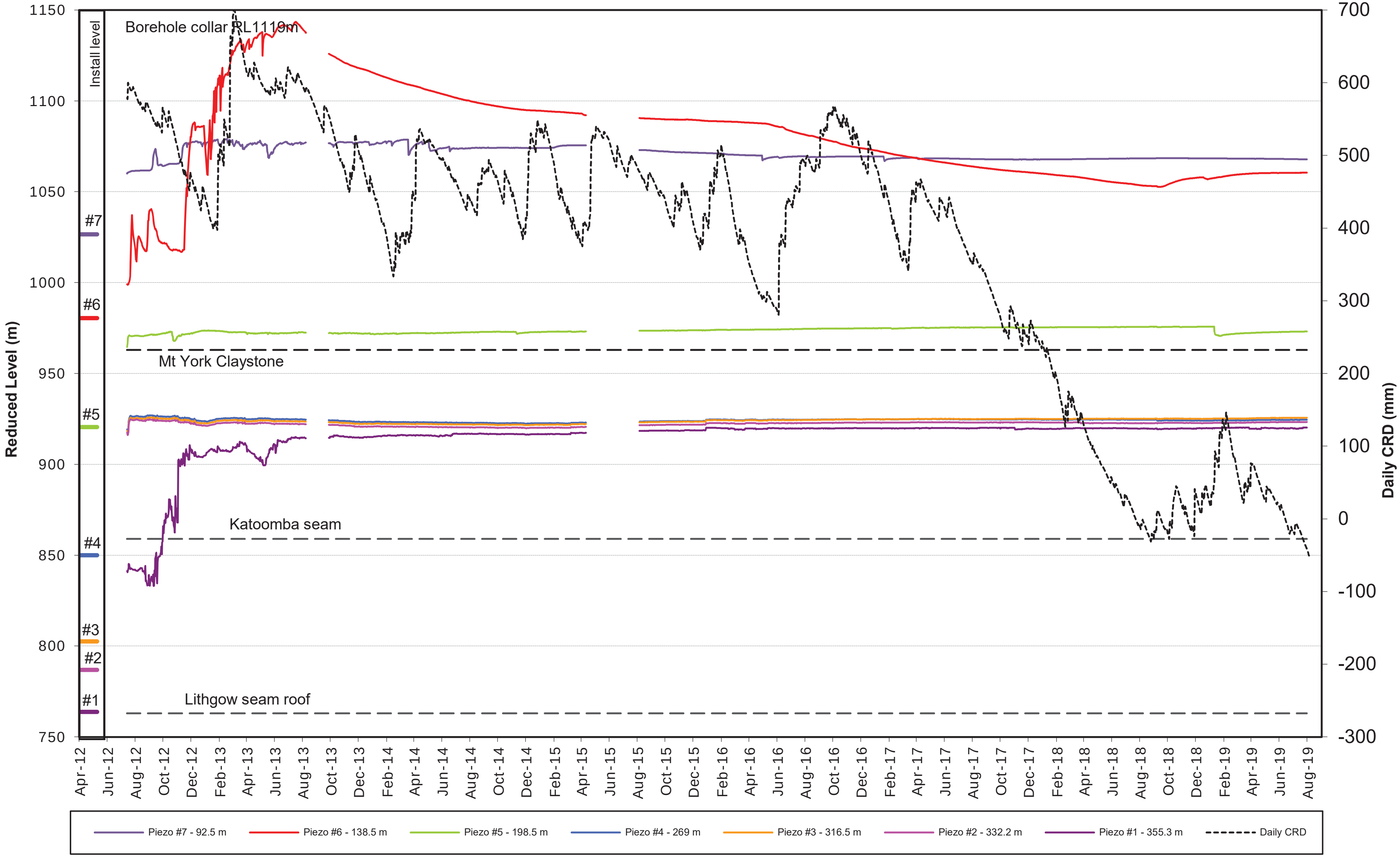
Borehole collar RL 1060 m
Install level
Mt York Claystone
Katoomba Seam
Lithgow Seam Roof
#6
#5
#4
#3
#2
#1
Piezometric Head (mAHD)
Daily CRD (mm)
1050
1000
950
900
850
800
750
700
650
700
600
500
400
300
200
100
0
-100
-200
-300
Jan-12
Apr-12
Jul-12
Oct-12
Jan-13
Apr-13
Jul-13
Oct-13
Jan-14
Apr-14
Jul-14
Oct-14
Jan-15
Apr-15
Jul-15
Oct-15
Jan-16
Apr-16
Jul-16
Oct-16
Jan-17
Apr-17
Jul-17
Oct-17
Jan-18
Apr-18
Jul-18
Oct-18
Jan-19
Apr-19
Jul-19
Piezo #6 - 174m
Piezo #5 - 251m
Piezo #4 - 275m
Piezo #3 - 335m
Piezo #2 - 356.3m
Piezo #1 - 380.3m
Daily CRD



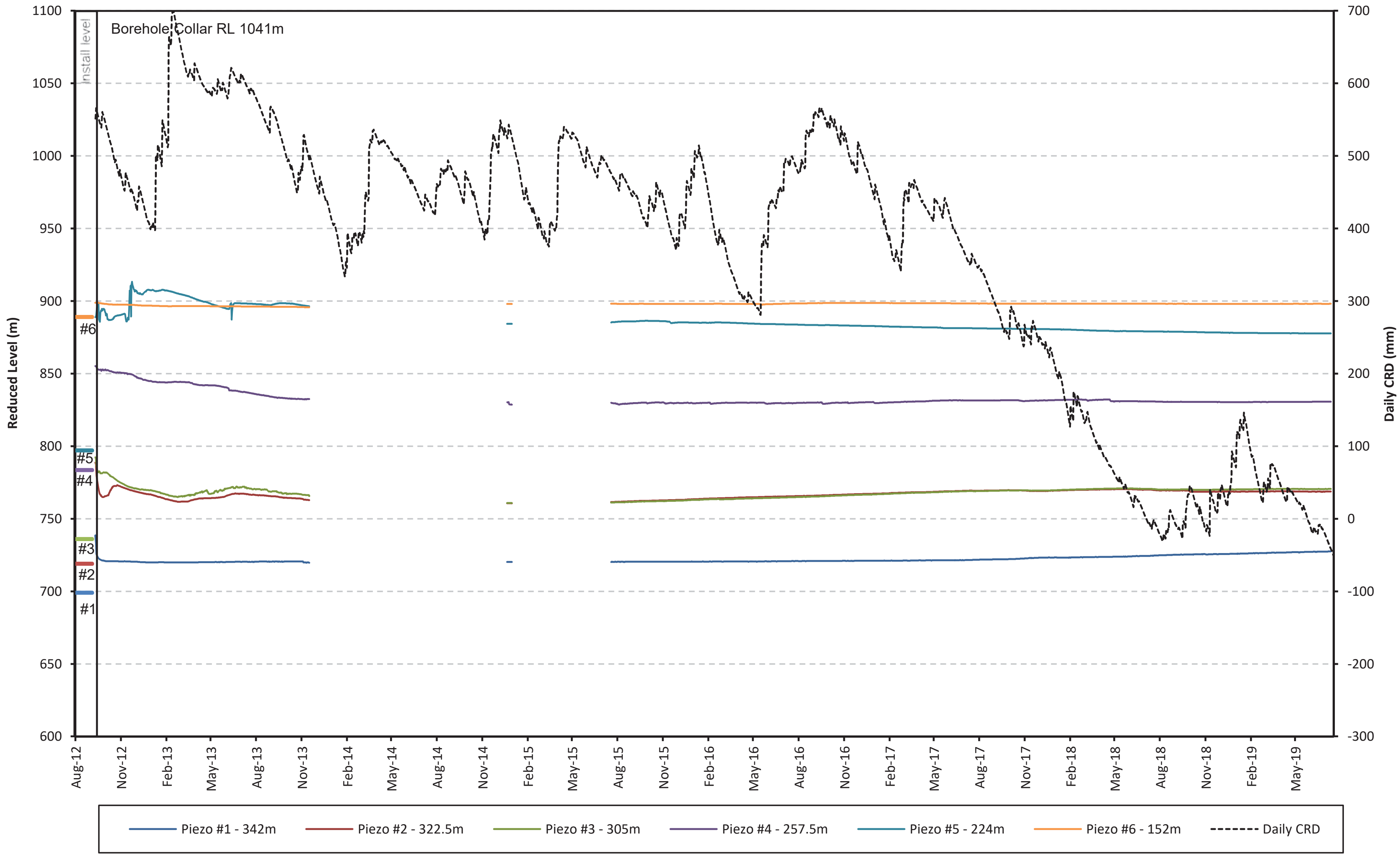
Borehole collar RL1062 m
Install level
#7
#6
#5
#4
#3
#2
#1
Mt York Claystone
Katoomba Seam
Piezometric Head (mAHD)
Daily CRD (mm)
1100
1050
1000
950
900
850
800
750
700
600
500
400
300
200
100
0
-100
-200
-300
Oct-11
Jan-12
Apr-12
Jul-12
Oct-12
Jan-13
Apr-13
Jul-13
Oct-13
Jan-14
Apr-14
Jul-14
Oct-14
Jan-15
Apr-15
Jul-15
Oct-15
Jan-16
Apr-16
Jul-16
Oct-16
Jan-17
Apr-17
Jul-17
Oct-17
Jan-18
Apr-18
Jul-18
Oct-18
Jan-19
Apr-19
Jul-19
Piezo #7 - 54m
Piezo #6 - 81m
Piezo #5 - 147.5m
Piezo #4 - 209.7m
Piezo #3 - 212.5m
Piezo #2 - 238m
Piezo #1 - 290m
Daily CRD



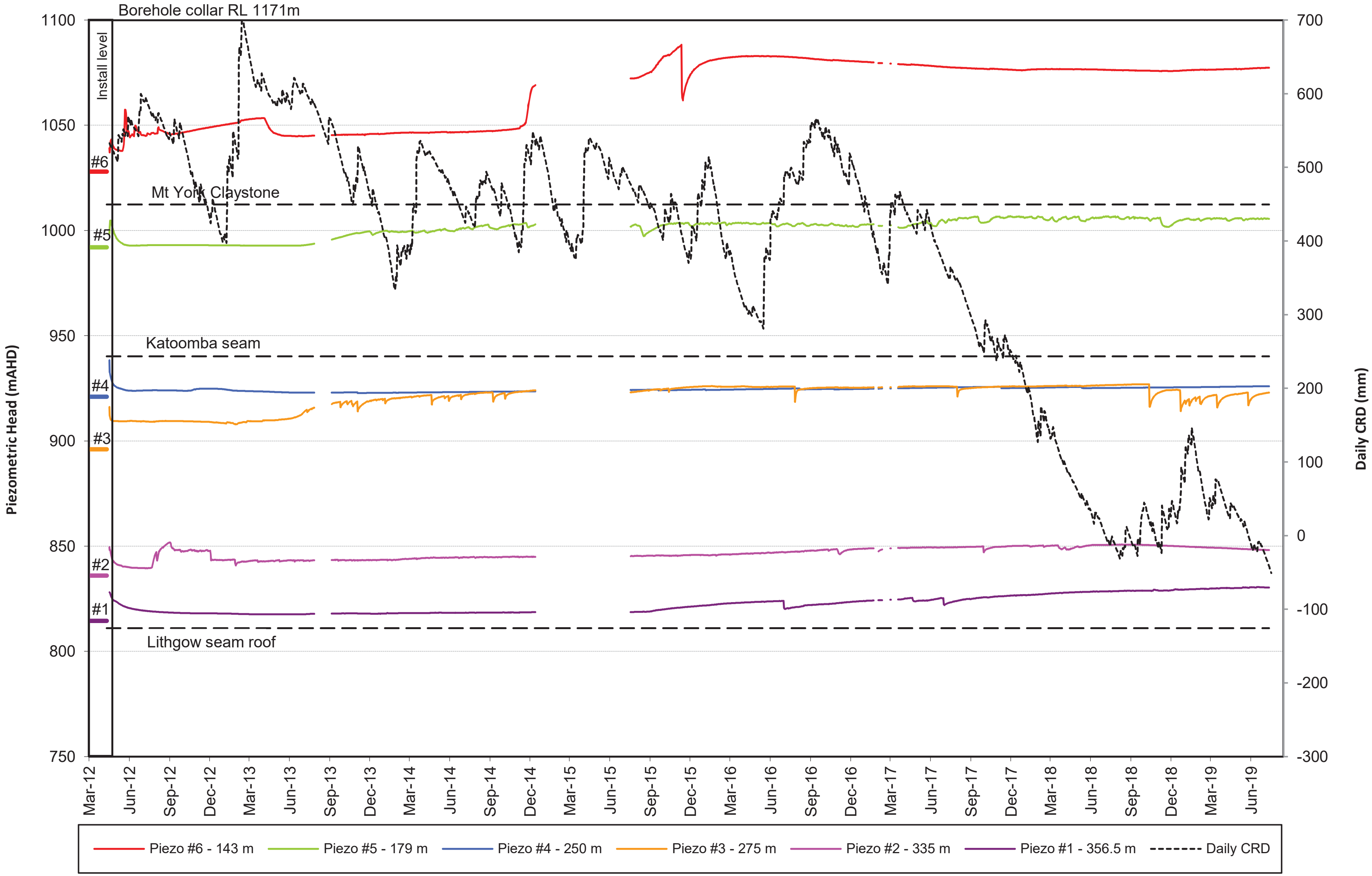
Borehole collar RL1140 m
Install level
Piezometric Head (mAHD)
Daily CRD (mm)
1200
1150
1100
1050
1000
950
900
850
800
750
700
700
600
500
400
300
200
100
0
-100
-200
-300
#6
#5
#4
#3
#2
#1
Mt York Claystone
Katoomba Seam
Lithgow Seam roof
Aug-12
Oct-12
Dec-12
Feb-13
Apr-13
Jun-13
Aug-13
Oct-13
Dec-13
Feb-14
Apr-14
Jun-14
Aug-14
Oct-14
Dec-14
Feb-15
Apr-15
Jun-15
Aug-15
Oct-15
Dec-15
Feb-16
Apr-16
Jun-16
Aug-16
Oct-16
Dec-16
Feb-17
Apr-17
Jun-17
Aug-17
Oct-17
Dec-17
Feb-18
Apr-18
Jun-18
Aug-18
Oct-18
Dec-18
Feb-19
Apr-19
Jun-19
Piezo #6 -127 m
Piezo #5 -224 m
Piezo #4 - 304.4 m
Piezo #3 - 331.8 m
Piezo #2 - 383 m
Piezo #1 - 399.7 m
Daily CRD



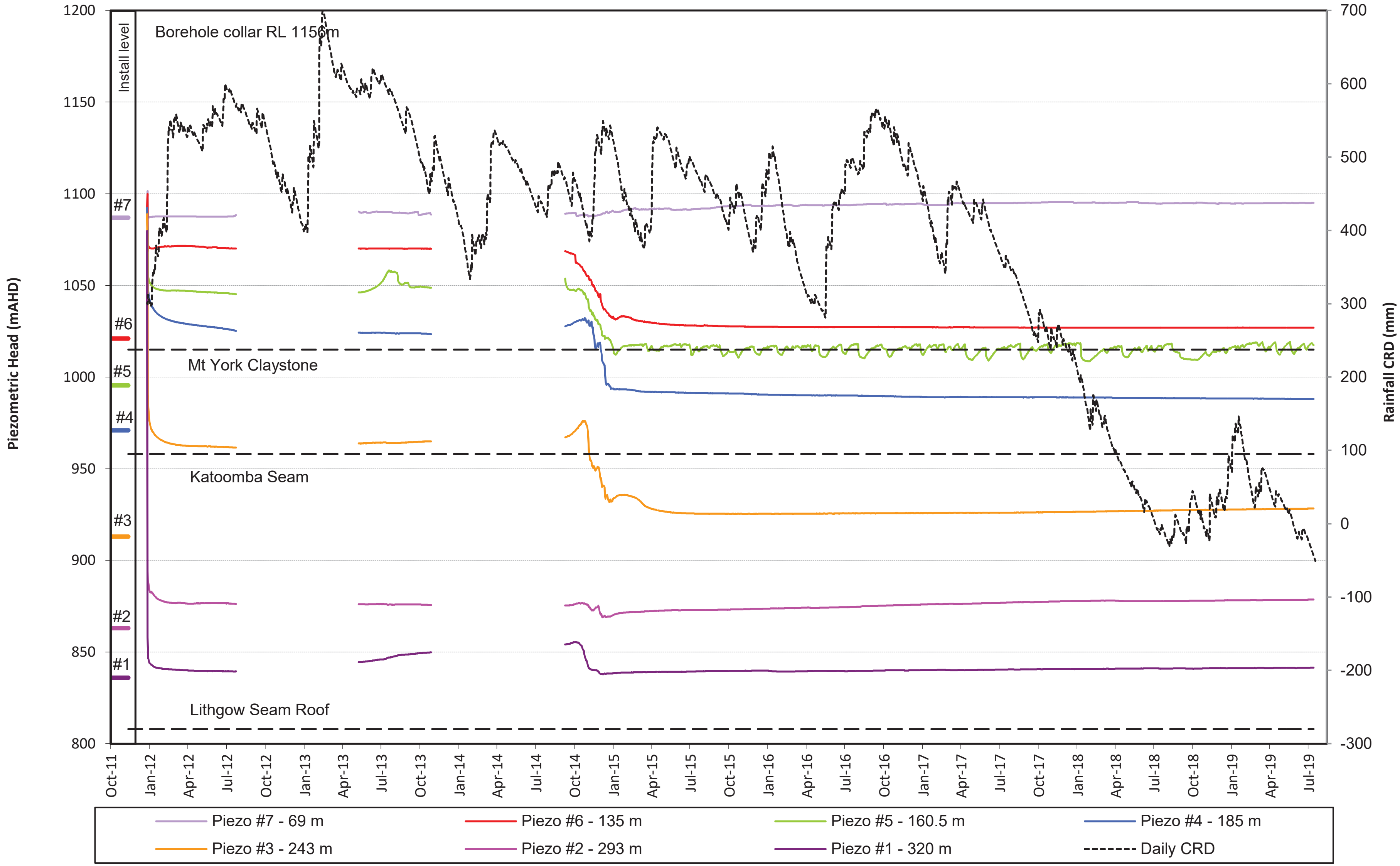
Borehole collar RL1119m
Install level
Mt York Claystone
Katoomba seam
Lithgow seam roof
#7
#6
#5
#4
#3
#2
#1
Reduced Level (m)
Daily CRD (mm)
1150
1100
1050
1000
950
900
850
800
750
700
600
500
400
300
200
100
0
-100
-200
-300
Apr-12
Jun-12
Aug-12
Oct-12
Dec-12
Feb-13
Apr-13
Jun-13
Aug-13
Oct-13
Dec-13
Feb-14
Apr-14
Jun-14
Aug-14
Oct-14
Dec-14
Feb-15
Apr-15
Jun-15
Aug-15
Oct-15
Dec-15
Feb-16
Apr-16
Jun-16
Aug-16
Oct-16
Dec-16
Feb-17
Apr-17
Jun-17
Aug-17
Oct-17
Dec-17
Feb-18
Apr-18
Jun-18
Aug-18
Oct-18
Dec-18
Feb-19
Apr-19
Jun-19
Aug-19
Piezo #7 - 92.5 m
Piezo #6 - 138.5 m
Piezo #5 - 198.5 m
Piezo #4 - 269 m
Piezo #3 - 316.5 m
Piezo #2 - 332.2 m
Piezo #1 - 355.3 m
Daily CRD



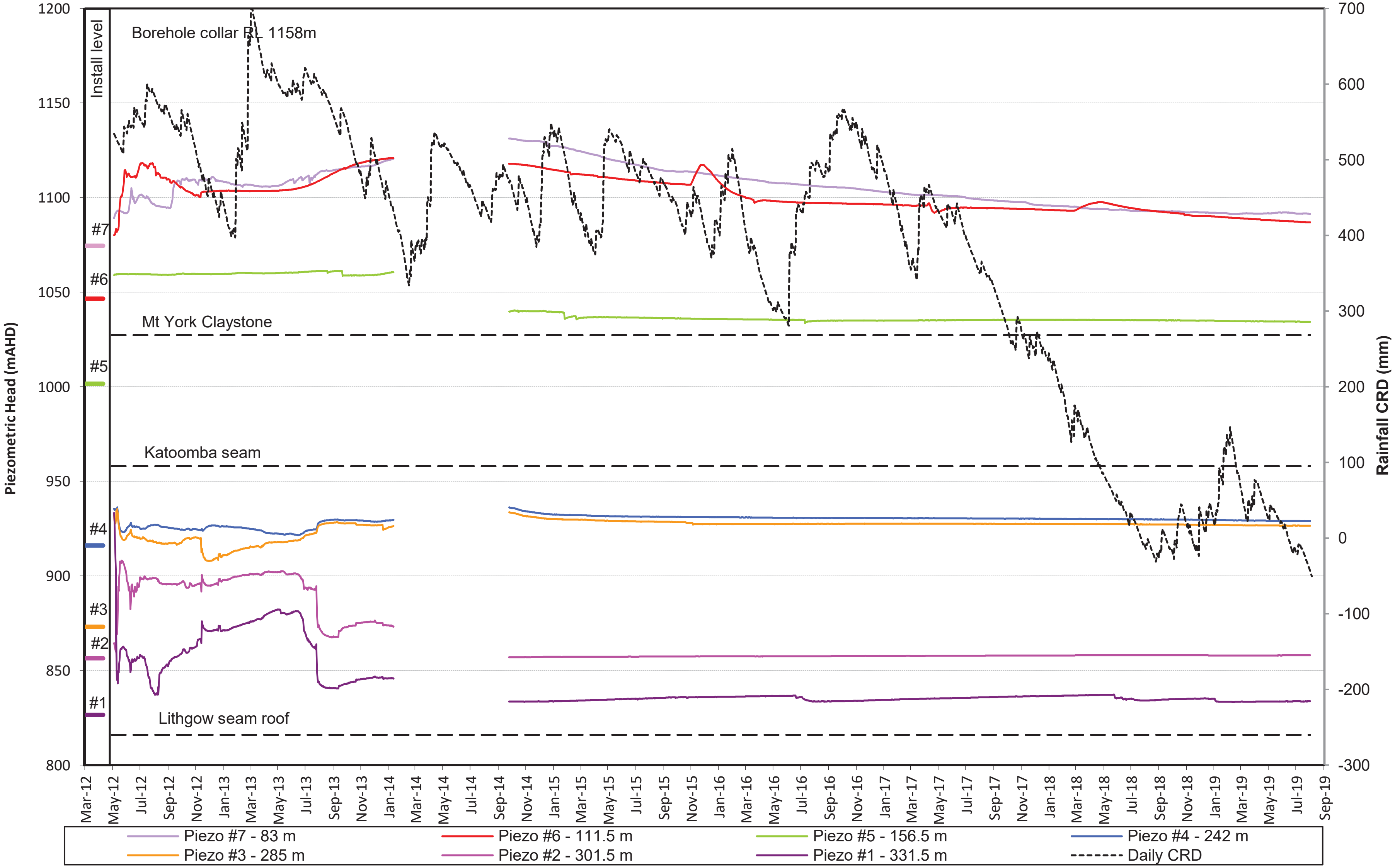
Borehole Collar RL 1041m
Install level
Reduced Level (m)
Daily CRD (mm)
1100
1050
1000
950
900
850
800
750
700
650
600
700
600
500
400
300
200
100
0
-100
-200
-300
#6
#5
#4
#3
#2
#1
Aug-12
Nov-12
Feb-13
May-13
Aug-13
Nov-13
Feb-14
May-14
Aug-14
Nov-14
Feb-15
May-15
Aug-15
Nov-15
Feb-16
May-16
Aug-16
Nov-16
Feb-17
May-17
Aug-17
Nov-17
Feb-18
May-18
Aug-18
Nov-18
Feb-19
May-19
Piezo #1 - 342m
Piezo #2 - 322.5m
Piezo #3 - 305m
Piezo #4 - 257.5m
Piezo #5 - 224m
Piezo #6 - 152m
Daily CRD



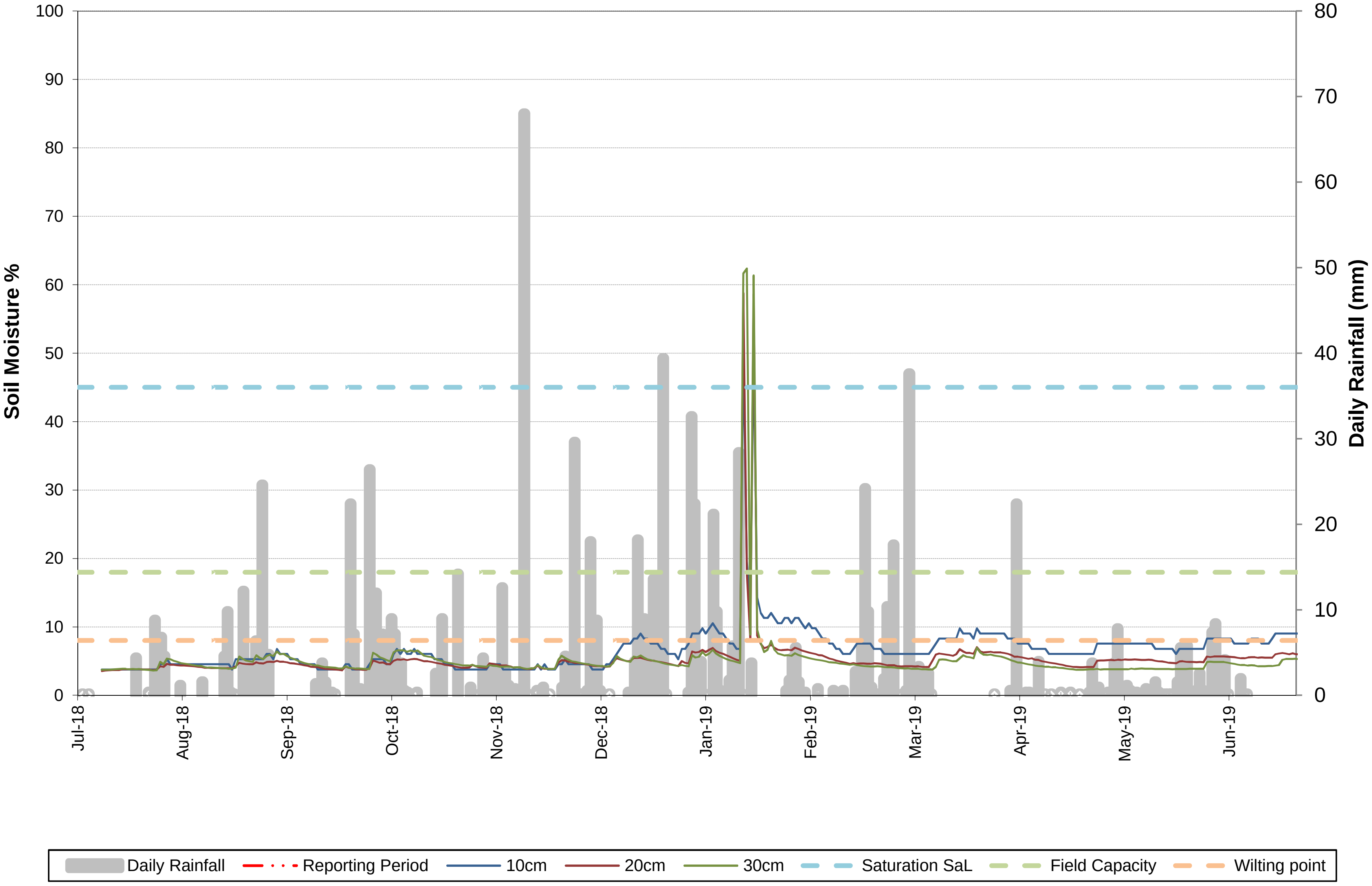
Borehole collar RL 1171m
Install level
Mt York Claystone
Katoomba seam
Lithgow seam roof
#6
#5
#4
#3
#2
#1
Piezometric Head (mAHD)
Daily CRD (mm)
1100
1050
1000
950
900
850
800
750
700
600
500
400
300
200
100
0
-100
-200
-300
Mar-12
Jun-12
Sep-12
Dec-12
Mar-13
Jun-13
Sep-13
Dec-13
Mar-14
Jun-14
Sep-14
Dec-14
Mar-15
Jun-15
Sep-15
Dec-15
Mar-16
Jun-16
Sep-16
Dec-16
Mar-17
Jun-17
Sep-17
Dec-17
Mar-18
Jun-18
Sep-18
Dec-18
Mar-19
Jun-19
Piezo #6 - 143 m
Piezo #5 - 179 m
Piezo #4 - 250 m
Piezo #3 - 275 m
Piezo #2 - 335 m
Piezo #1 - 356.5 m
Daily CRD



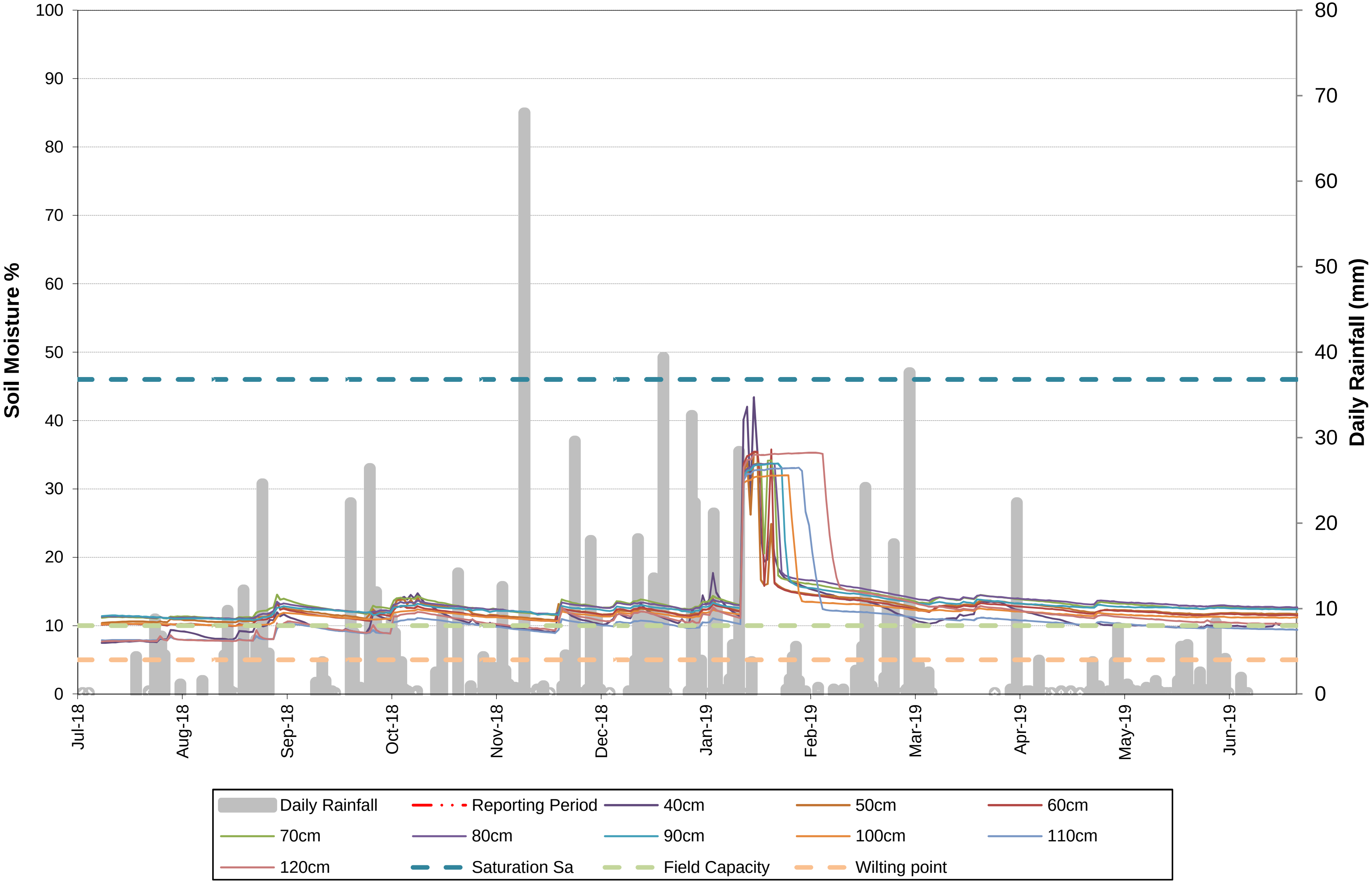
Borehole collar RL 1156m
Install level
Mt York Claystone
Katoomba Seam
Lithgow Seam Roof
#7
#6
#5
#4
#3
#2
#1
Piezometric Head (mAHD)
Rainfall CRD (mm)
1200
1150
1100
1050
1000
950
900
850
800
700
600
500
400
300
200
100
0
-100
-200
-300
Oct-11
Jan-12
Apr-12
Jul-12
Oct-12
Jan-13
Apr-13
Jul-13
Oct-13
Jan-14
Apr-14
Jul-14
Oct-14
Jan-15
Apr-15
Jul-15
Oct-15
Jan-16
Apr-16
Jul-16
Oct-16
Jan-17
Apr-17
Jul-17
Oct-17
Jan-18
Apr-18
Jul-18
Oct-18
Jan-19
Apr-19
Jul-19
Piezo #7 - 69 m
Piezo #6 - 135 m
Piezo #5 - 160.5 m
Piezo #4 - 185 m
Piezo #3 - 243 m
Piezo #2 - 293 m
Piezo #1 - 320 m
Daily CRD



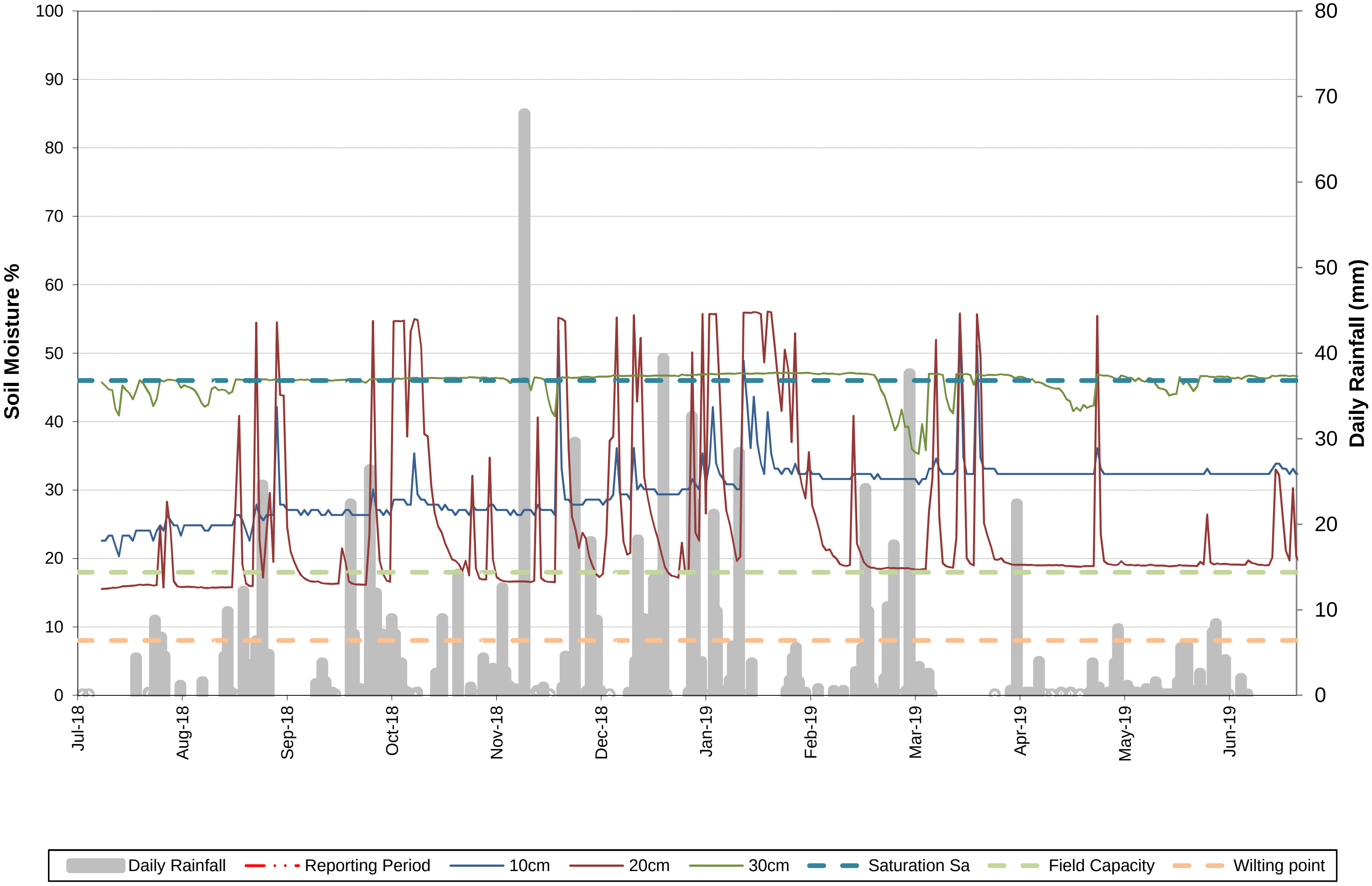
Borehole collar RL 1158m
Install level
Mt York Claystone
Katoomba seam
Lithgow seam roof
#7
#6
#5
#4
#3
#2
#1
Piezometric Head (mAHD)
Rainfall CRD (mm)
1200
1150
1100
1050
1000
950
900
850
800
700
600
500
400
300
200
100
0
-100
-200
-300
Mar-12
May-12
Jul-12
Sep-12
Nov-12
Jan-13
Mar-13
May-13
Jul-13
Sep-13
Nov-13
Jan-14
Mar-14
May-14
Jul-14
Sep-14
Nov-14
Jan-15
Mar-15
May-15
Jul-15
Sep-15
Nov-15
Jan-16
Mar-16
May-16
Jul-16
Sep-16
Nov-16
Jan-17
Mar-17
May-17
Jul-17
Sep-17
Nov-17
Jan-18
Mar-18
May-18
Jul-18
Sep-18
Nov-18
Jan-19
Mar-19
May-19
Jul-19
Sep-19
Piezo #7 - 83 m
Piezo #6 - 111.5 m
Piezo #5 - 156.5 m
Piezo #4 - 242 m
Piezo #3 - 285 m
Piezo #2 - 301.5 m
Piezo #1 - 331.5 m
Daily CRD



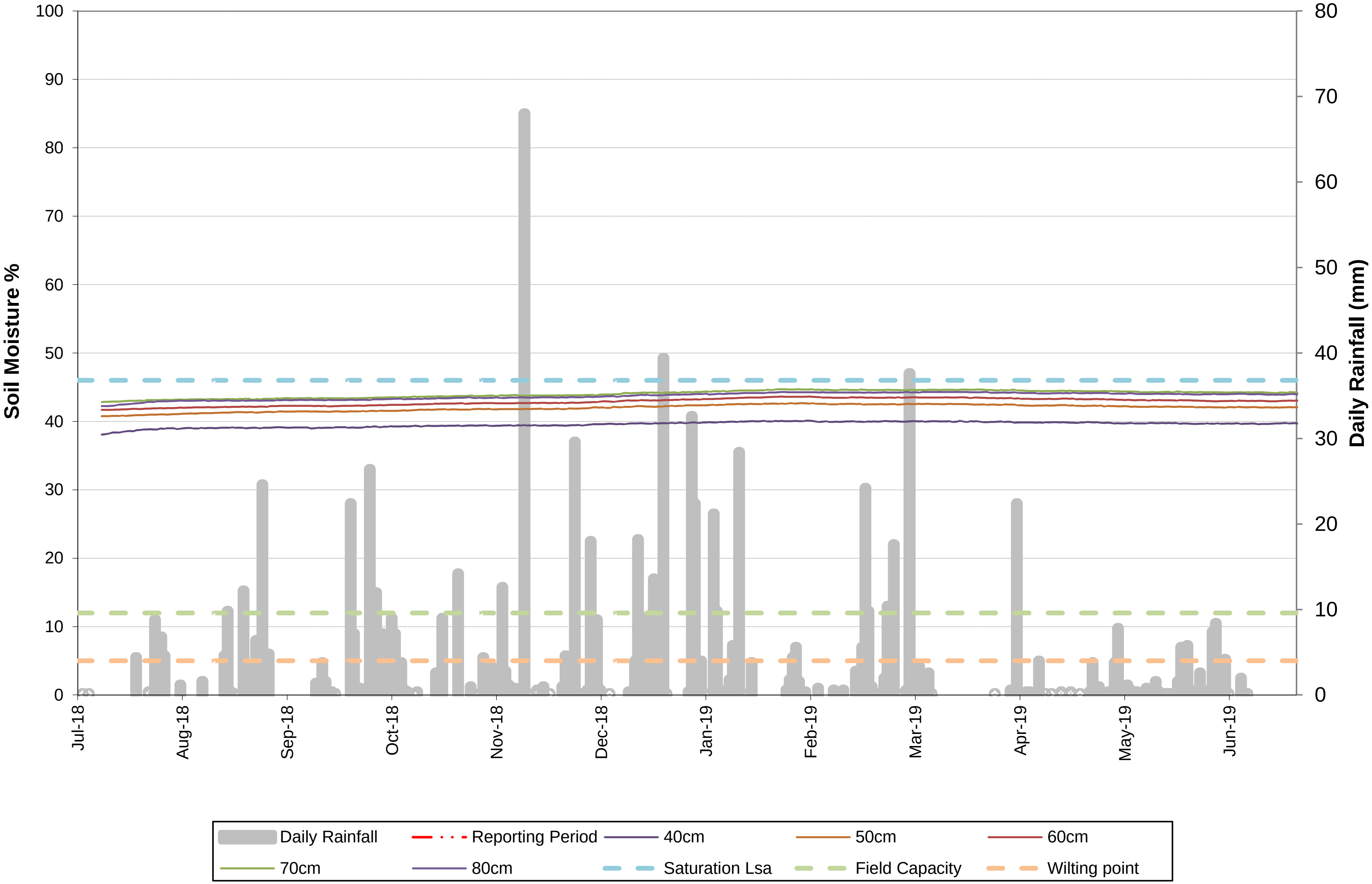
Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
10cm
20cm
30cm
Saturation SaL
Field Capacity
Wilting point

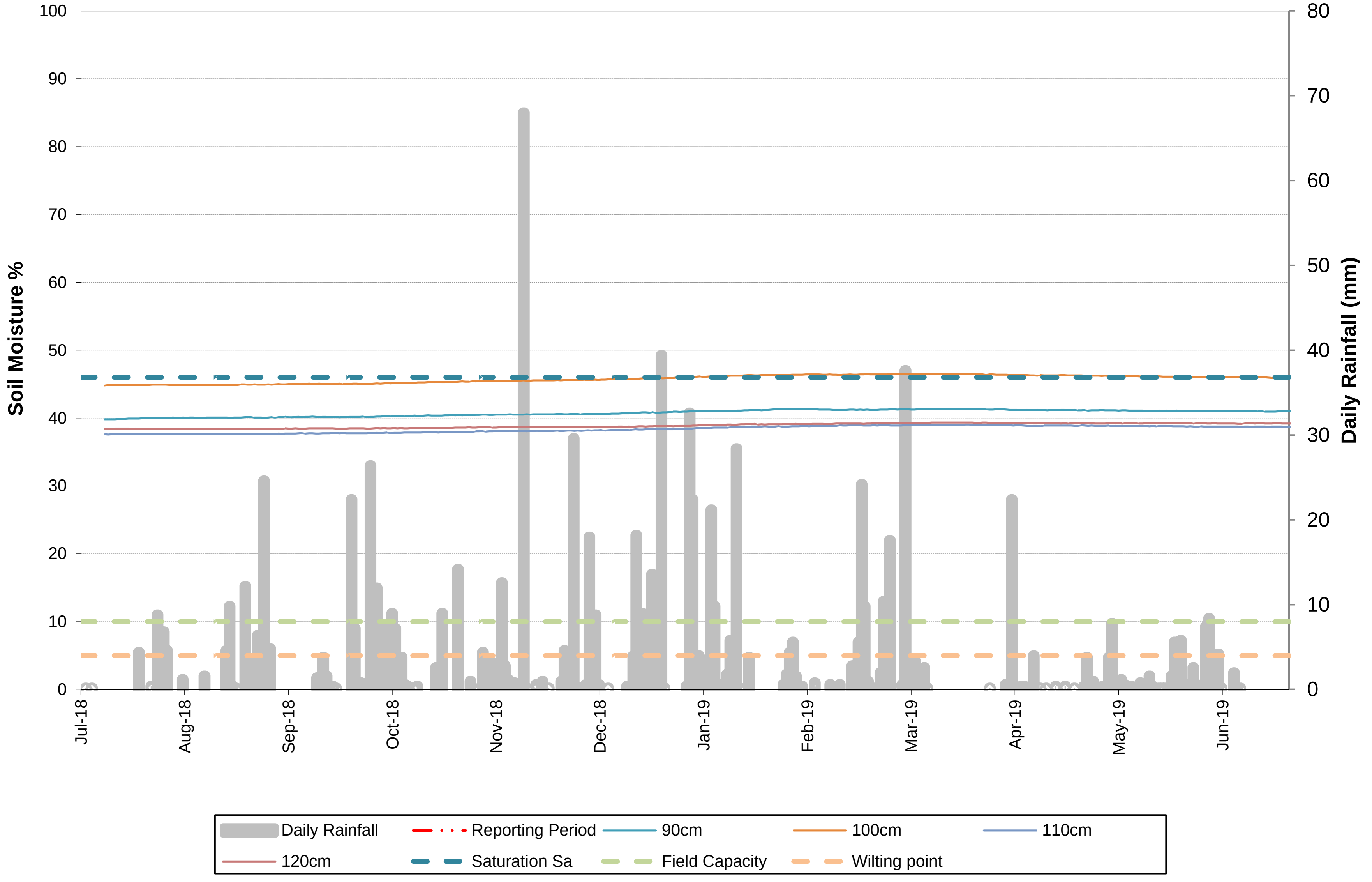


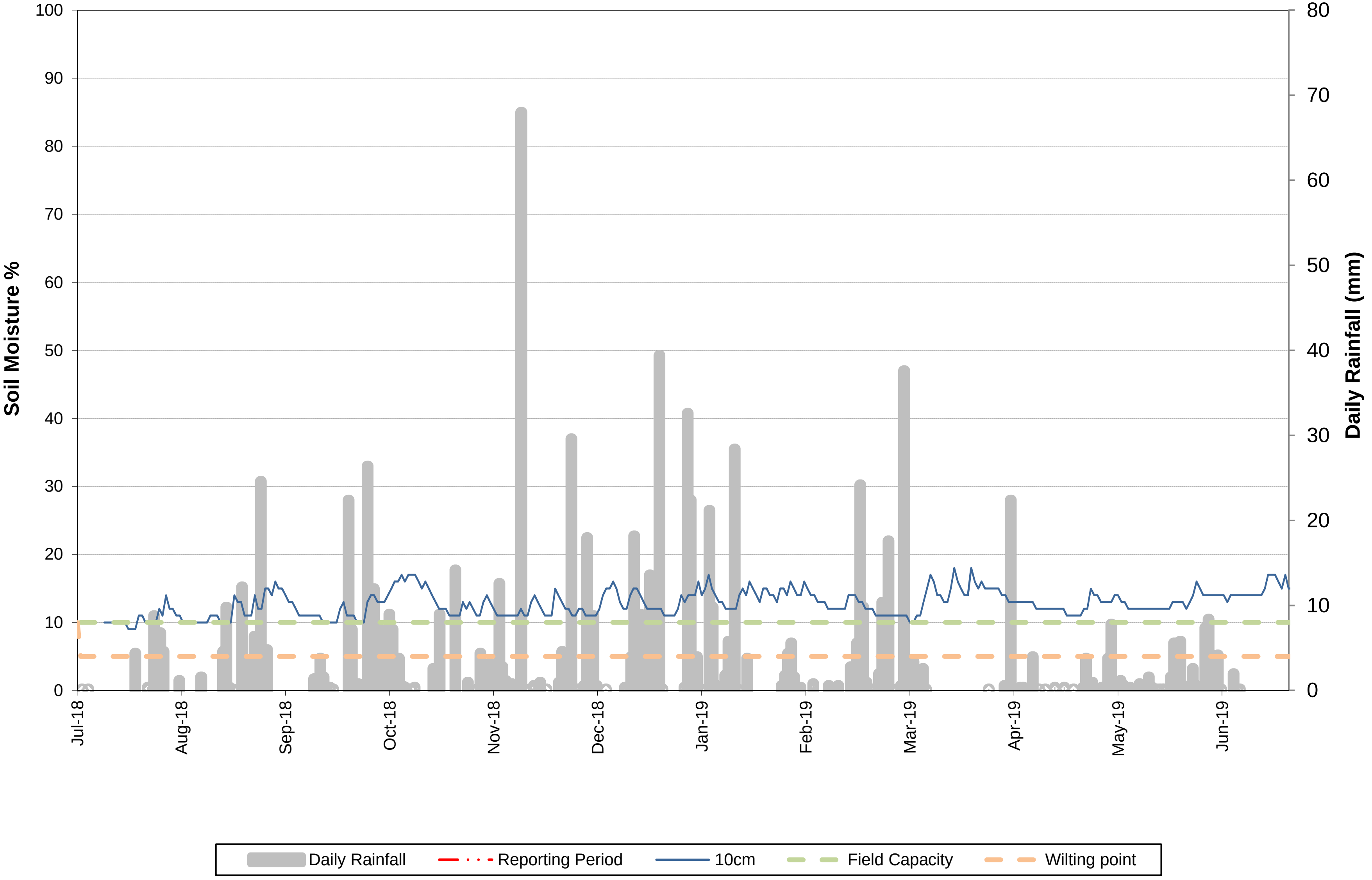
Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
40cm
50cm
60cm
70cm
80cm
90cm
100cm
110cm
120cm
Saturation Sa
Field Capacity
Wilting point



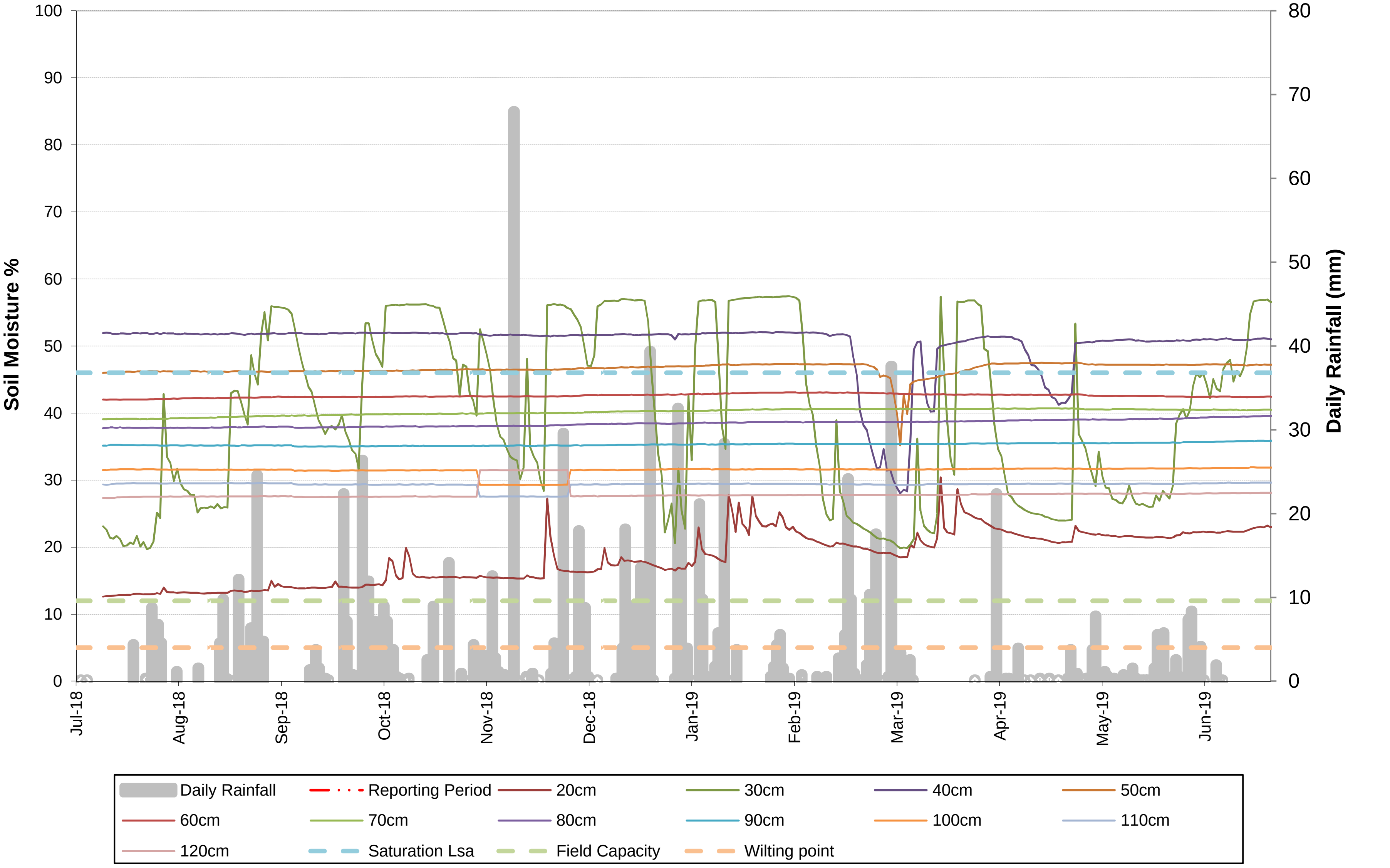
Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
10cm
20cm
30cm
Saturation Sa
Field Capacity
Wilting point


Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
40cm
50cm
60cm
70cm
80cm
Saturation Lsa
Field Capacity
Wilting point

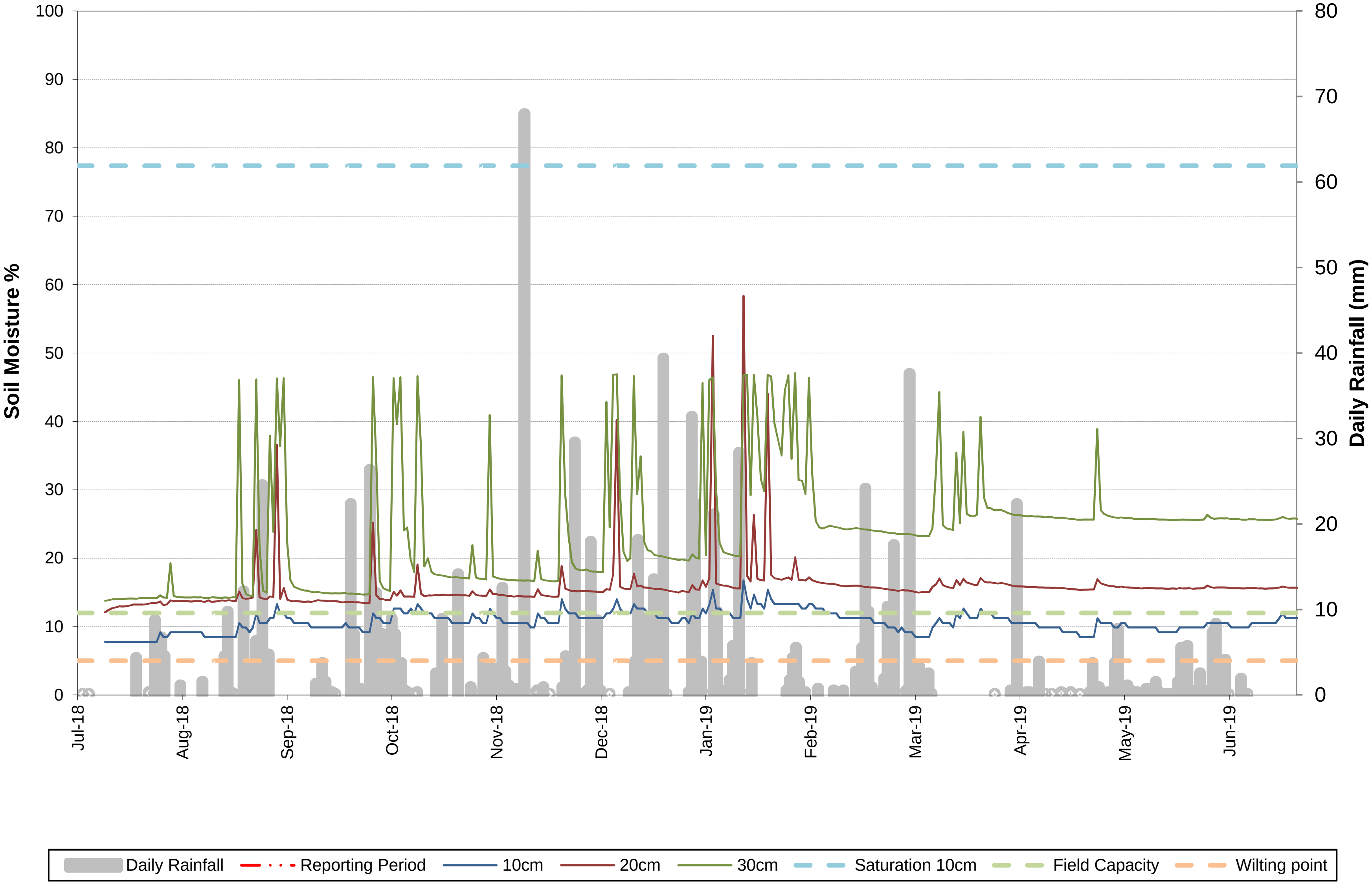

Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
90cm
100cm
110cm
120cm
Saturation Sa
Field Capacity
Wilting point



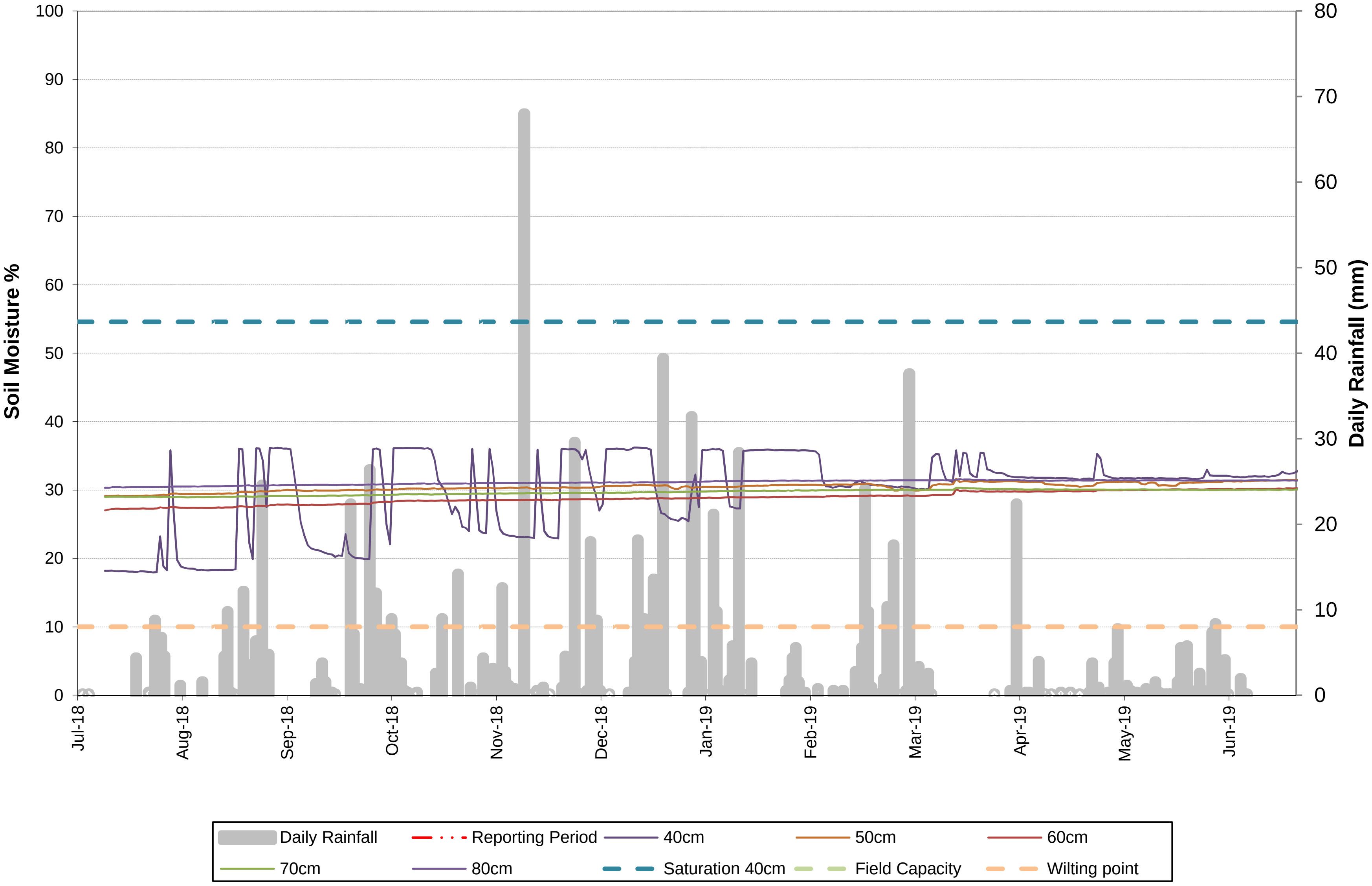
Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
10cm
Field Capacity
Wilting point



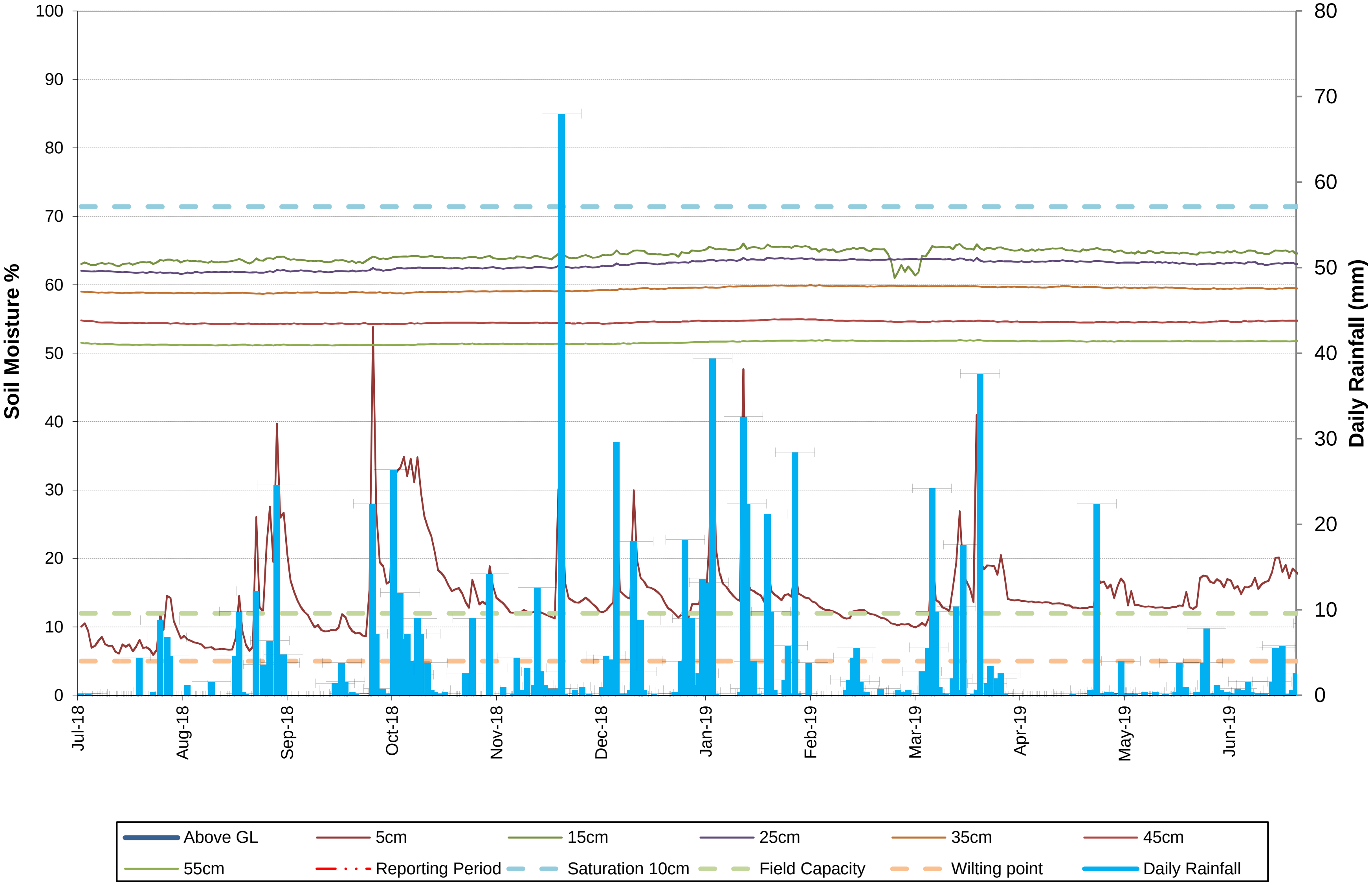
Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
20cm
30cm
40cm
50cm
60cm
70cm
80cm
90cm
100cm
110cm
120cm
Saturation Lsa
Field Capacity
Wilting point



Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
10cm
20cm
30cm
Saturation 10cm
Field Capacity
Wilting point



Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
40cm
50cm
60cm
70cm
80cm
Saturation 40cm
Field Capacity
Wilting point



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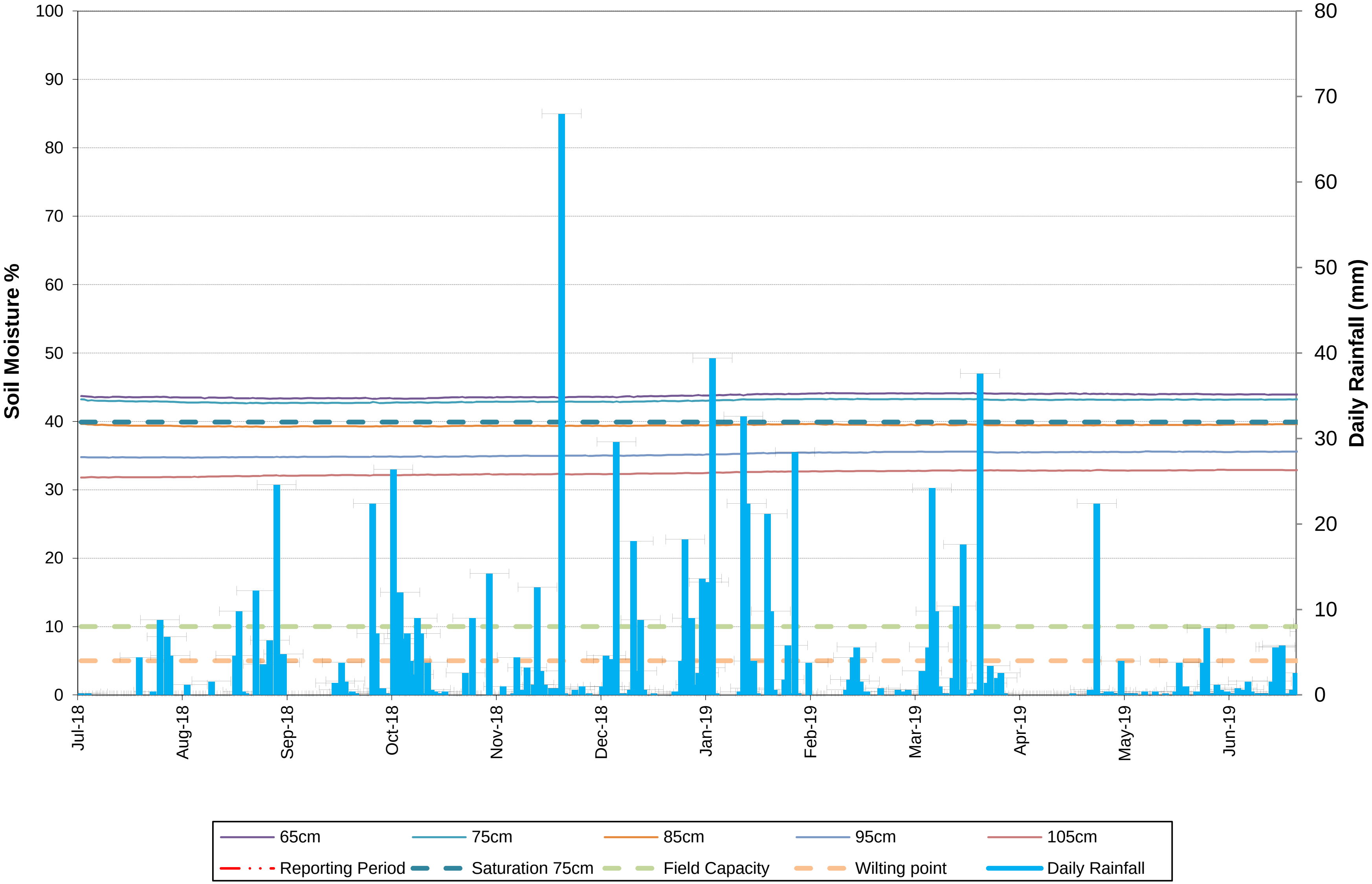
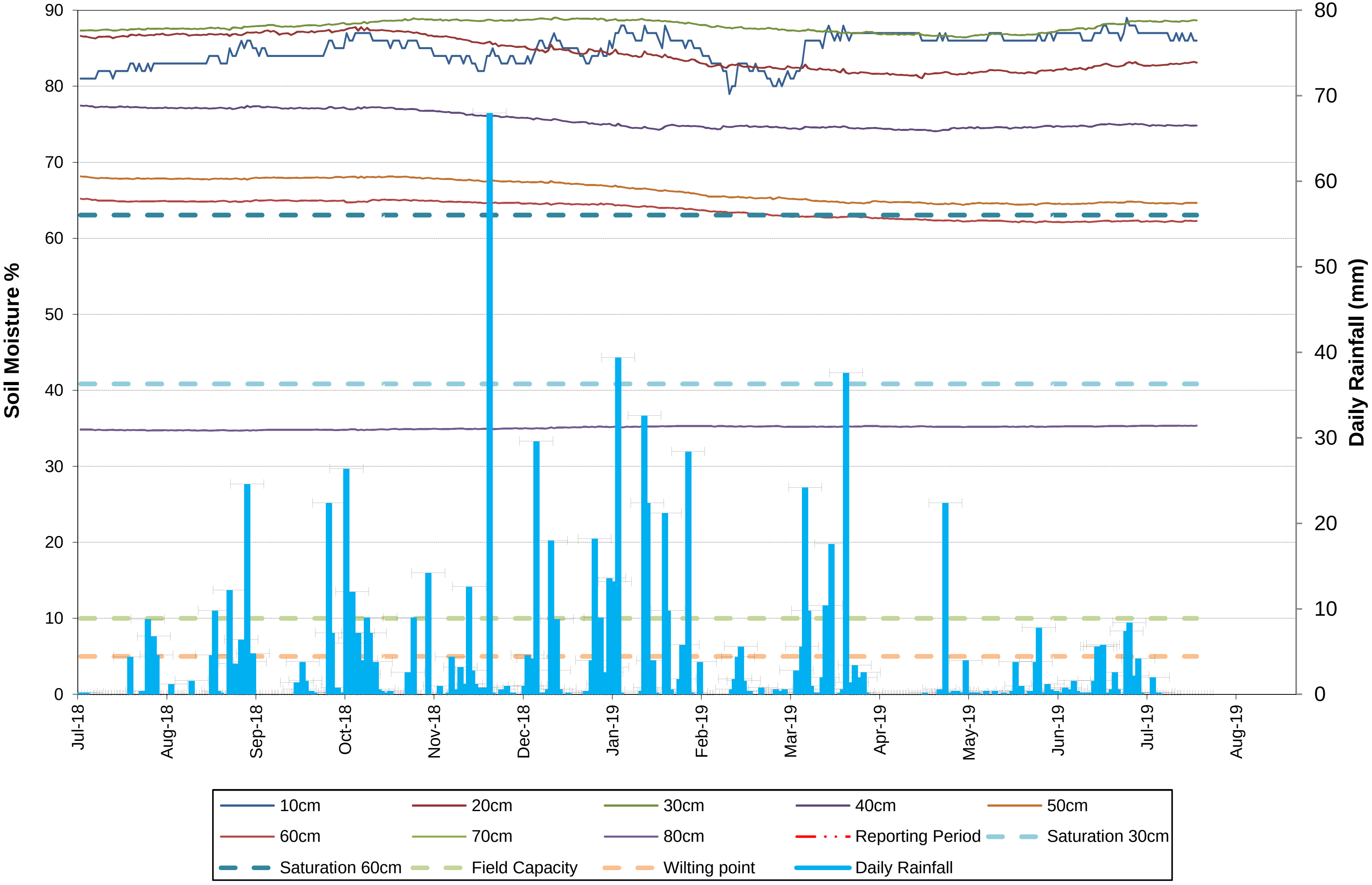
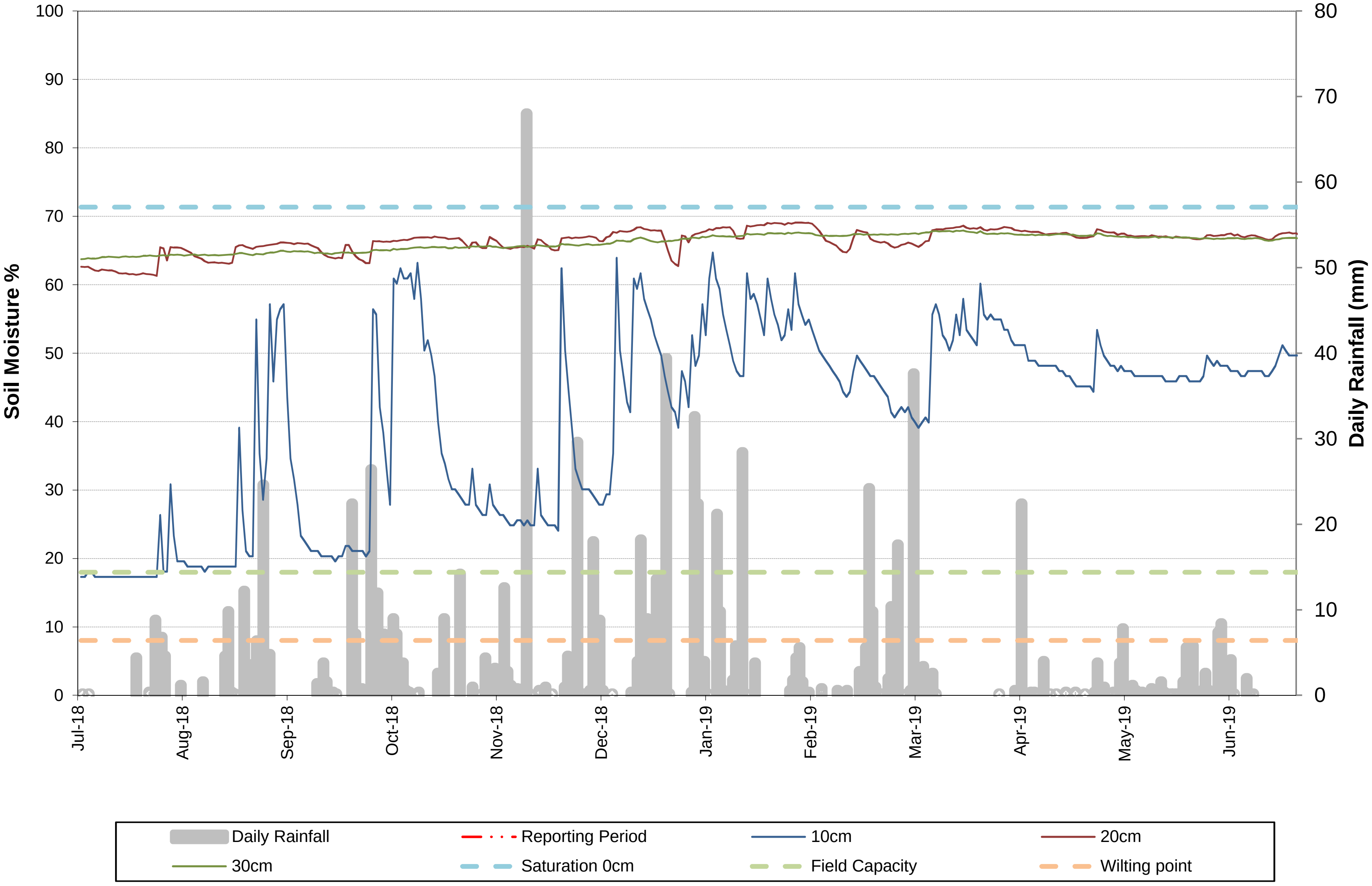
BA1SM Soil Moisture (0 - 55cm) - Appendix E

J:\IE\Projects\04_Eastern\IA161510\21 Deliverables\Appendices\D\data\[Soil Moisture 2019v1.xlsx]BA1SM 0-55

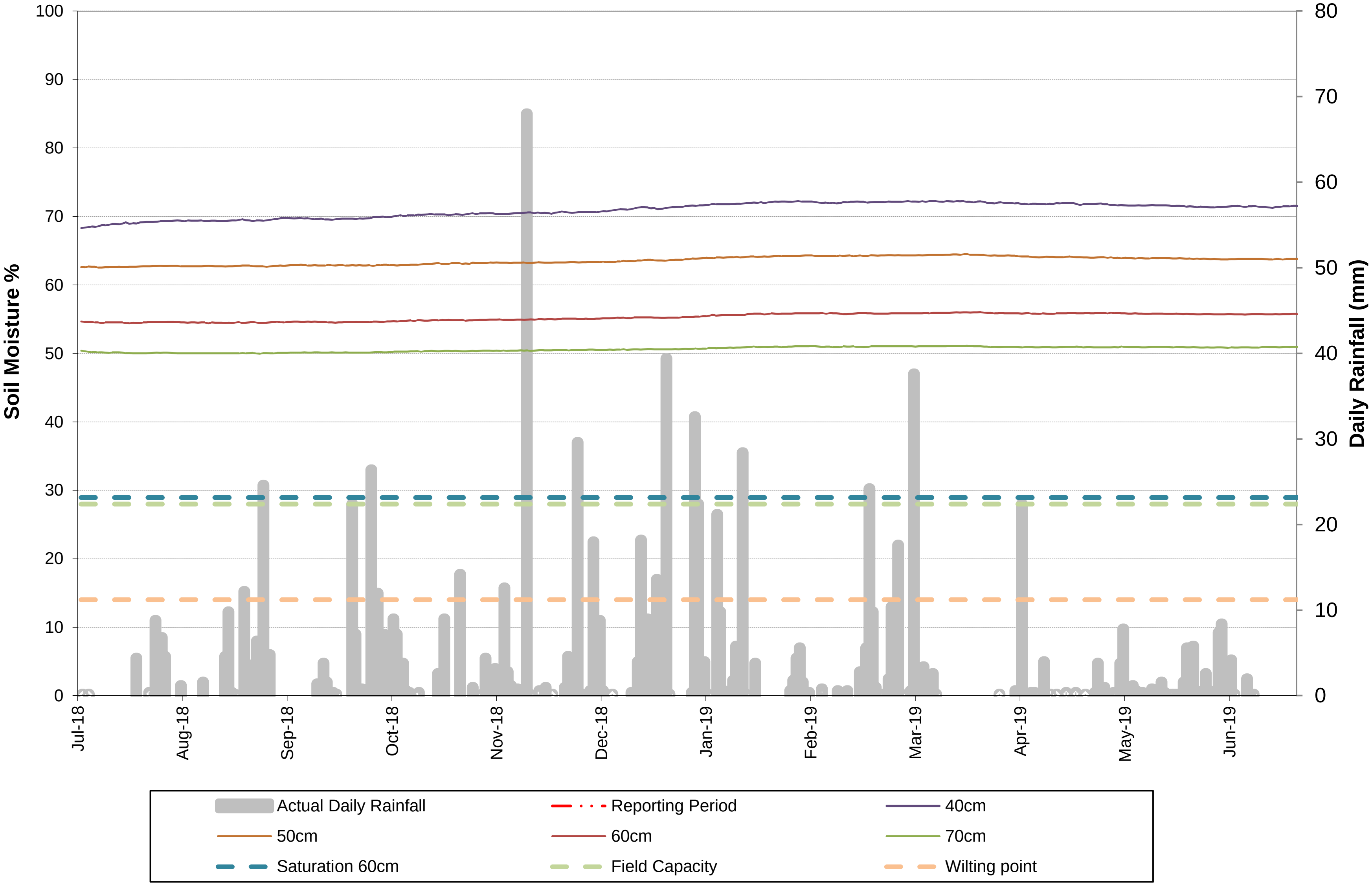


100
90
80
70
60
50
40
30
20
10
0
Soil Moisture %
80
70
60
50
40
30
20
10
0
Daily Rainfall (mm)
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
65cm
75cm
85cm
95cm
105cm
Reporting Period
Saturation 75cm
Field Capacity
Wilting point
Daily Rainfall

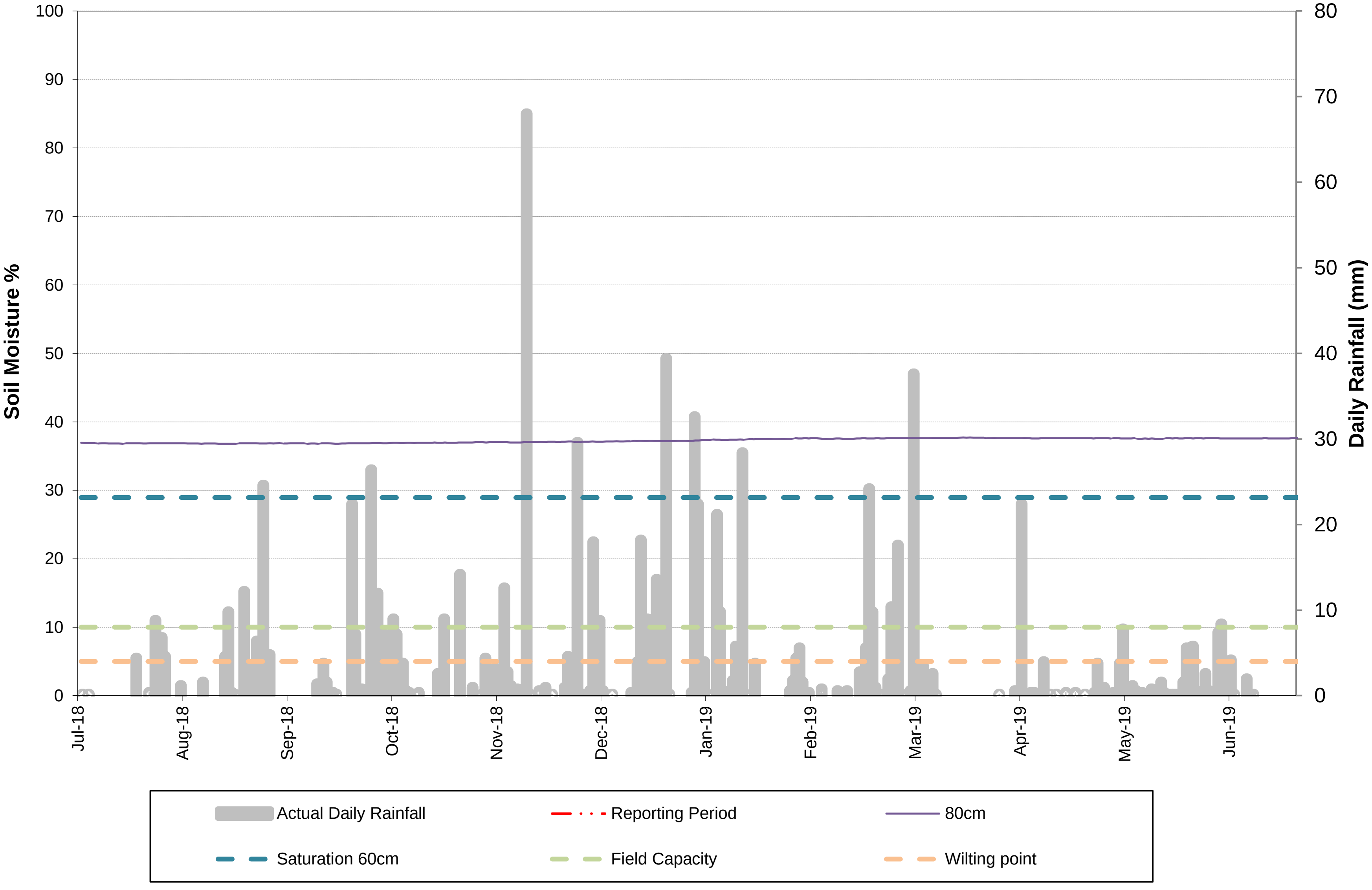

Soil Moisture %
Daily Rainfall (mm)
0
10
20
30
40
50
60
70
80
90
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Jul-19
Aug-19
10cm
20cm
30cm
40cm
50cm
60cm
70cm
80cm
Reporting Period
Saturation 30cm
Saturation 60cm
Field Capacity
Wilting point
Daily Rainfall

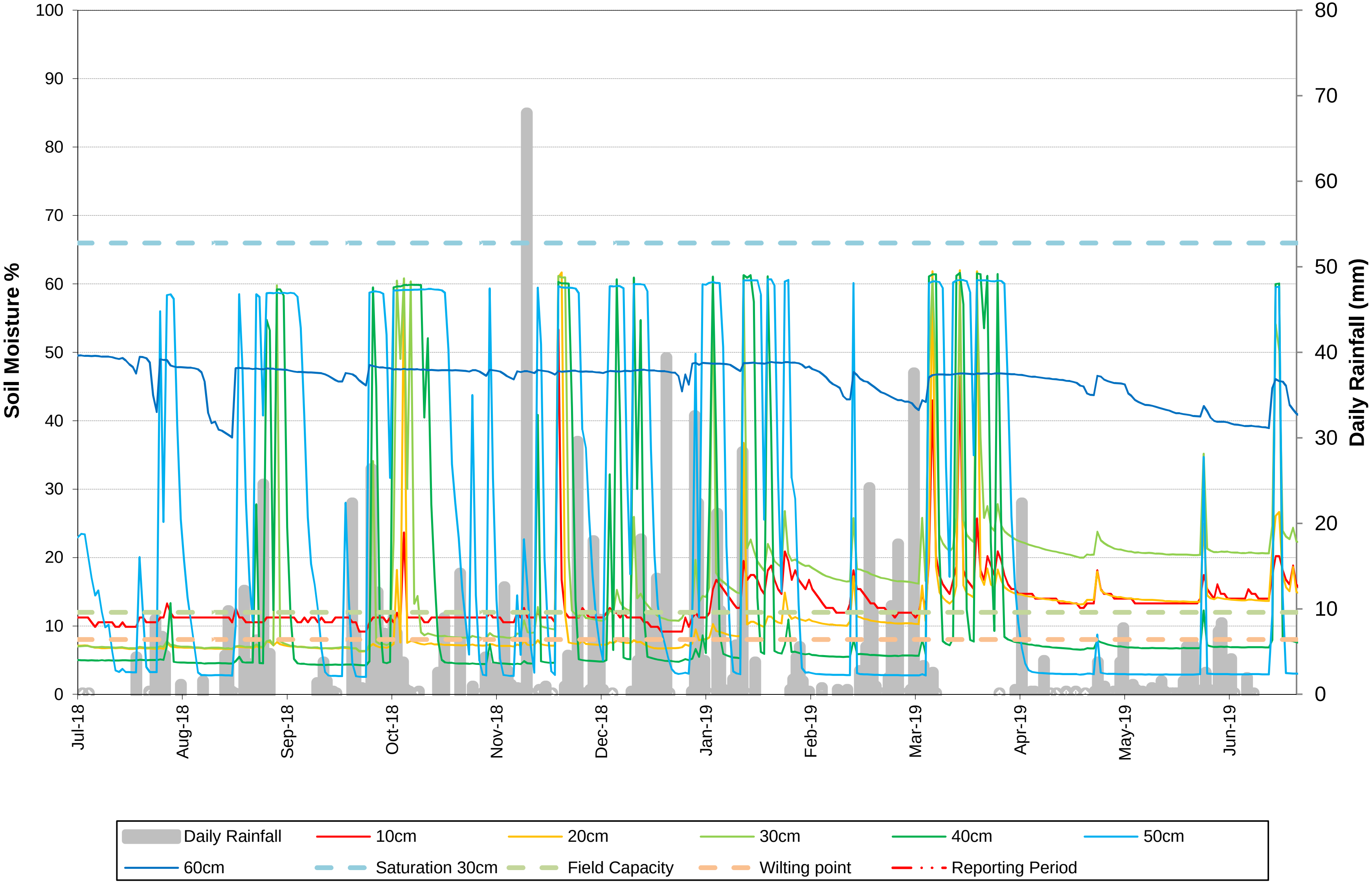


Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
10cm
20cm
30cm
Saturation 0cm
Field Capacity
Wilting point

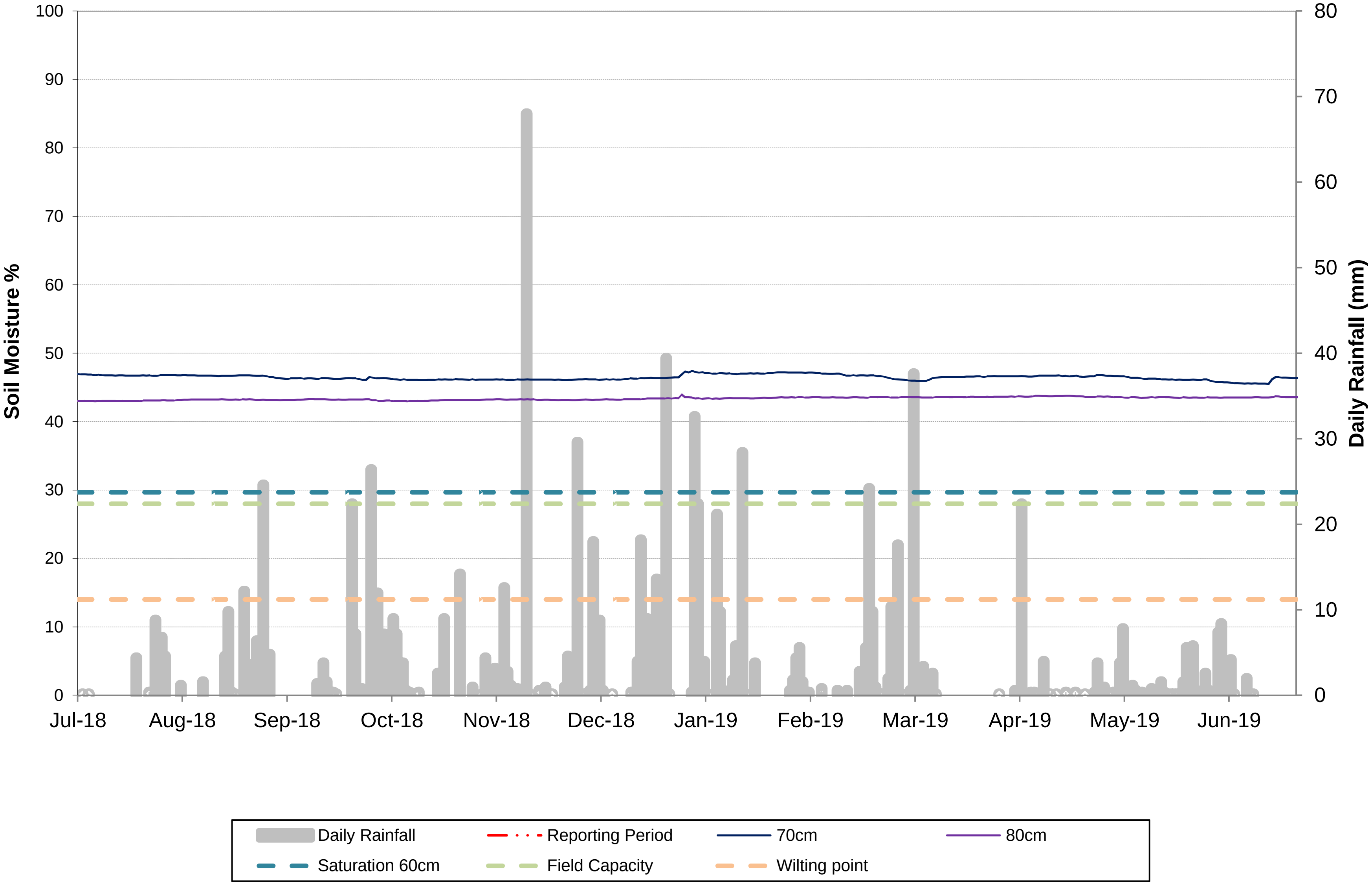


100
90
80
70
60
50
40
30
20
10
0
Soil Moisture %
80
70
60
50
40
30
20
10
0
Daily Rainfall (mm)
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Actual Daily Rainfall
Reporting Period
40cm
50cm
60cm
70cm
Saturation 60cm
Field Capacity
Wilting point


Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Actual Daily Rainfall
Reporting Period
80cm
Saturation 60cm
Field Capacity
Wilting point



BE1SM Soil Moisture (10 - 60cm) - Appendix E



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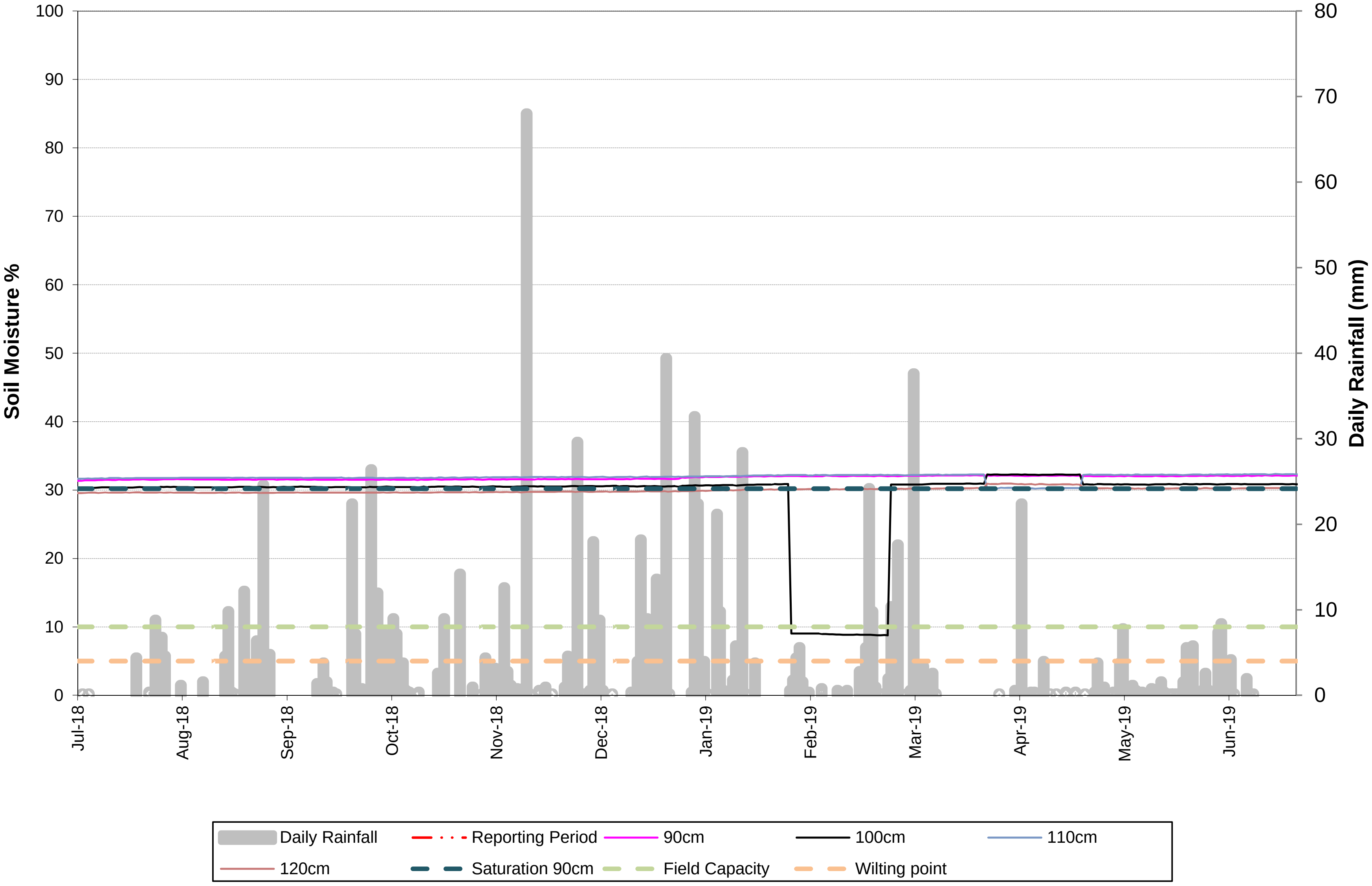
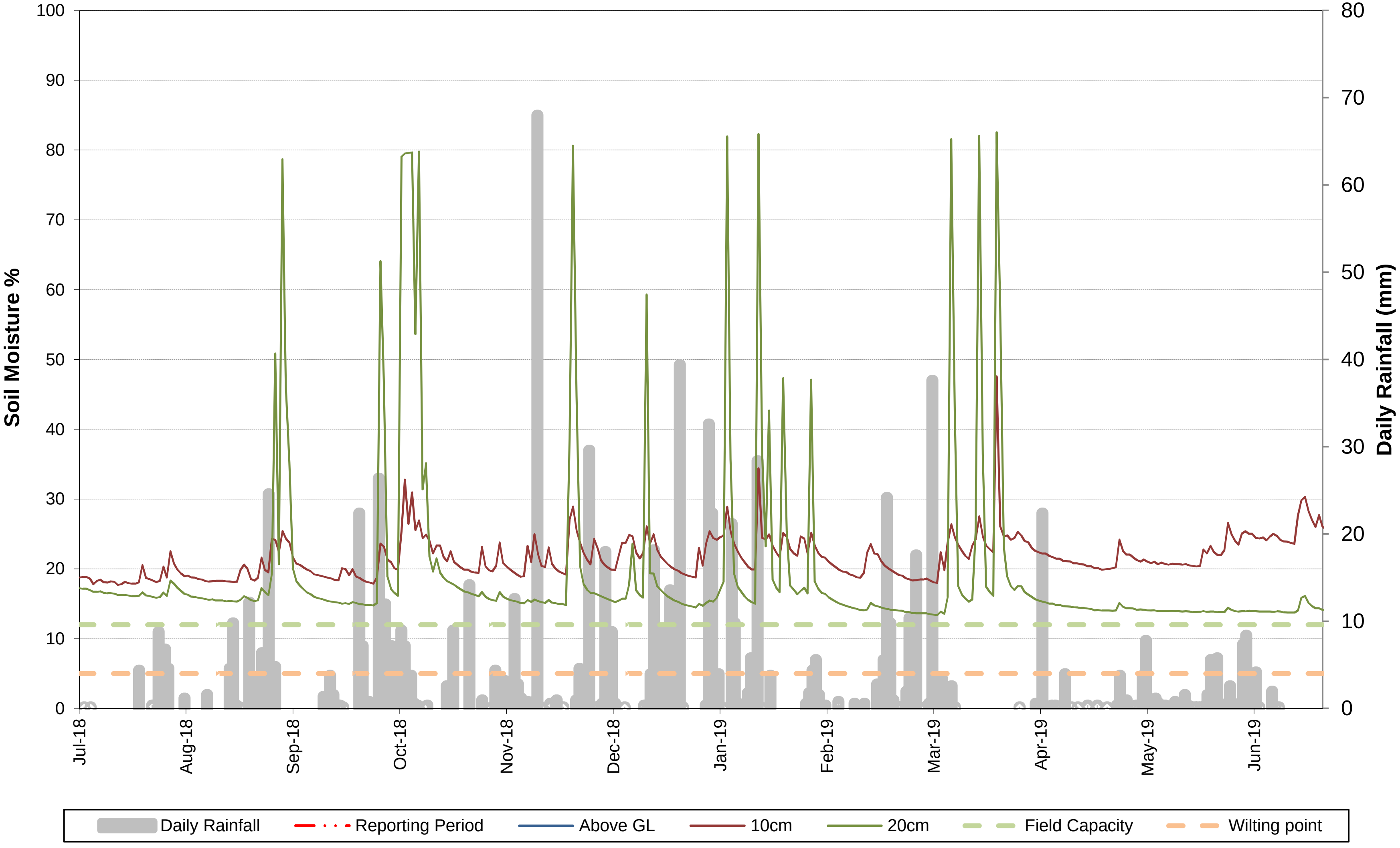
BE1SM Soil Moisture (70 - 80cm) - Appendix E

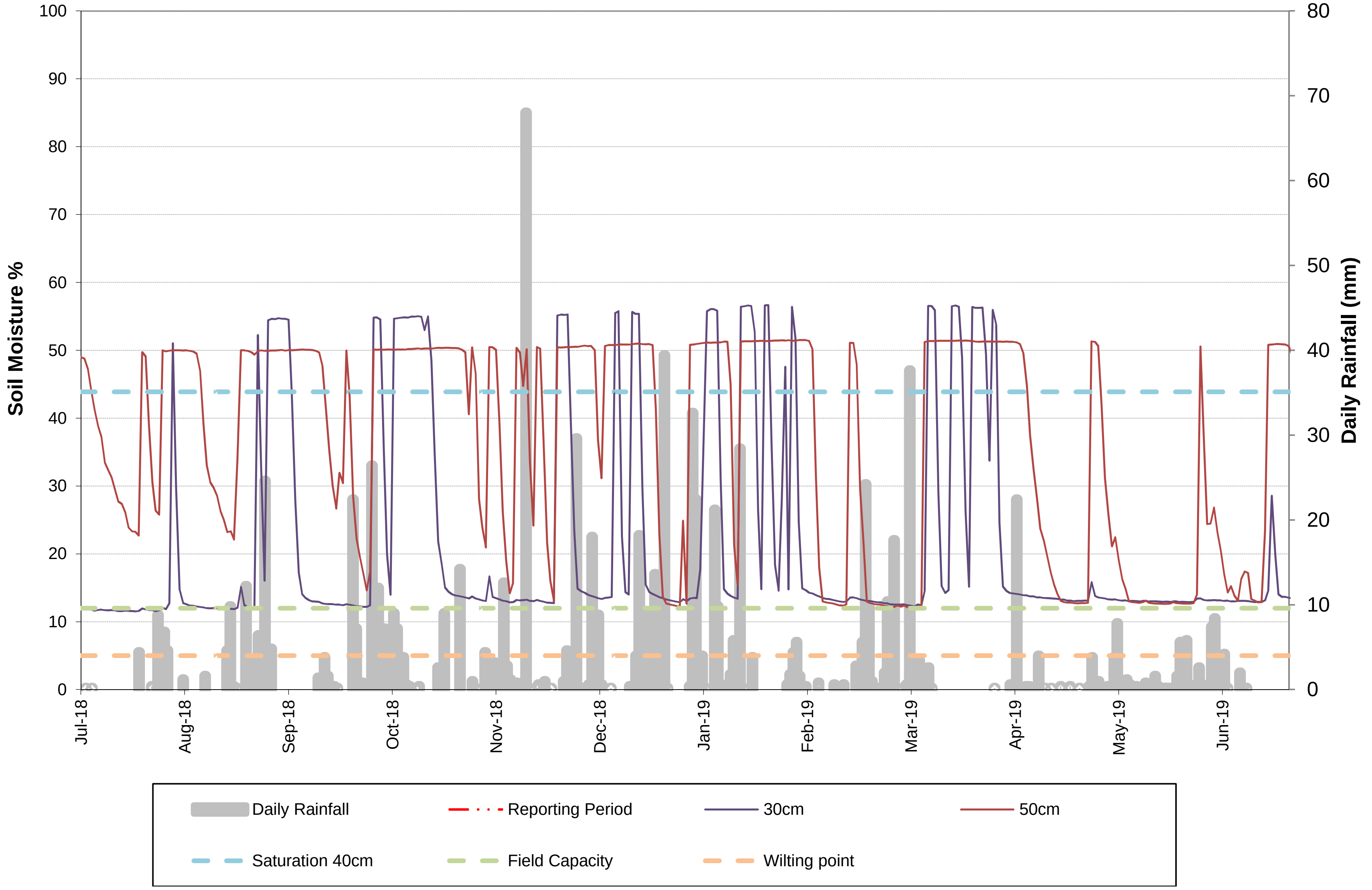
J:\IE\Projects\04_Eastern\IA161510\21 Deliverables\Appendices\D\data\[Soil Moisture 2019v1.xlsx]BE1SM 70-80



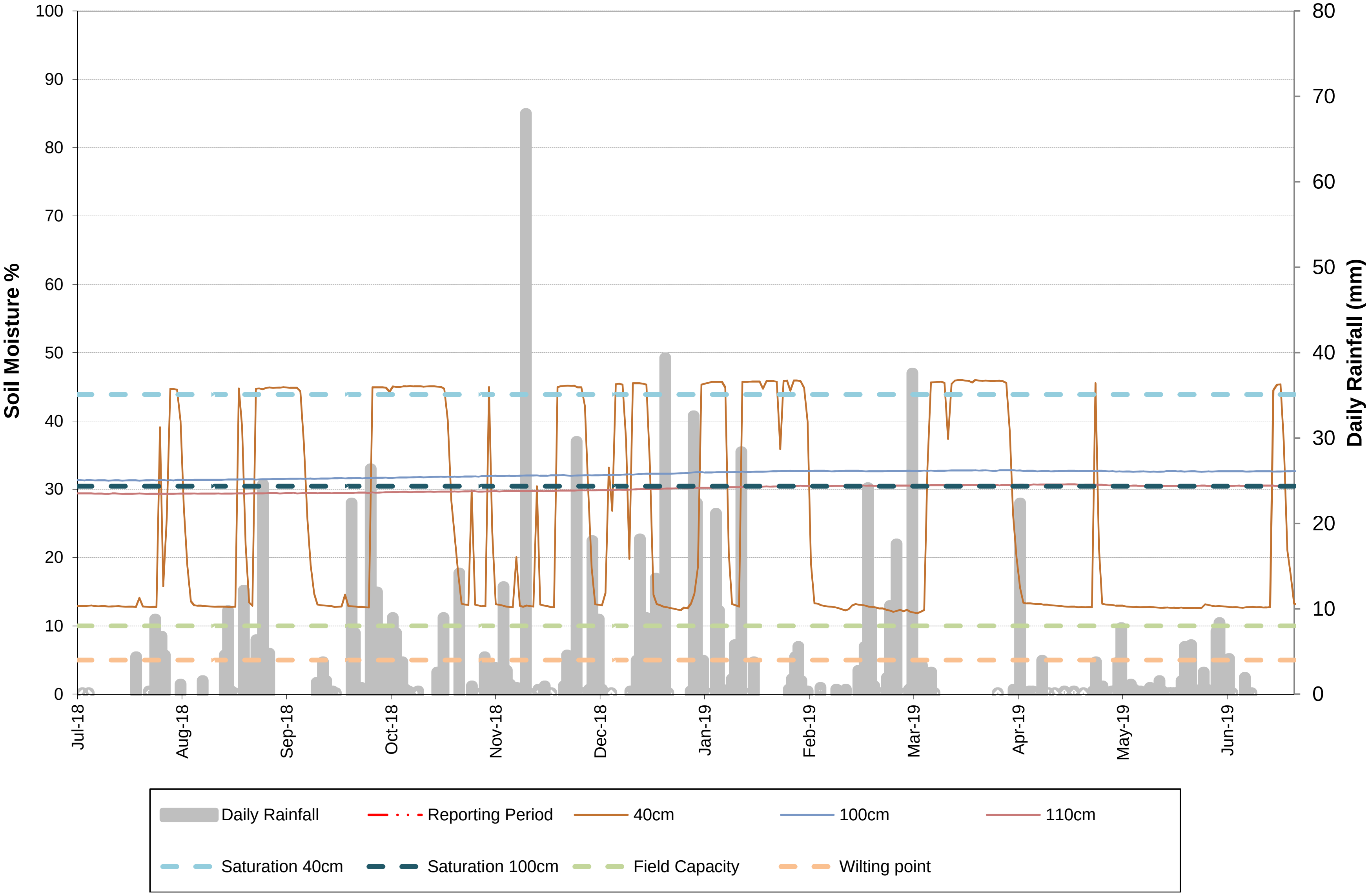
Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
90cm
100cm
110cm
120cm
Saturation 90cm
Field Capacity
Wilting point



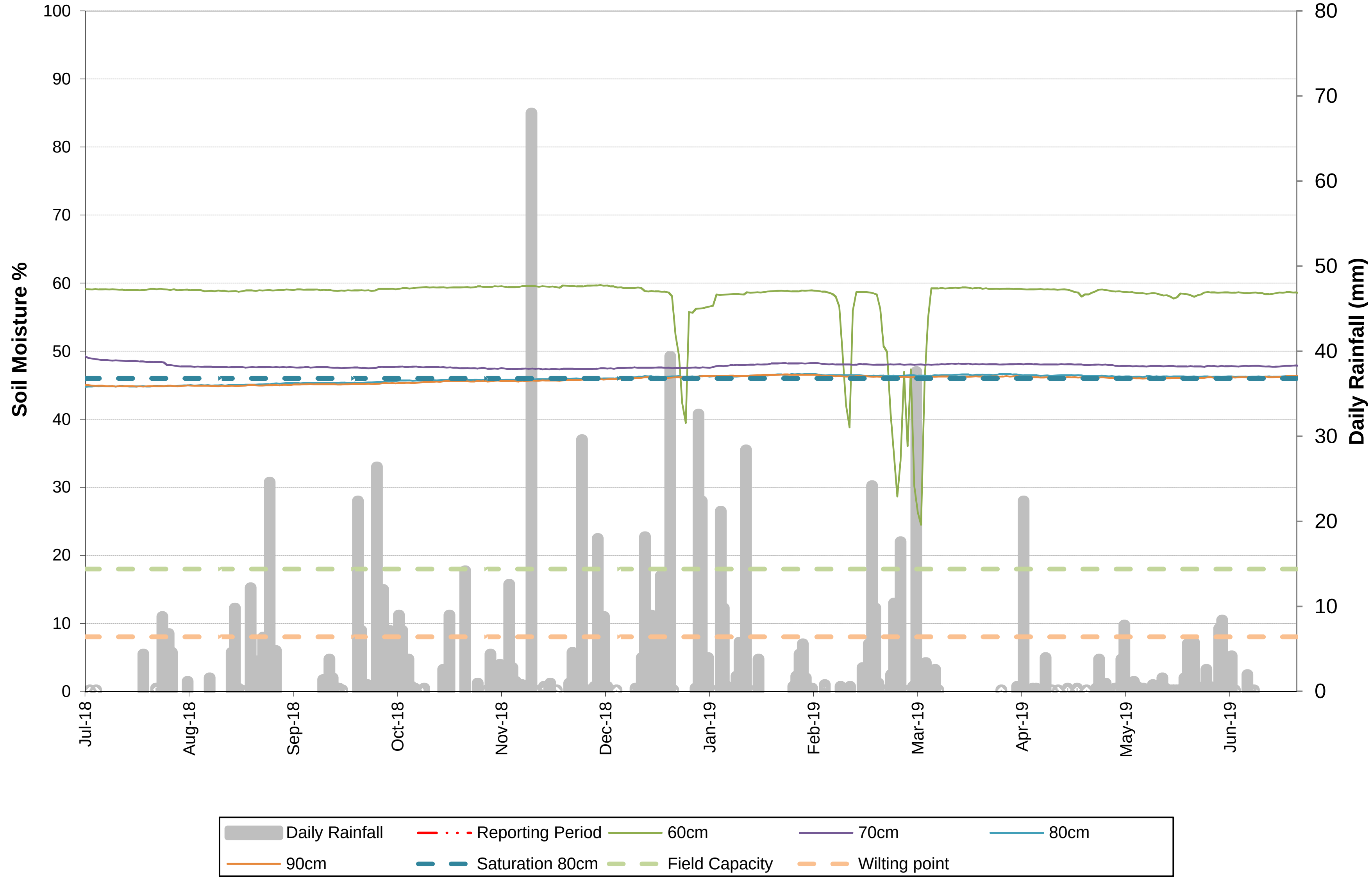
100
90
80
70
60
50
40
30
20
10
0
Soil Moisture %
80
70
60
50
40
30
20
10
0
Daily Rainfall (mm)
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
Above GL
10cm
20cm
Field Capacity
Wilting point



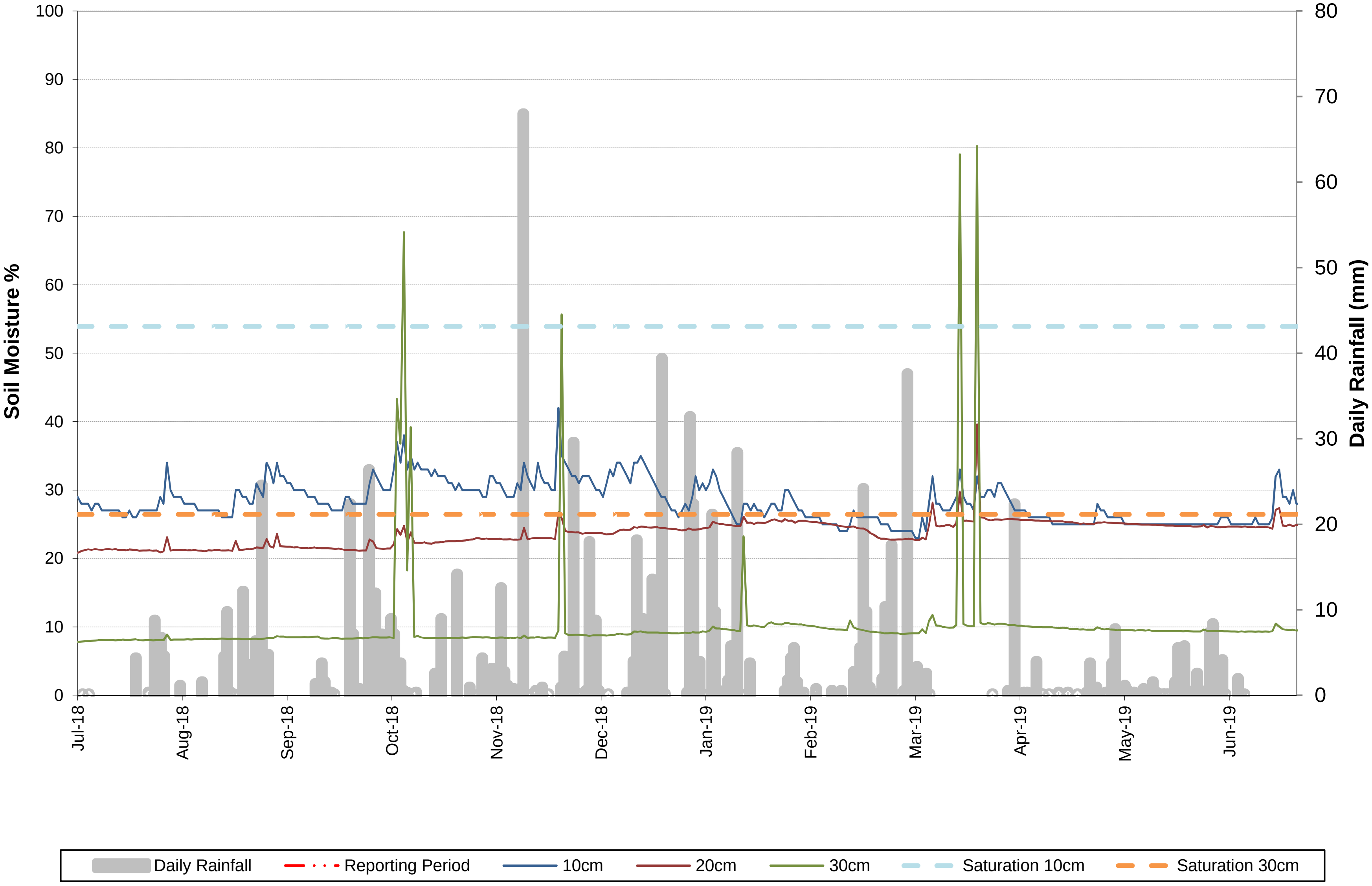
Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
30cm
50cm
Saturation 40cm
Field Capacity
Wilting point



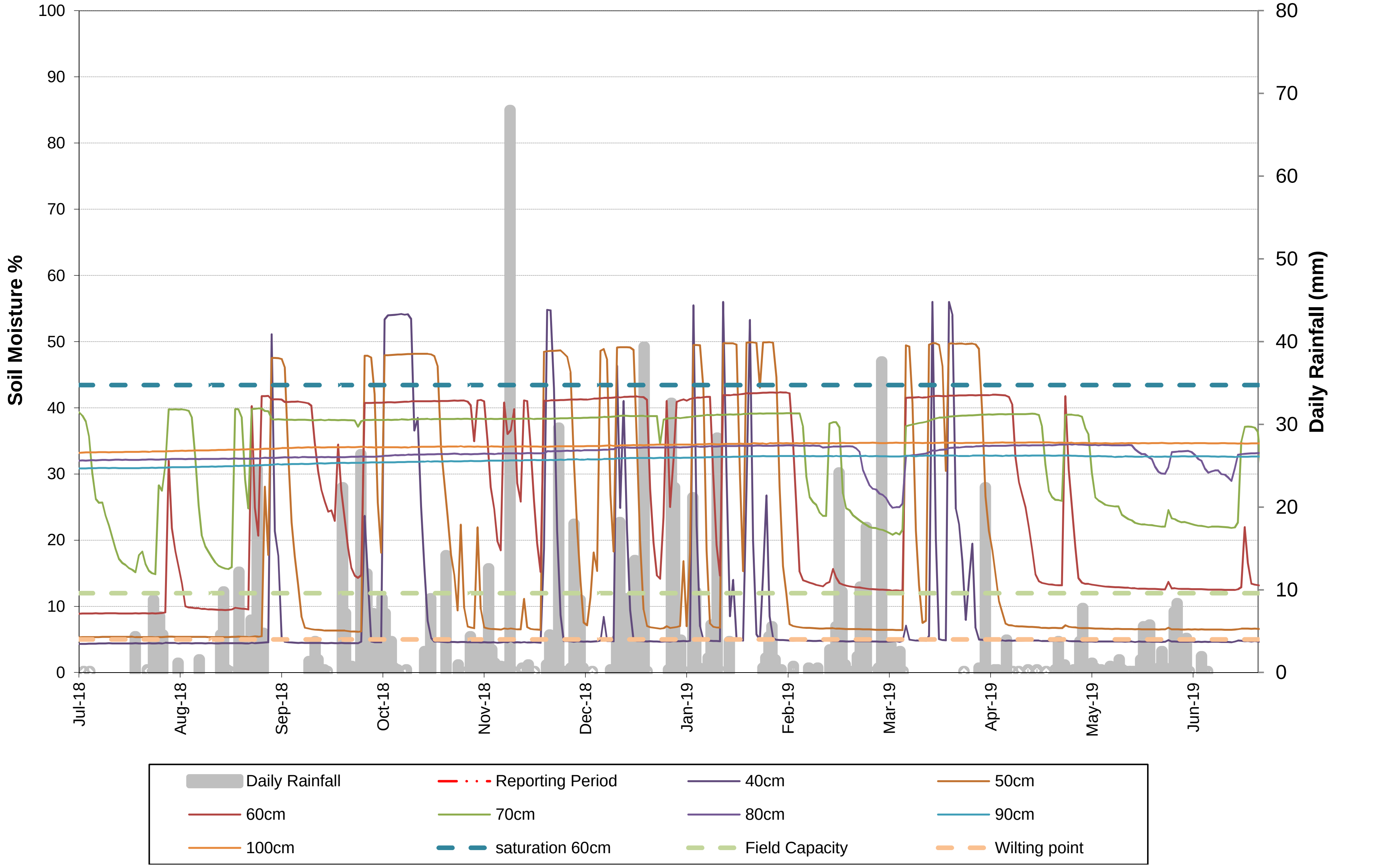
Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
40cm
100cm
110cm
Saturation 40cm
Saturation 100cm
Field Capacity
Wilting point



Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
60cm
70cm
80cm
90cm
Saturation 80cm
Field Capacity
Wilting point

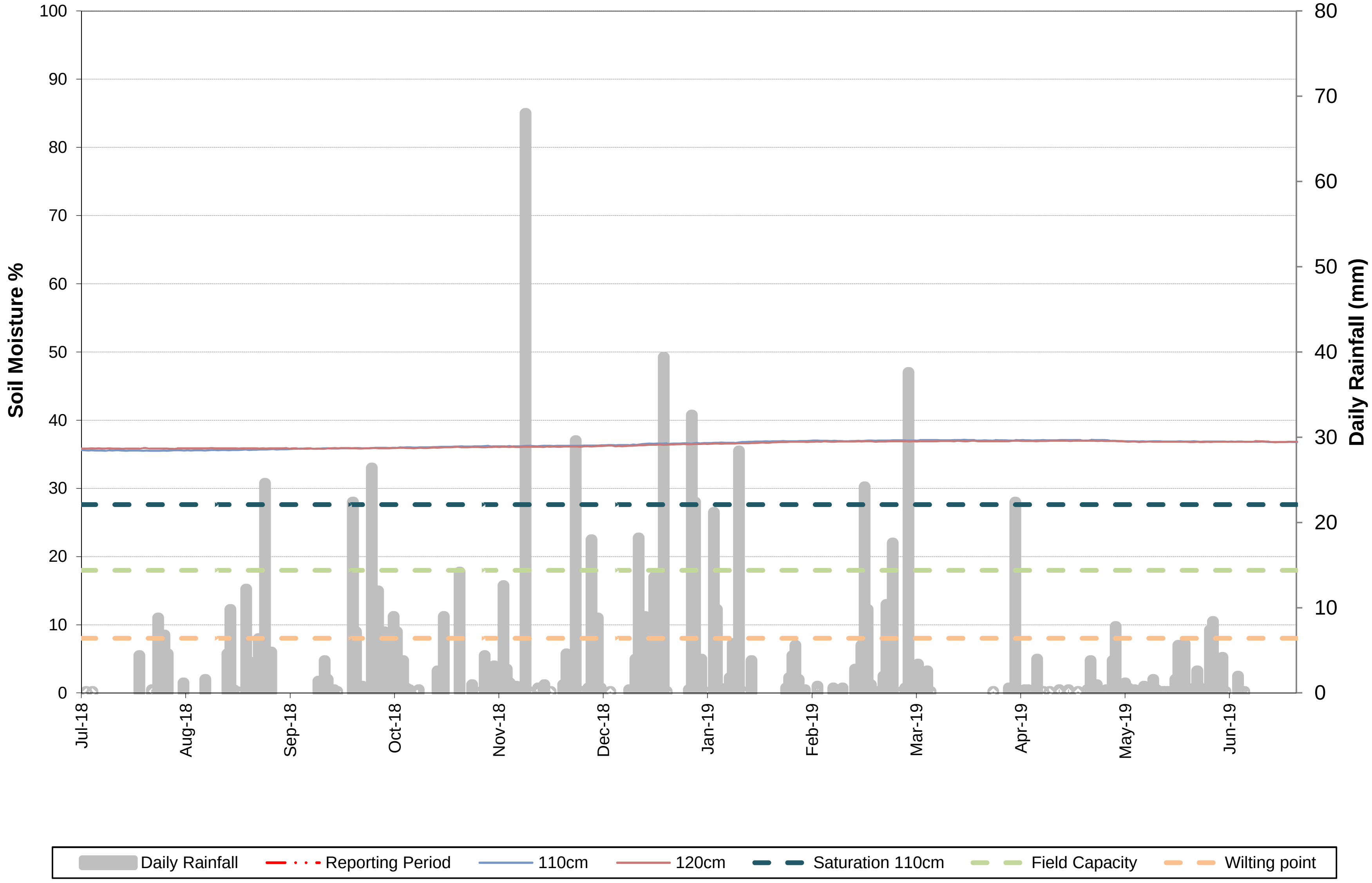


Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
10cm
20cm
30cm
Saturation 10cm
Saturation 30cm



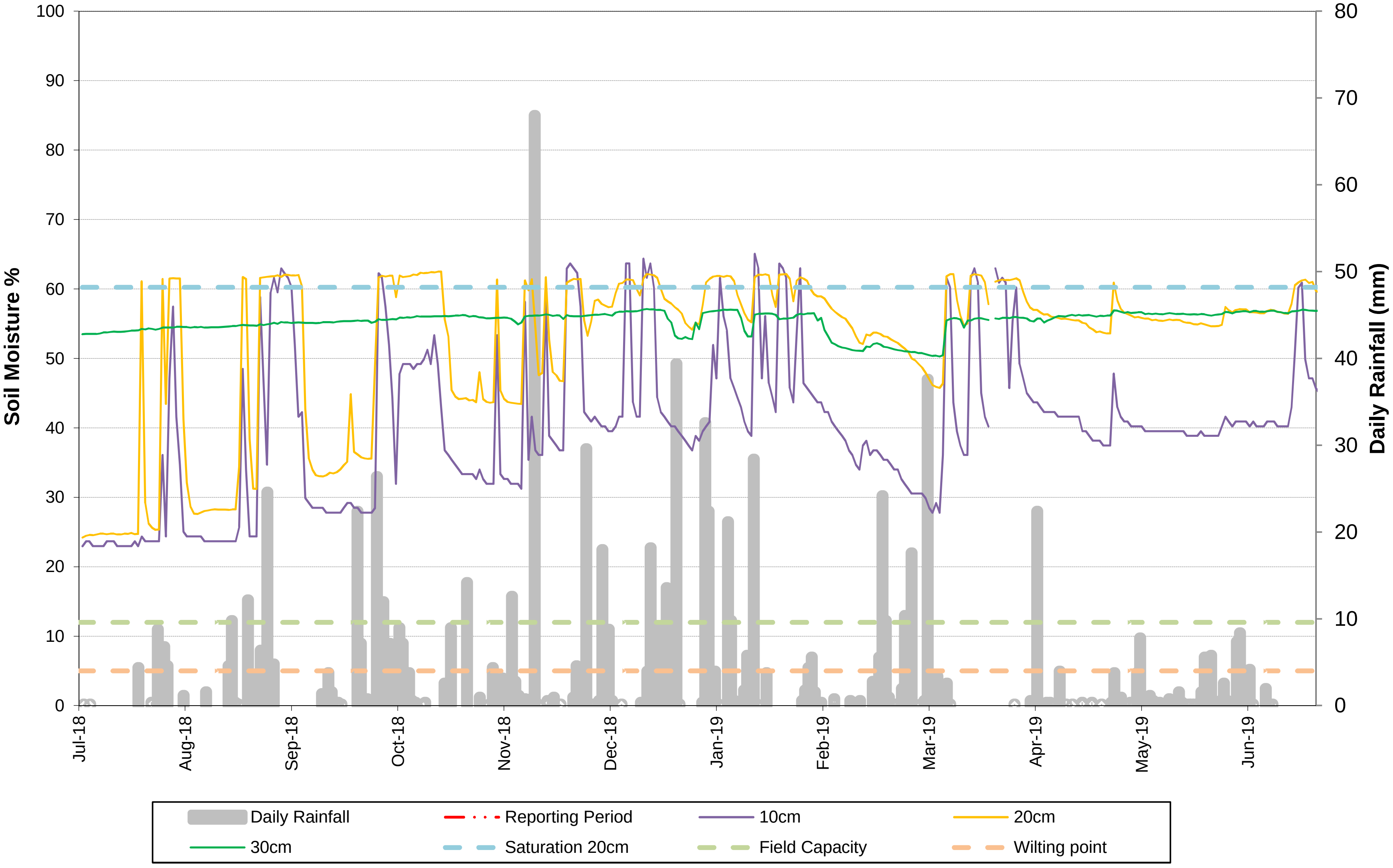
FT1SM Soil Moisture (40 - 100cm) - Appendix E

J:\IE\Projects\04_Eastern\IA161510\21 Deliverables\Appendices\D\data\[Soil Moisture 2019v1.xlsx]FT1SM 40-100

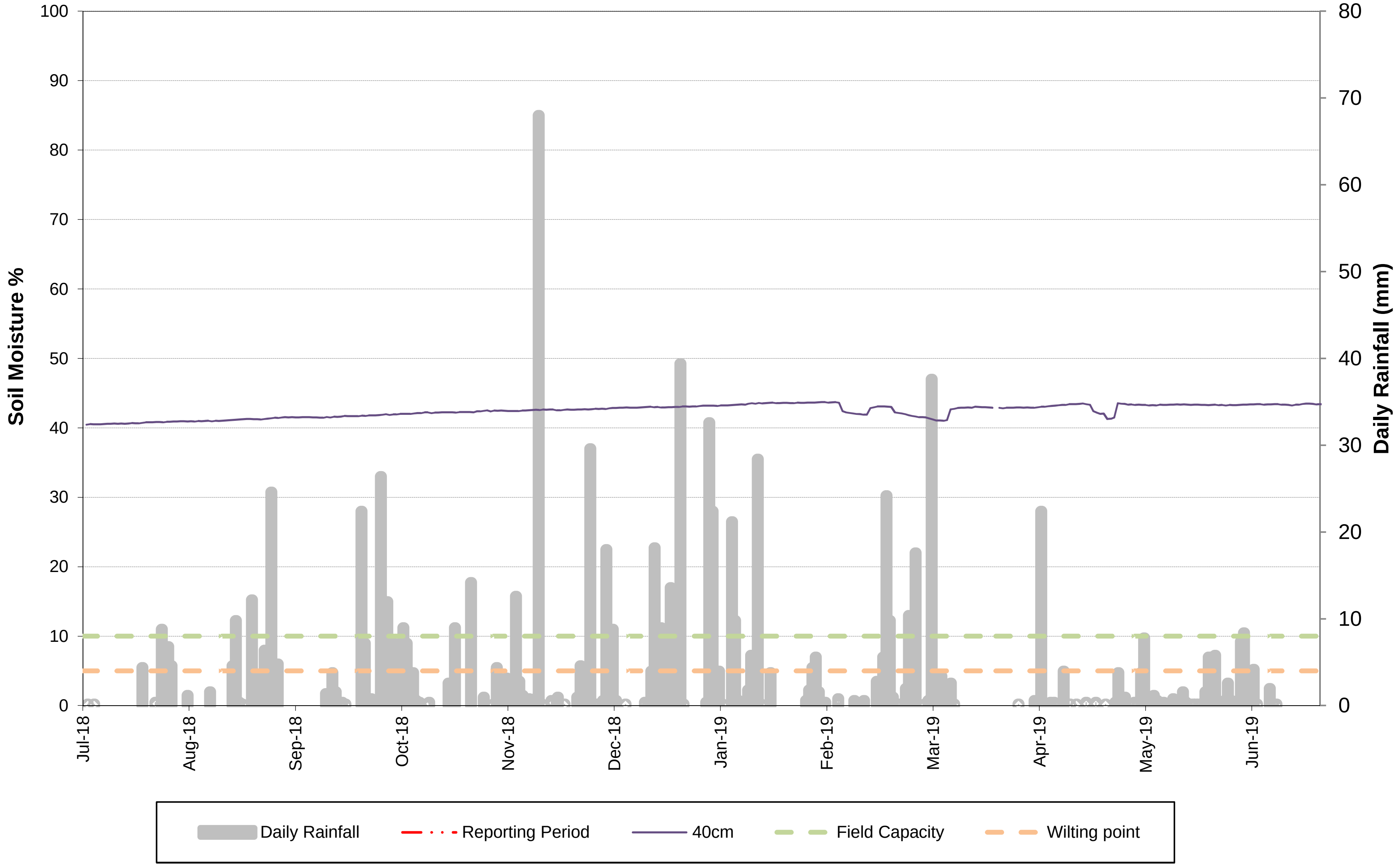


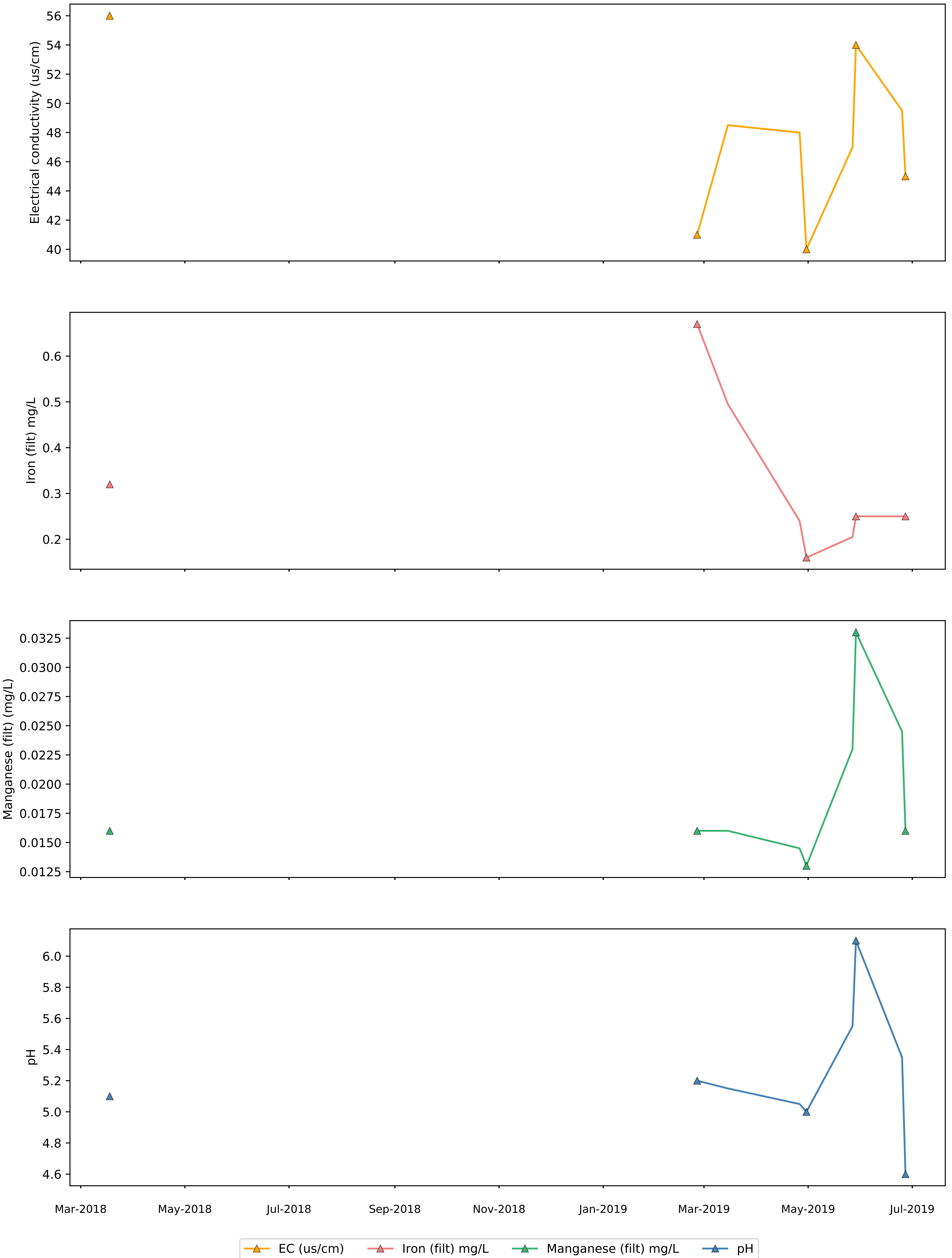
FT1SM Soil Moisture (110 - 120cm) - Appendix E

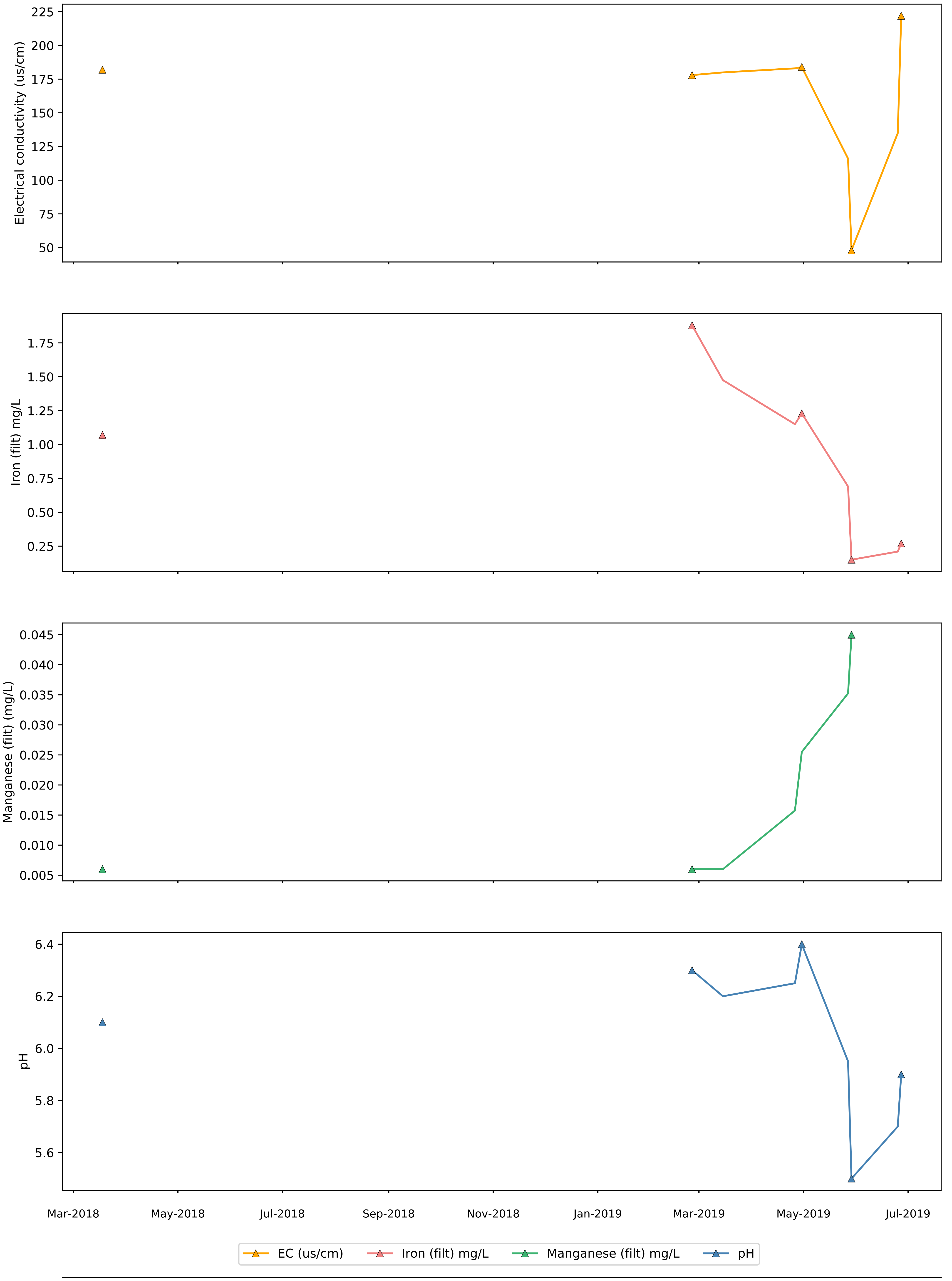
J:\IE\Projects\04_Eastern\IA161510\21 Deliverables\Appendices\D\data\[Soil Moisture 2019v1.xlsx]FT1SM 110-120



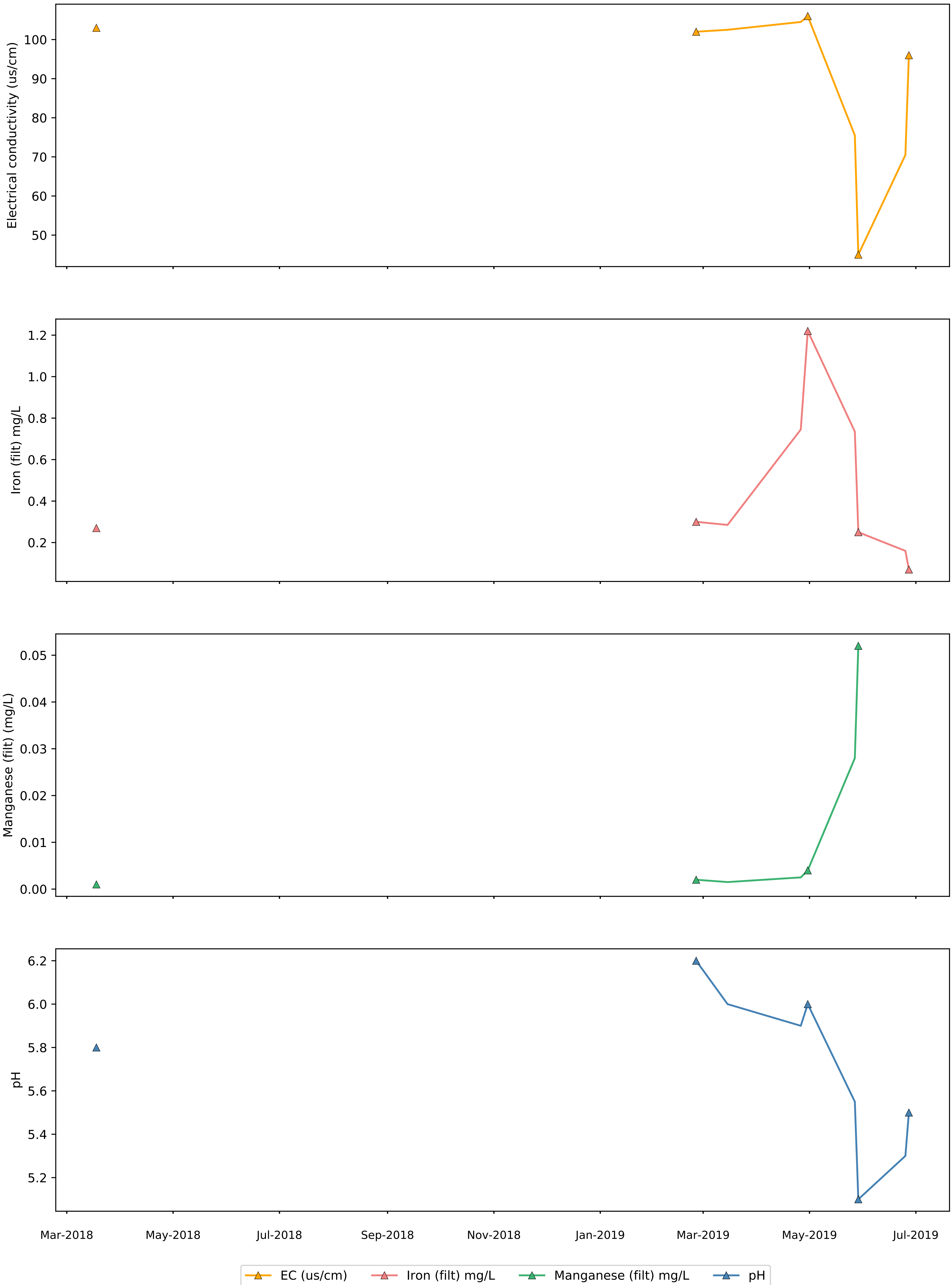
Soil Moisture %
Daily Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
10cm
20cm
30cm
Saturation 20cm
Field Capacity
Wilting point

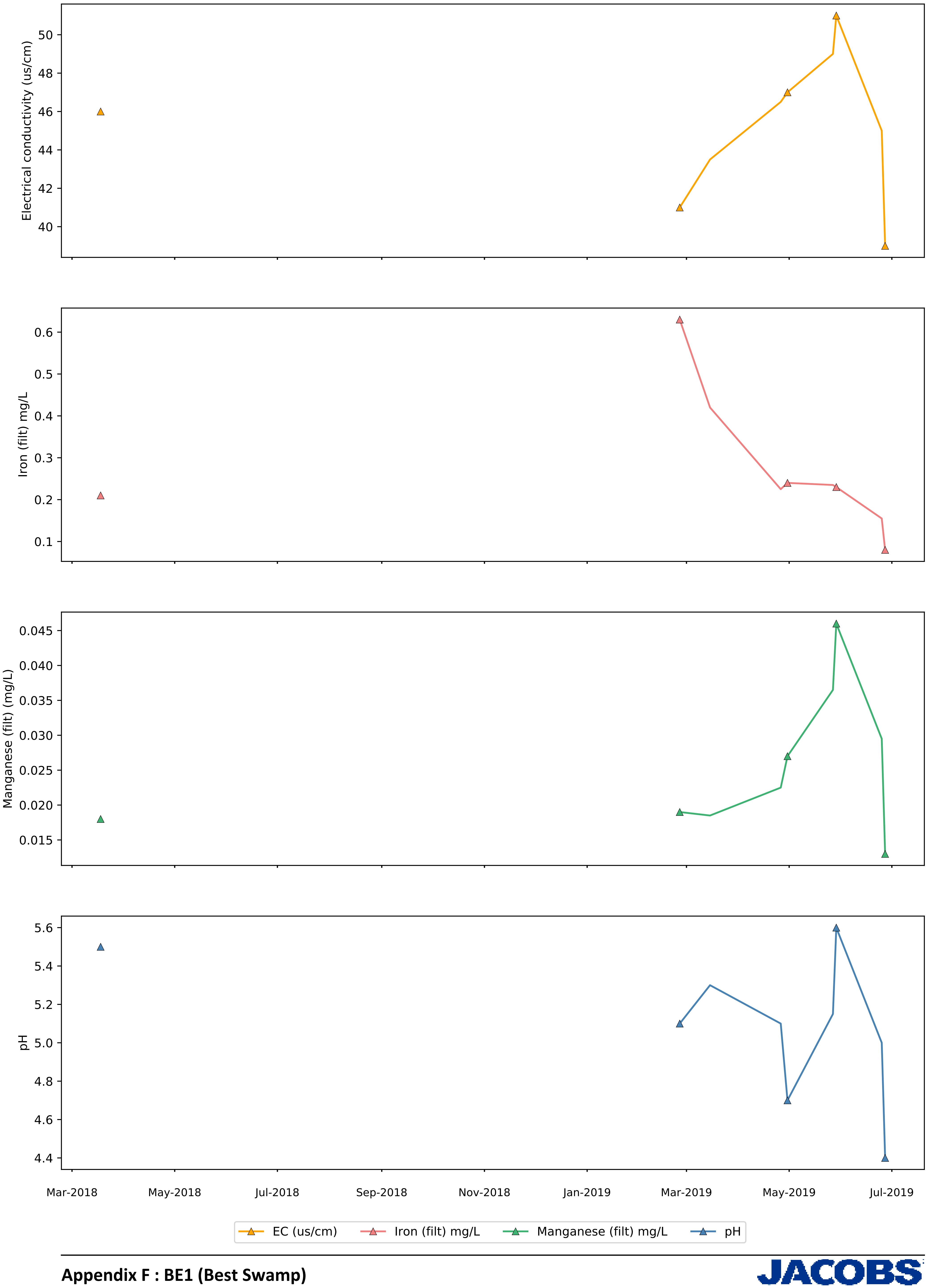

Soil Moisture %
100
90
80
70
60
50
40
30
20
10
0
Daily Rainfall (mm)
80
70
60
50
40
30
20
10
0
Jul-18
Aug-18
Sep-18
Oct-18
Nov-18
Dec-18
Jan-19
Feb-19
Mar-19
Apr-19
May-19
Jun-19
Daily Rainfall
Reporting Period
40cm
Field Capacity
Wilting point


Electrical conductivity (us/cm)
Iron (filt) mg/L
Manganese (filt) (mg/L)
pH
Mar-2018
May-2018
Jul-2018
Sep-2018
Nov-2018
Jan-2019
Mar-2019
May-2019
Jul-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

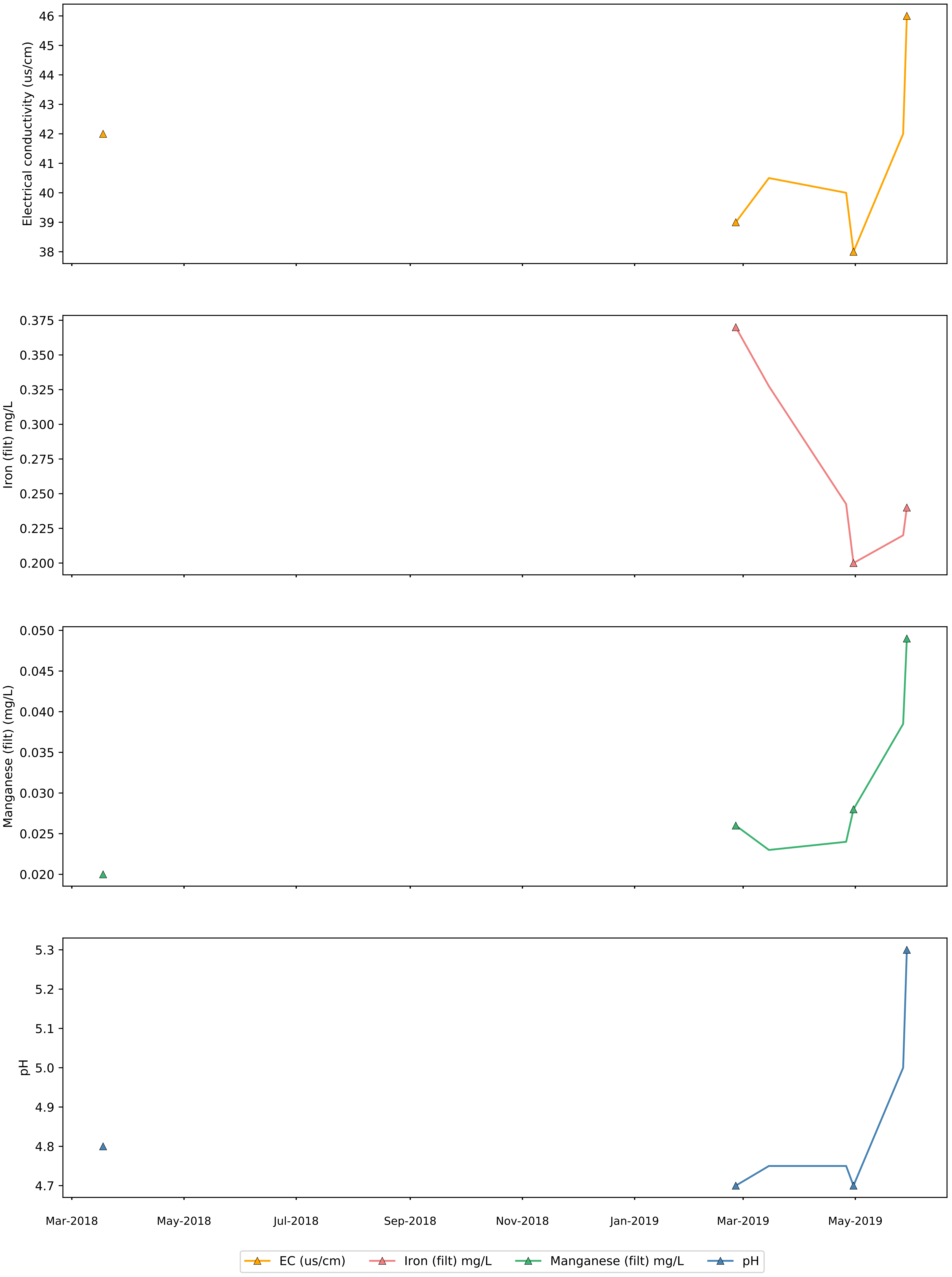


Appendix F : BA2 (Barrier Swamp)

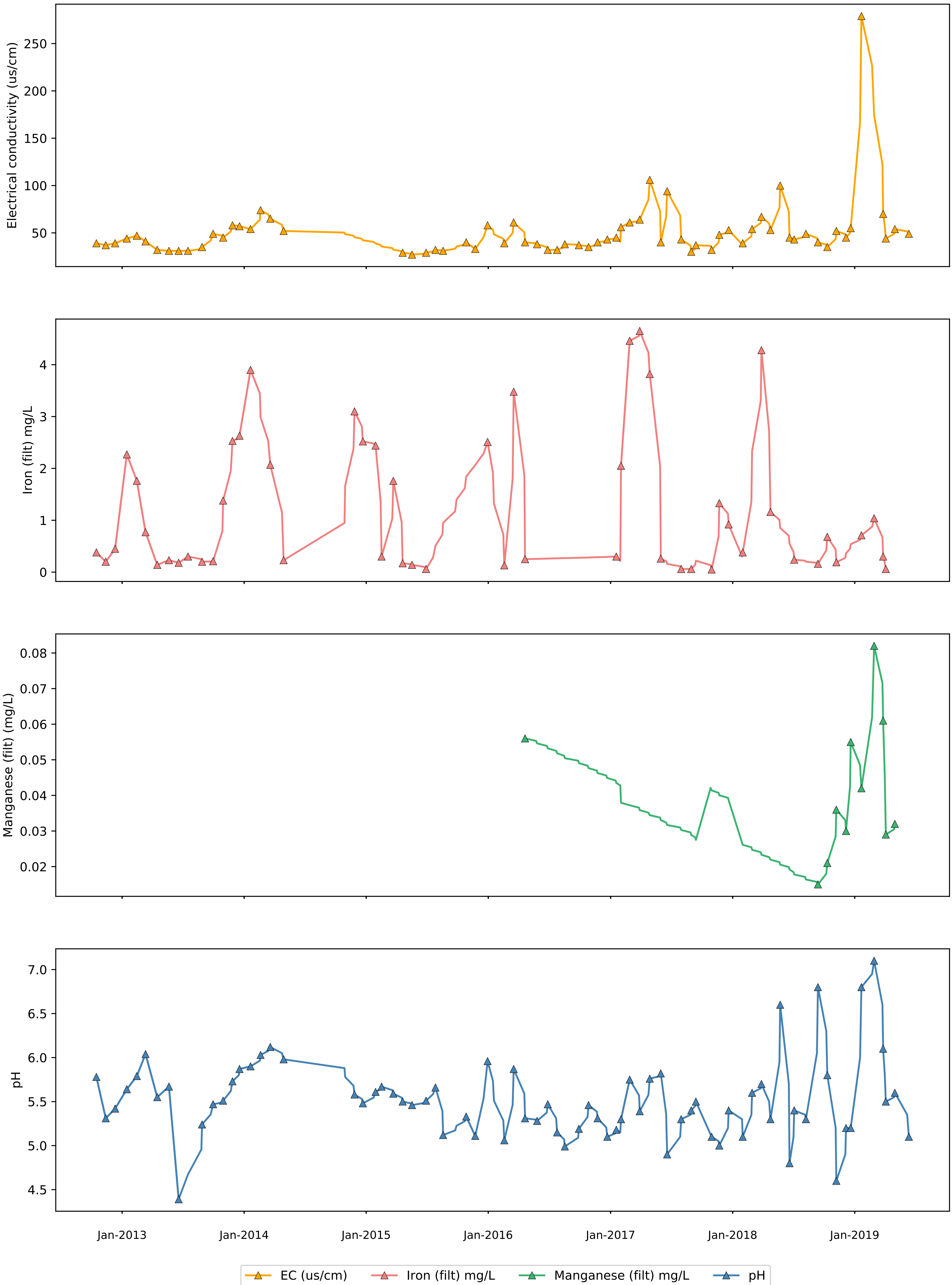

Electrical conductivity (us/cm)
100
90
80
70
60
50
Iron (filt) mg/L
1.2
1.0
0.8
0.6
0.4
0.2
Manganese (filt) (mg/L)
0.05
0.04
0.03
0.02
0.01
0.00
pH
6.2
6.0
5.8
5.6
5.4
5.2
Mar-2018
May-2018
Jul-2018
Sep-2018
Nov-2018
Jan-2019
Mar-2019
May-2019
Jul-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH



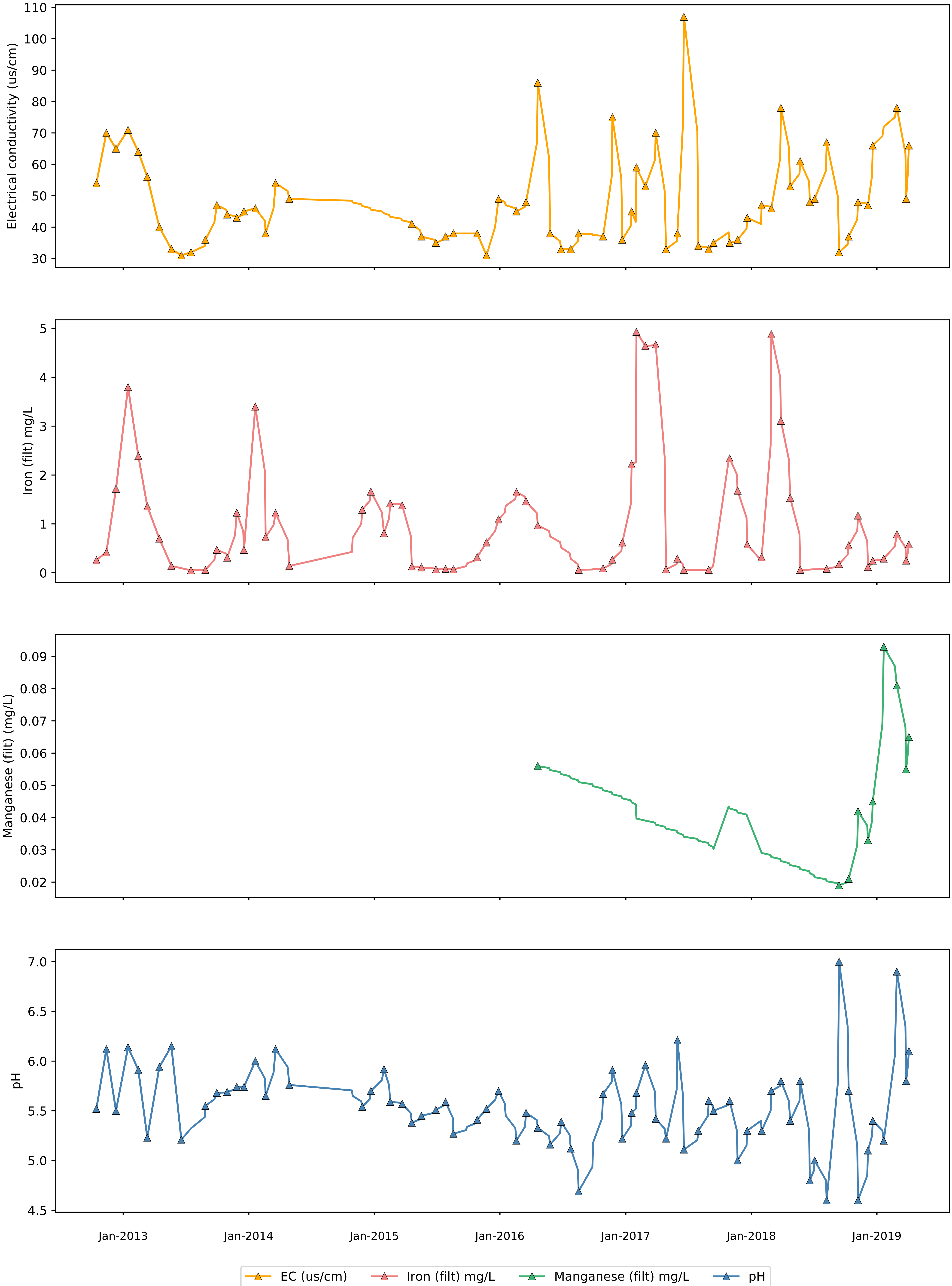
Electrical conductivity (us/cm)
40
42
44
46
48
50
Iron (filt) mg/L
0.1
0.2
0.3
0.4
0.5
0.6
Manganese (filt) (mg/L)
0.015
0.020
0.025
0.030
0.035
0.040
0.045
pH
4.4
4.6
4.8
5.0
5.2
5.4
5.6
Mar-2018
May-2018
Jul-2018
Sep-2018
Nov-2018
Jan-2019
Mar-2019
May-2019
Jul-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH



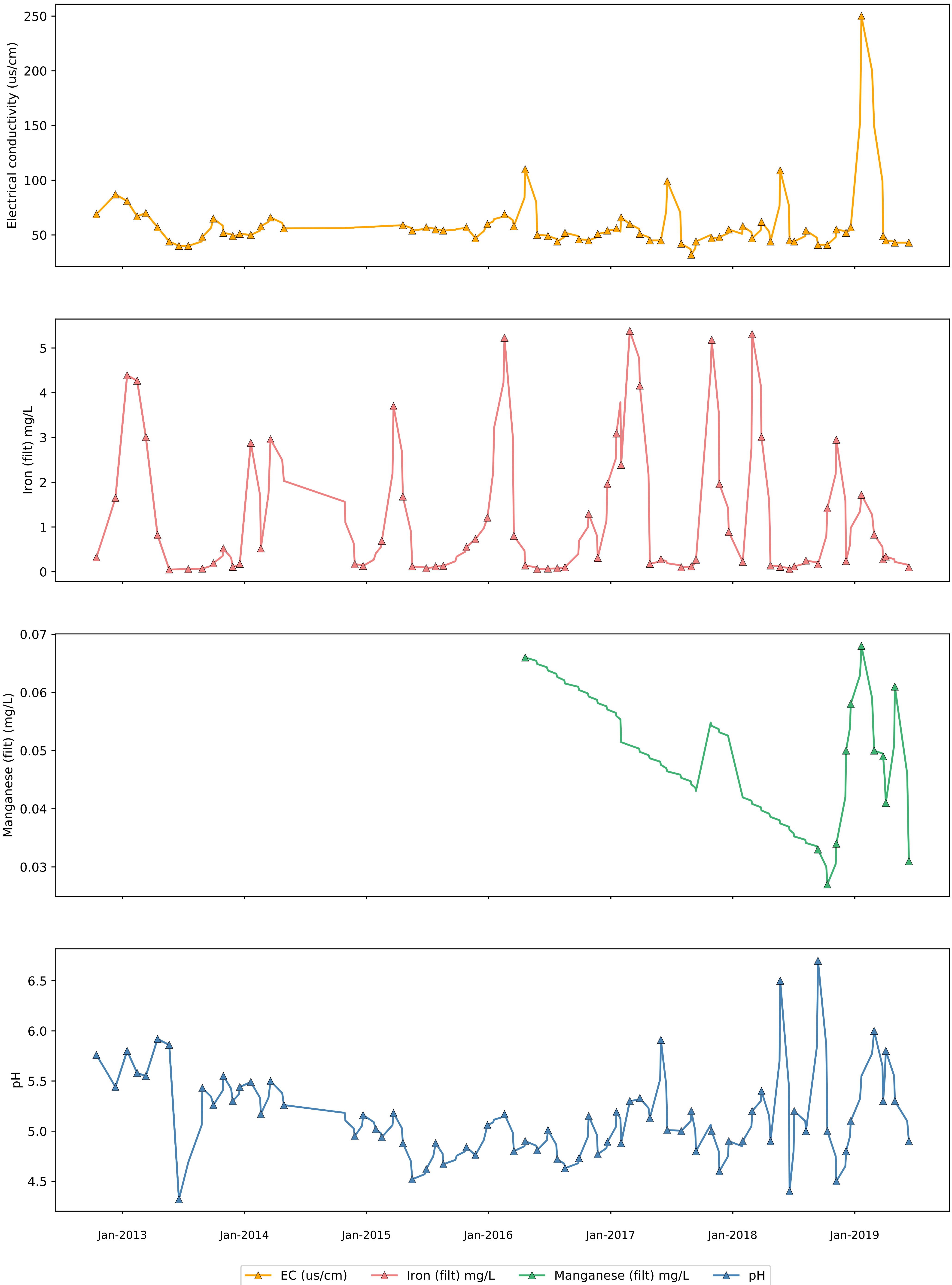
Appendix F : BE2 (Best Swamp)



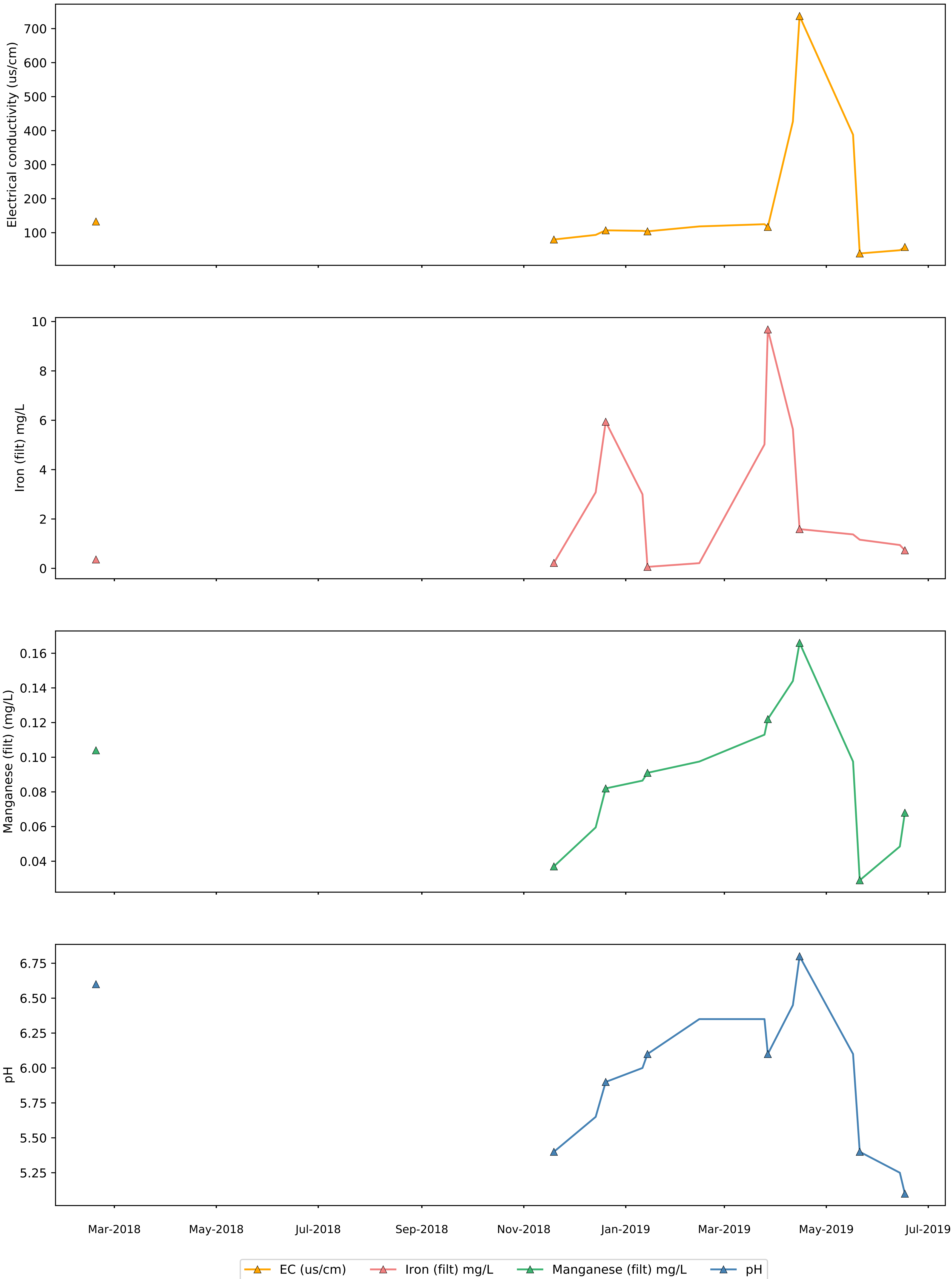
Electrical conductivity (us/cm)
250
200
150
100
50
Iron (filt) mg/L
4
3
2
1
0
Manganese (filt) (mg/L)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
pH
7.0
6.5
6.0
5.5
5.0
4.5
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

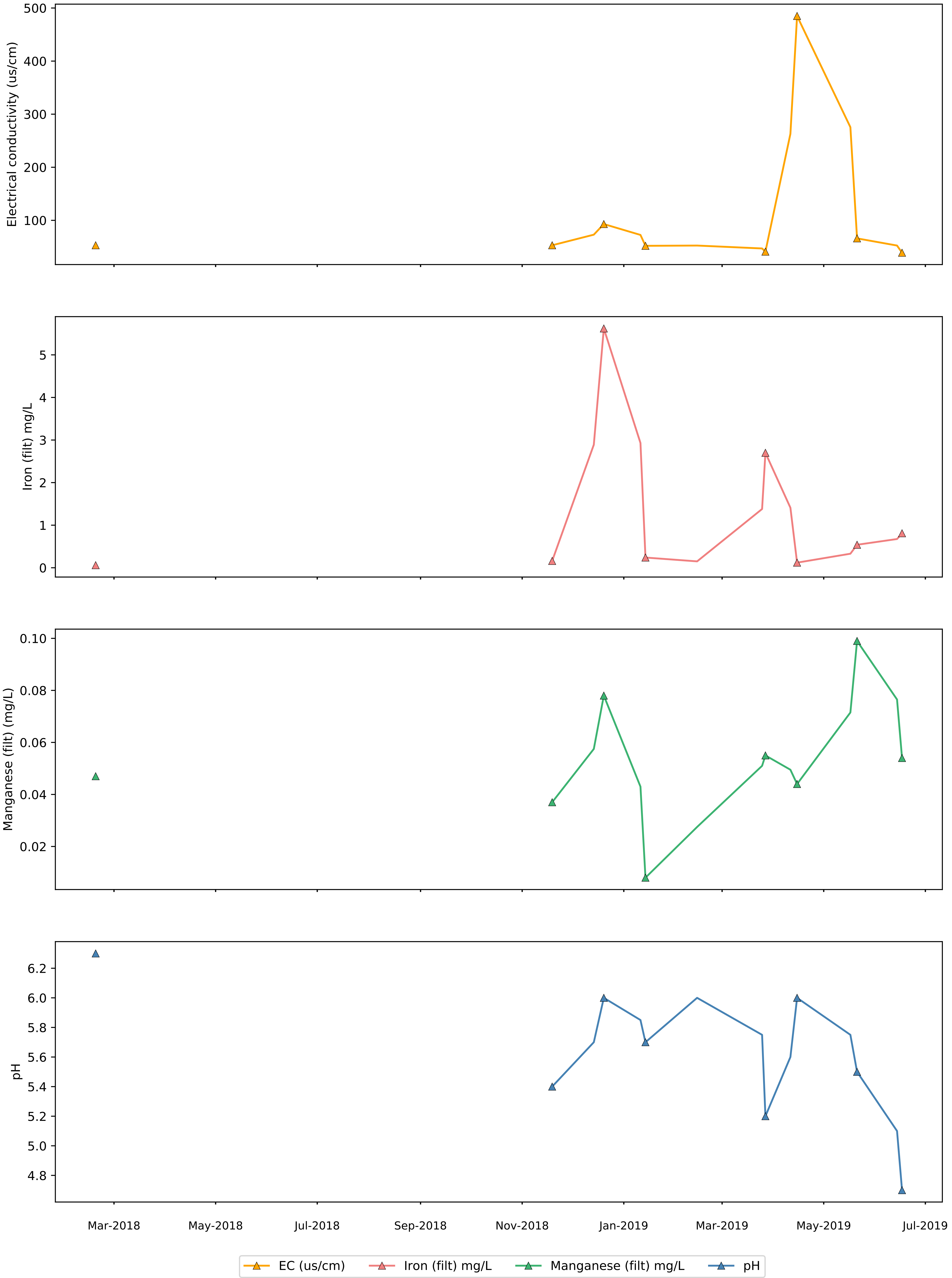


Electrical conductivity (us/cm)
110
100
90
80
70
60
50
40
30
Iron (filt) mg/L
5
4
3
2
1
0
Manganese (filt) (mg/L)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
pH
7.0
6.5
6.0
5.5
5.0
4.5
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

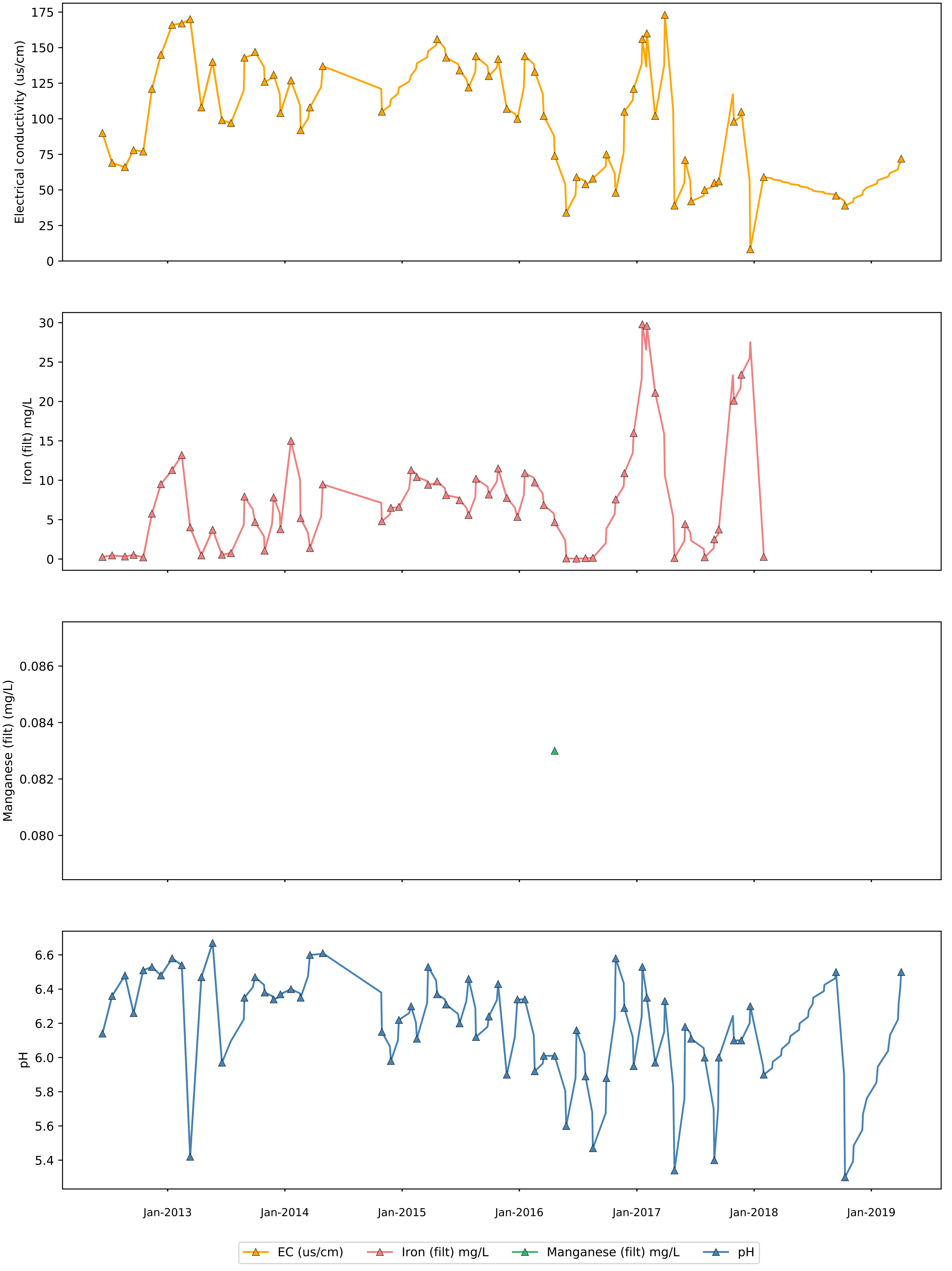


Electrical conductivity (us/cm)
250
200
150
100
50
Iron (filt) mg/L
5
4
3
2
1
0
Manganese (filt) (mg/L)
0.07
0.06
0.05
0.04
0.03
pH
6.5
6.0
5.5
5.0
4.5
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

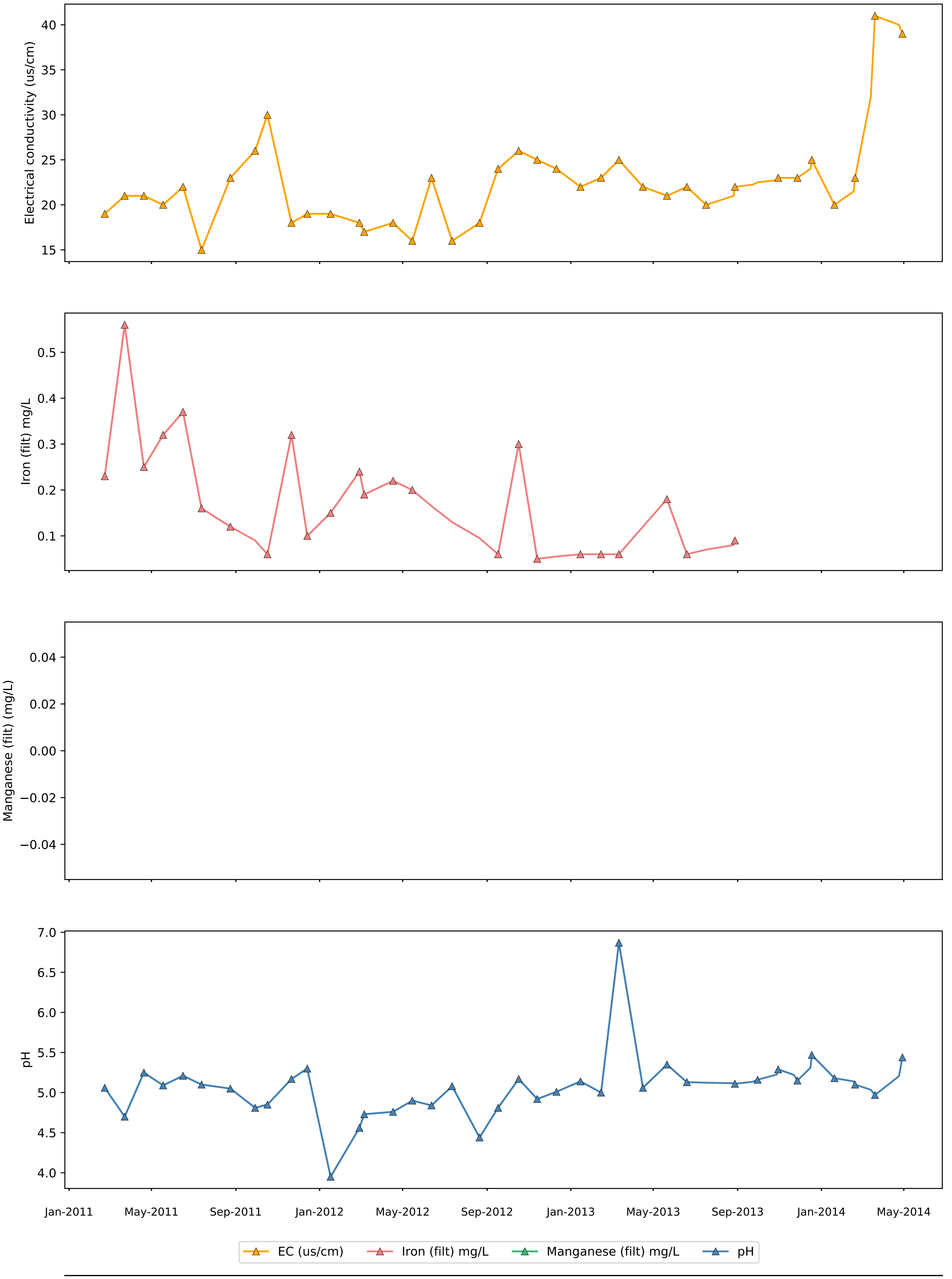

Electrical conductivity (us/cm)
700
600
500
400
300
200
100
Iron (filt) mg/L
10
8
6
4
2
0
Manganese (filt) (mg/L)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
pH
6.75
6.50
6.25
6.00
5.75
5.50
5.25
Mar-2018
May-2018
Jul-2018
Sep-2018
Nov-2018
Jan-2019
Mar-2019
May-2019
Jul-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

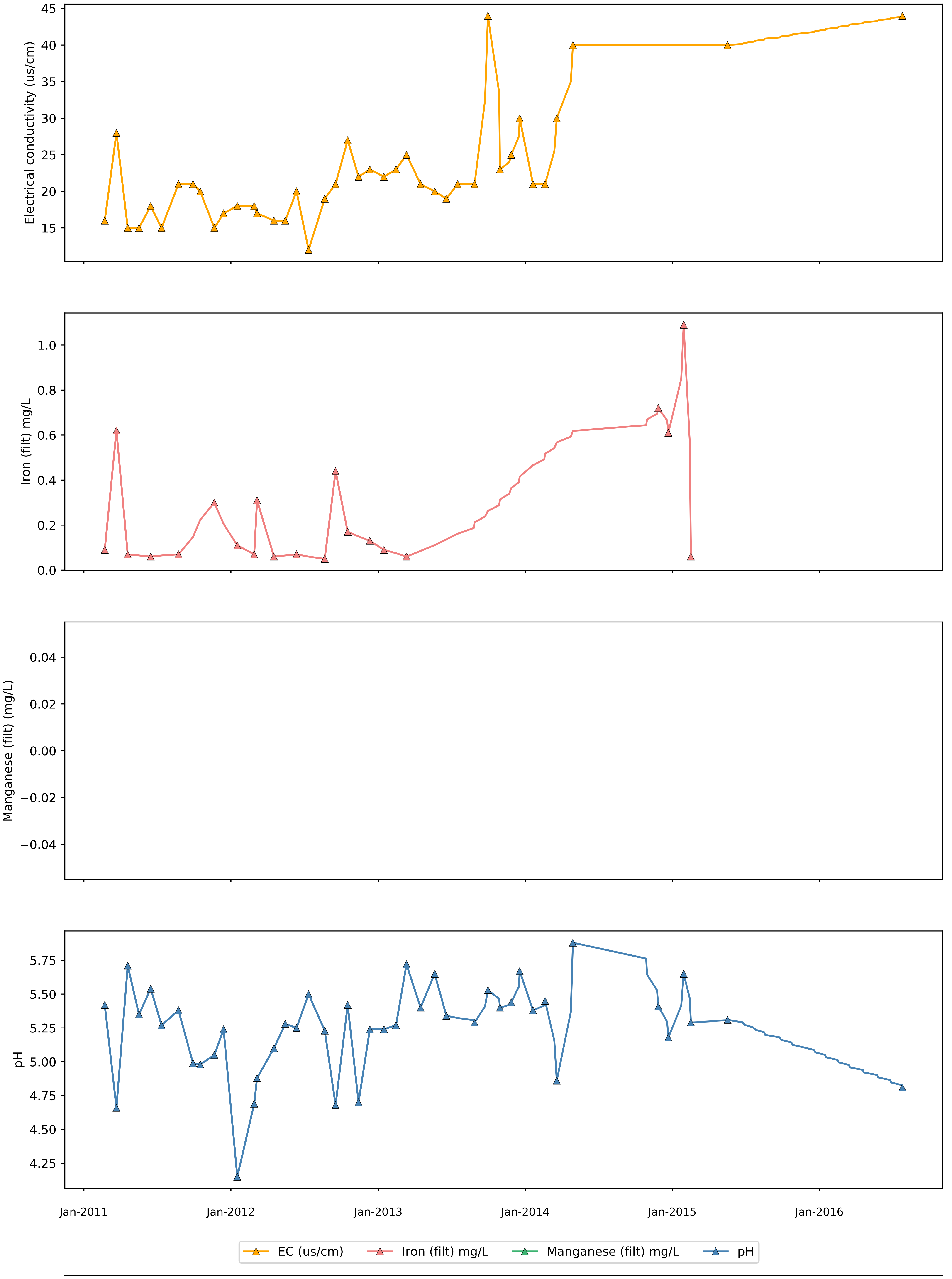


Electrical conductivity (us/cm)
Iron (filt) mg/L
Manganese (filt) (mg/L)
pH
Mar-2018
May-2018
Jul-2018
Sep-2018
Nov-2018
Jan-2019
Mar-2019
May-2019
Jul-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

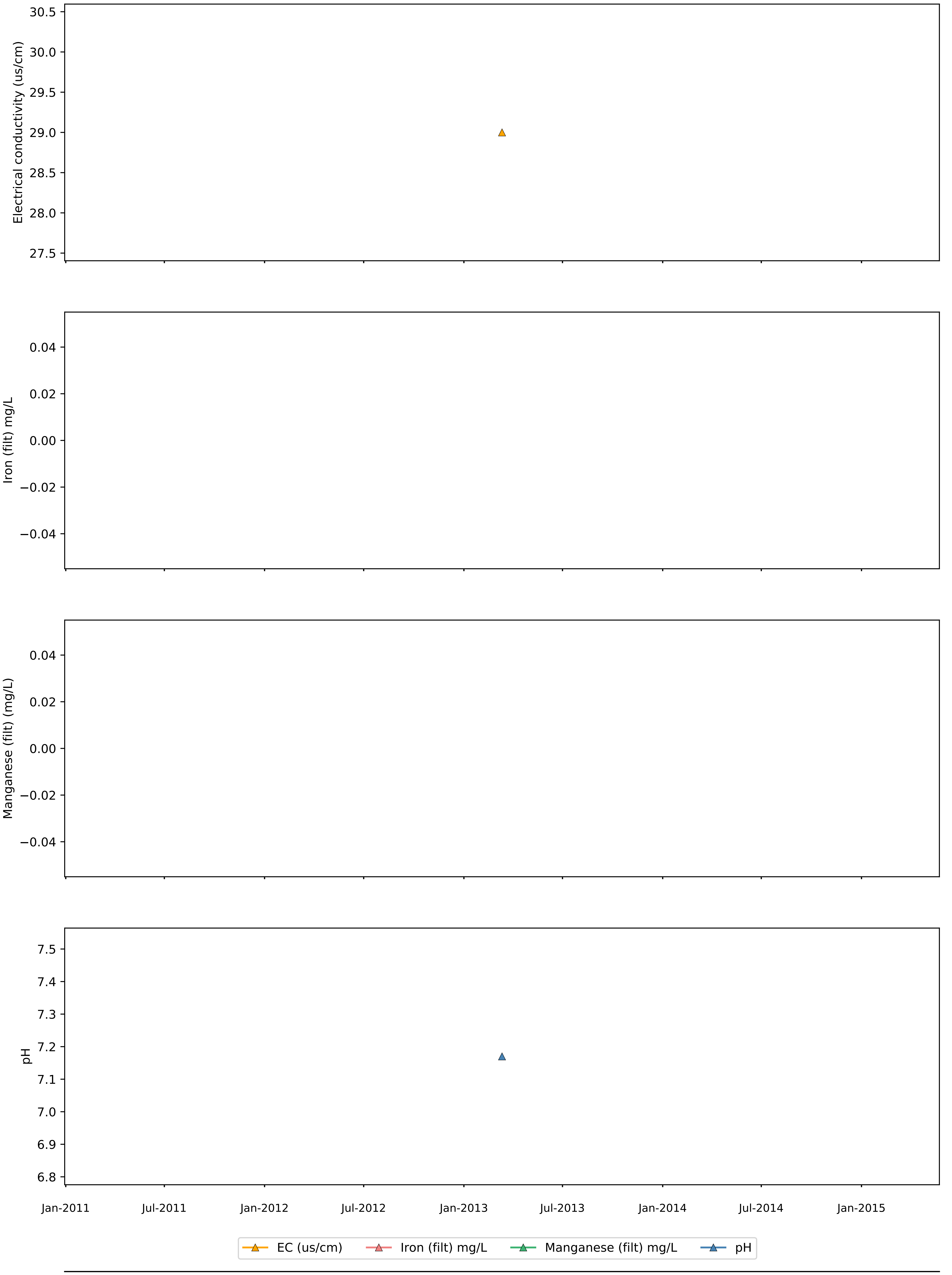


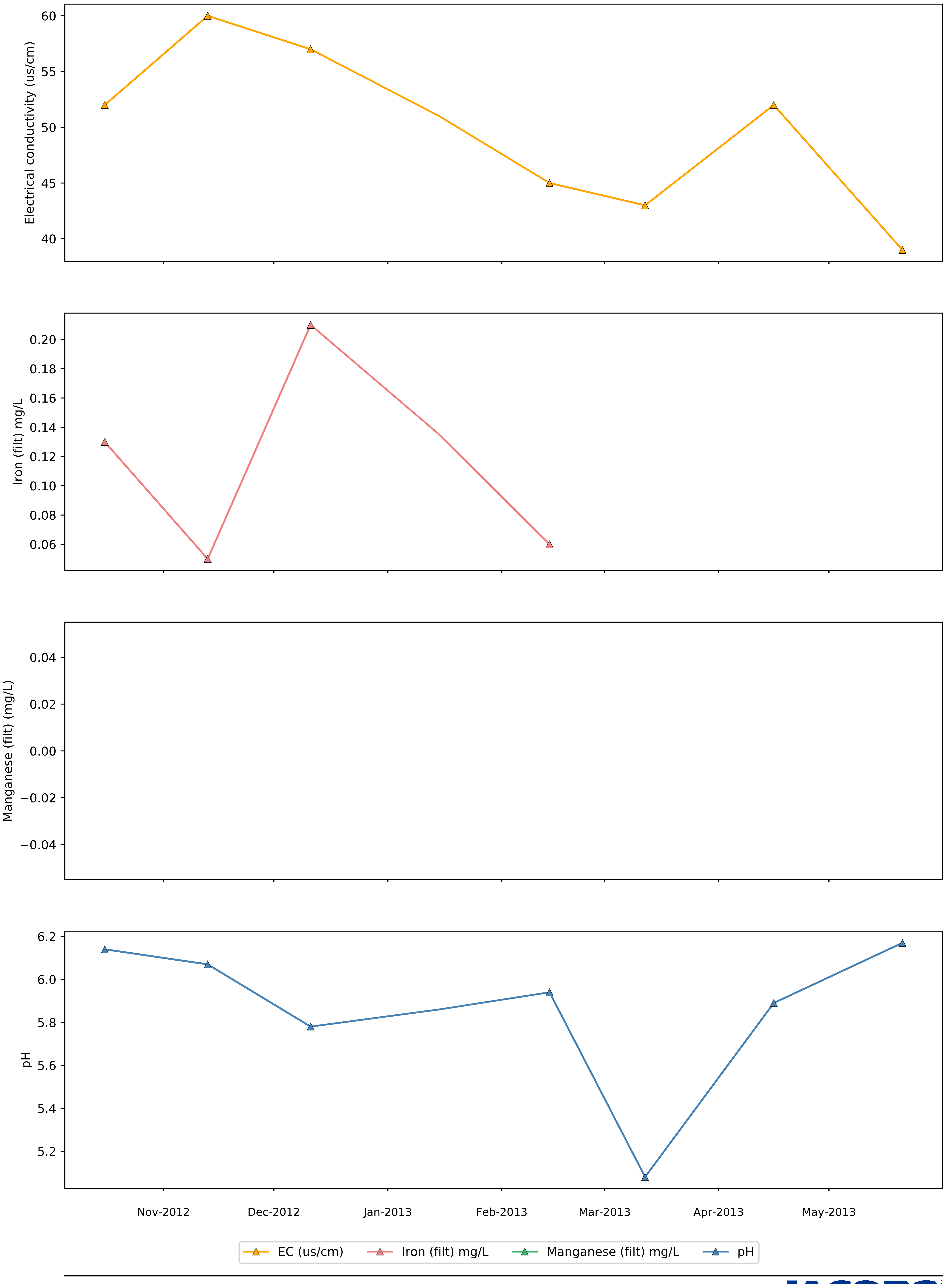
Appendix F : CC1


Electrical conductivity (us/cm)
40
35
30
25
20
15
Iron (filt) mg/L
0.5
0.4
0.3
0.2
0.1
Manganese (filt) (mg/L)
0.04
0.02
0.00
−0.02
−0.04
pH
7.0
6.5
6.0
5.5
5.0
4.5
4.0
Jan-2011
May-2011
Sep-2011
Jan-2012
May-2012
Sep-2012
Jan-2013
May-2013
Sep-2013
Jan-2014
May-2014
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

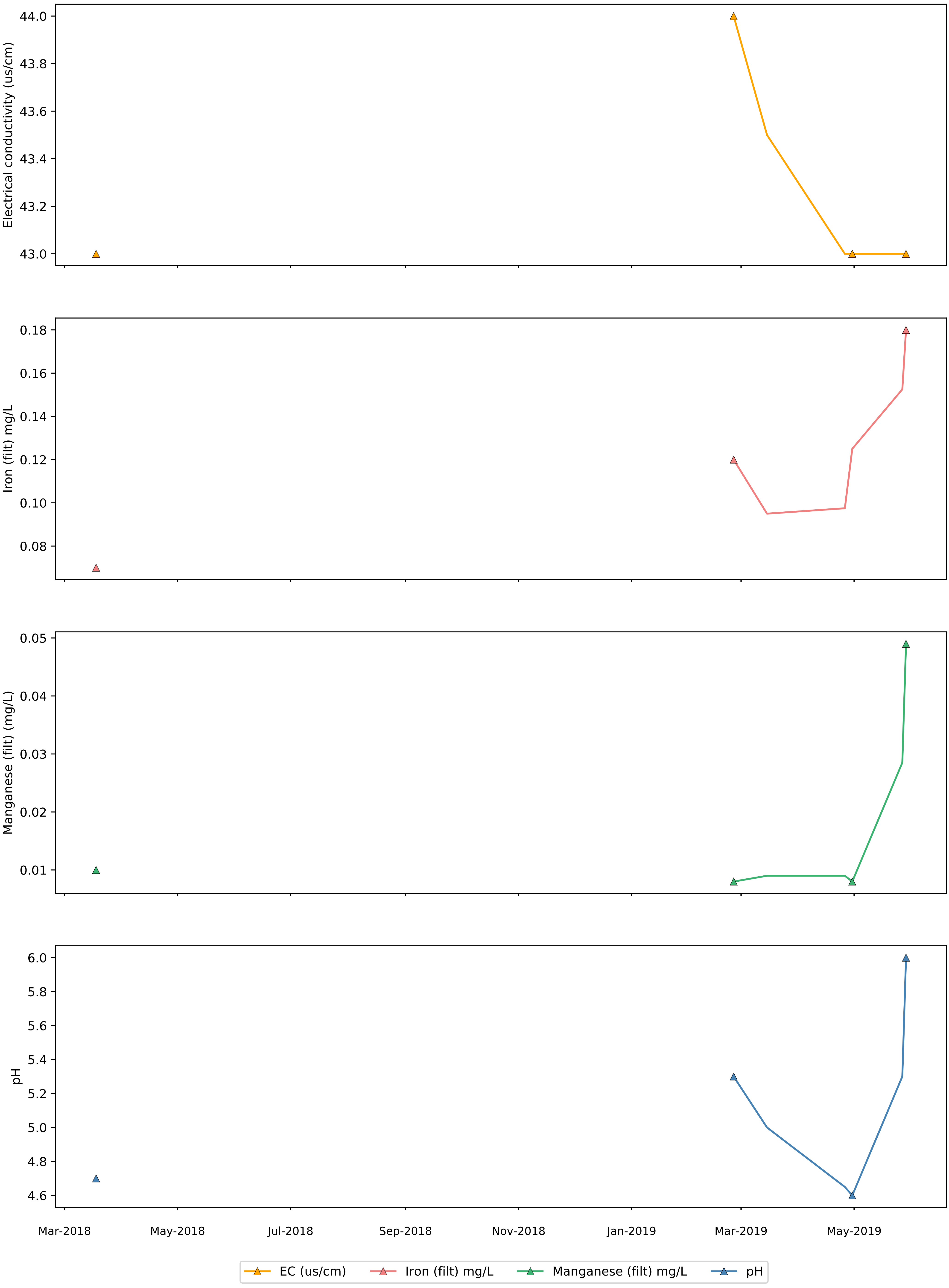


Electrical conductivity (us/cm)
Iron (filt) mg/L
Manganese (filt) (mg/L)
pH
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

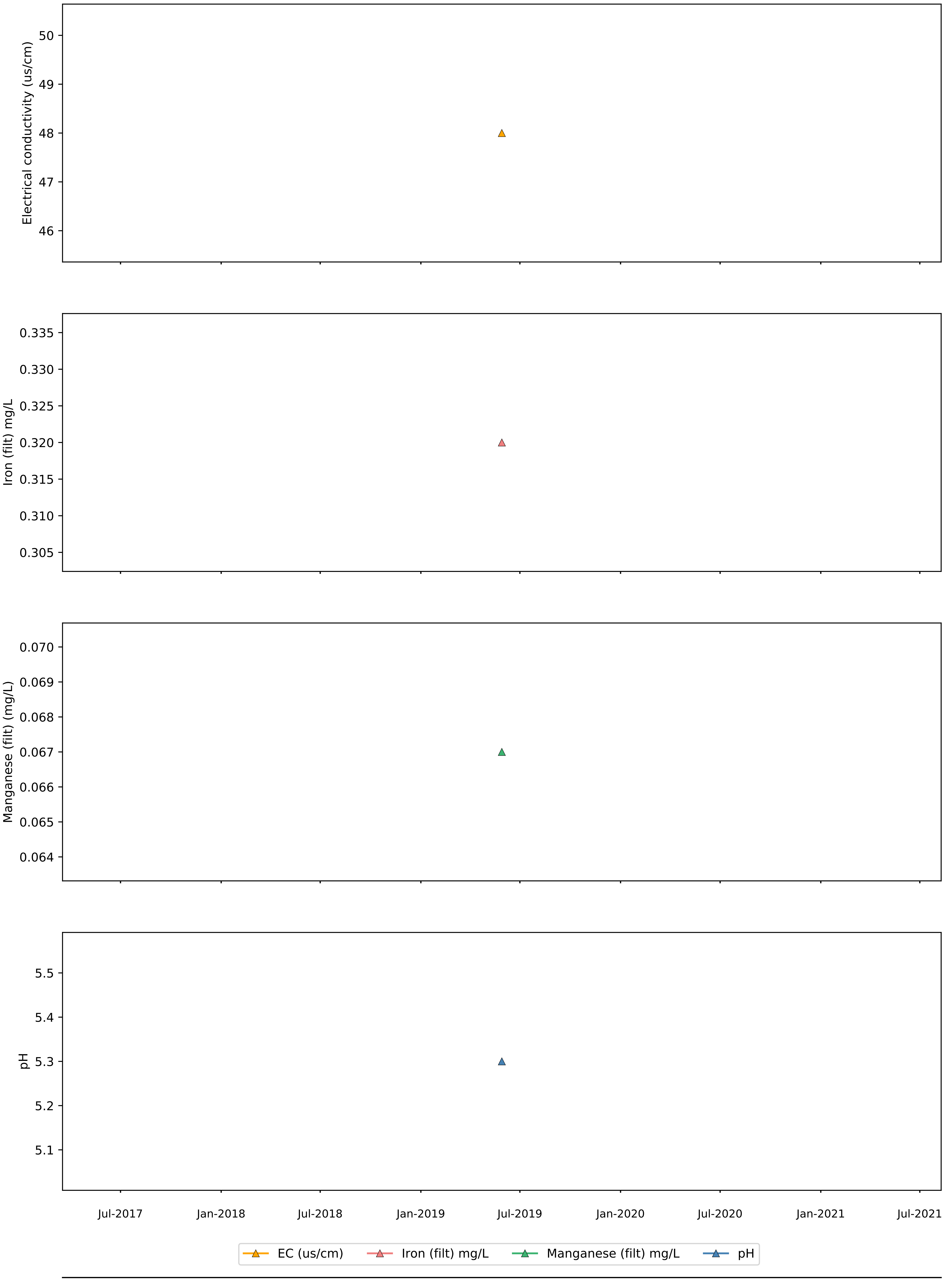

Electrical conductivity (us/cm)
Iron (filt) mg/L
Manganese (filt) (mg/L)
pH
Jan-2011
Jul-2011
Jan-2012
Jul-2012
Jan-2013
Jul-2013
Jan-2014
Jul-2014
Jan-2015
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

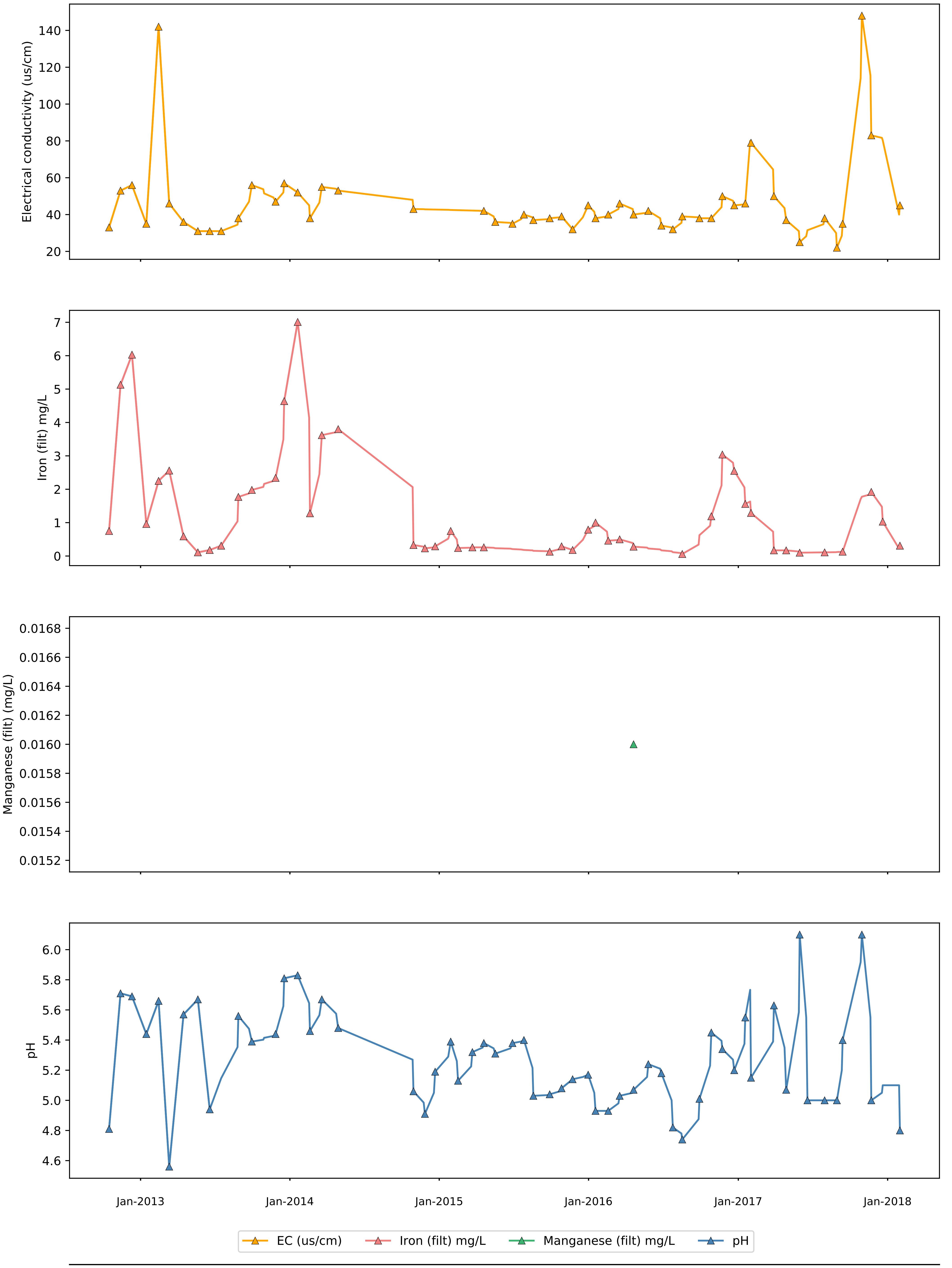


Electrical conductivity (us/cm)
60
55
50
45
40
Iron (filt) mg/L
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
Manganese (filt) (mg/L)
0.04
0.02
0.00
−0.02
−0.04
pH
6.2
6.0
5.8
5.6
5.4
5.2
Nov-2012
Dec-2012
Jan-2013
Feb-2013
Mar-2013
Apr-2013
May-2013
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

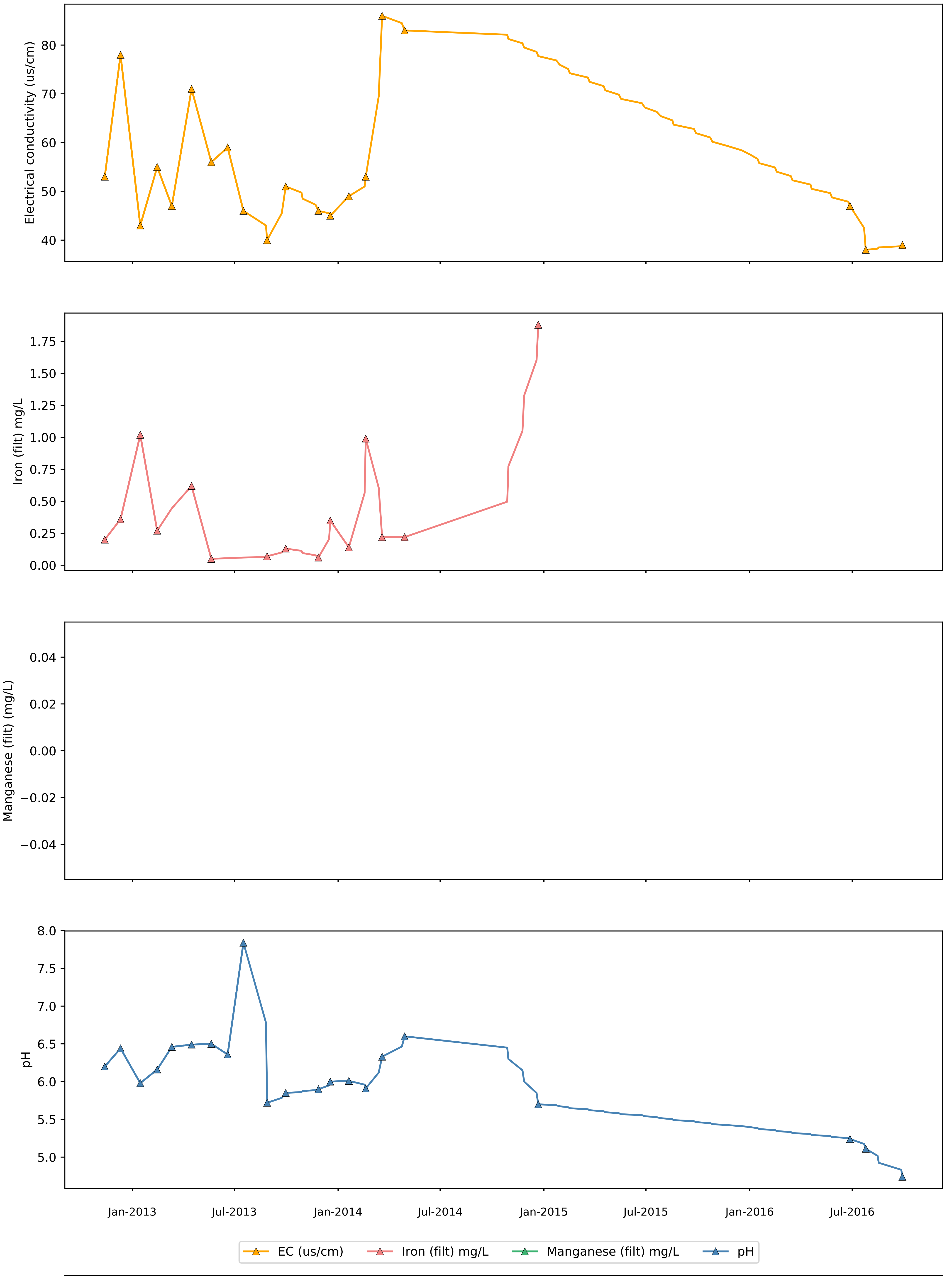


Electrical conductivity (us/cm)
44.0
43.8
43.6
43.4
43.2
43.0
Iron (filt) mg/L
0.18
0.16
0.14
0.12
0.10
0.08
Manganese (filt) (mg/L)
0.05
0.04
0.03
0.02
0.01
pH
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
Mar-2018
May-2018
Jul-2018
Sep-2018
Nov-2018
Jan-2019
Mar-2019
May-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

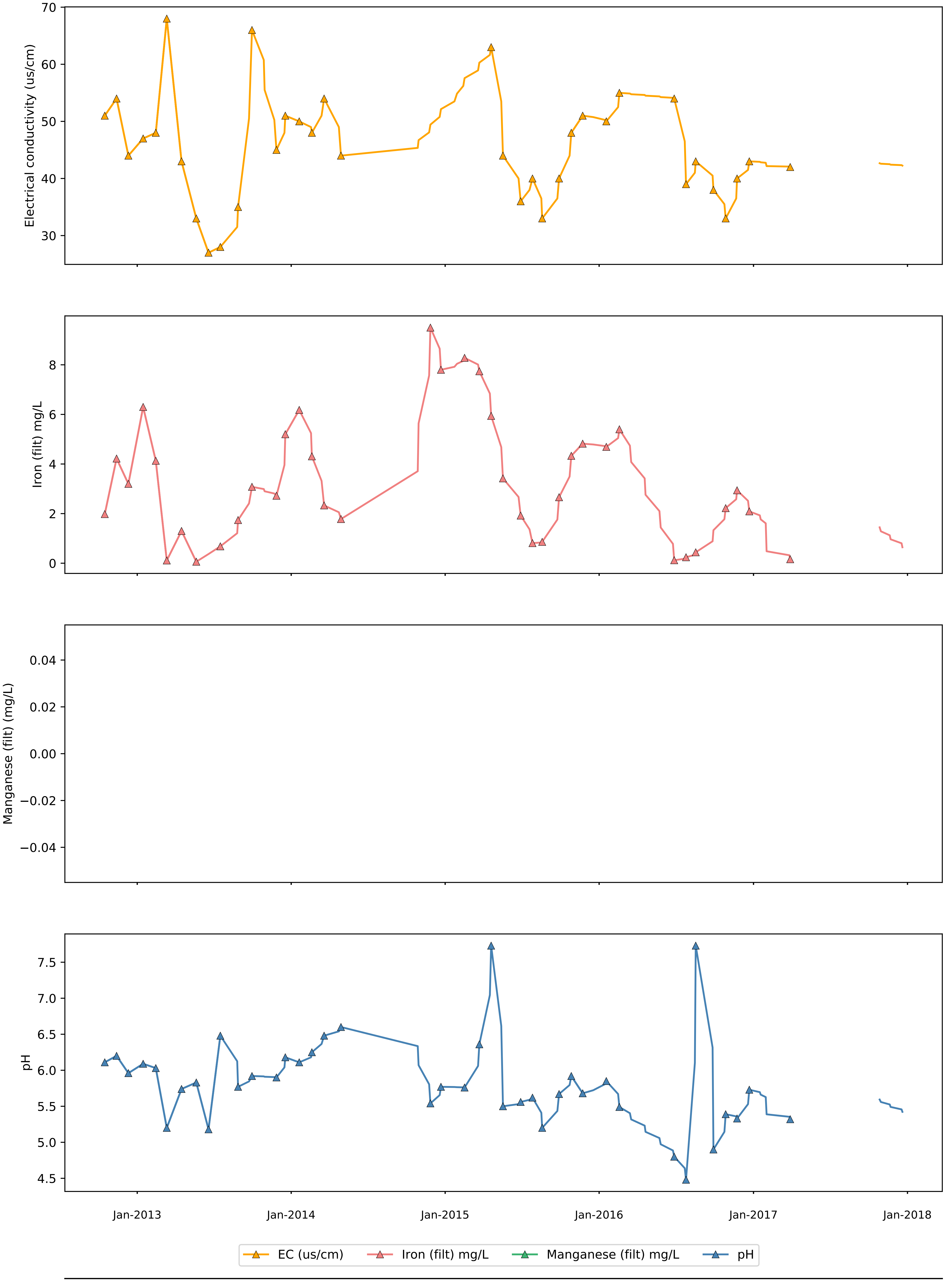

Electrical conductivity (us/cm)
50
49
48
47
46
Iron (filt) mg/L
0.335
0.330
0.325
0.320
0.315
0.310
0.305
Manganese (filt) (mg/L)
0.070
0.069
0.068
0.067
0.066
0.065
0.064
pH
5.5
5.4
5.3
5.2
5.1
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Jul-2019
Jan-2020
Jul-2020
Jan-2021
Jul-2021
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

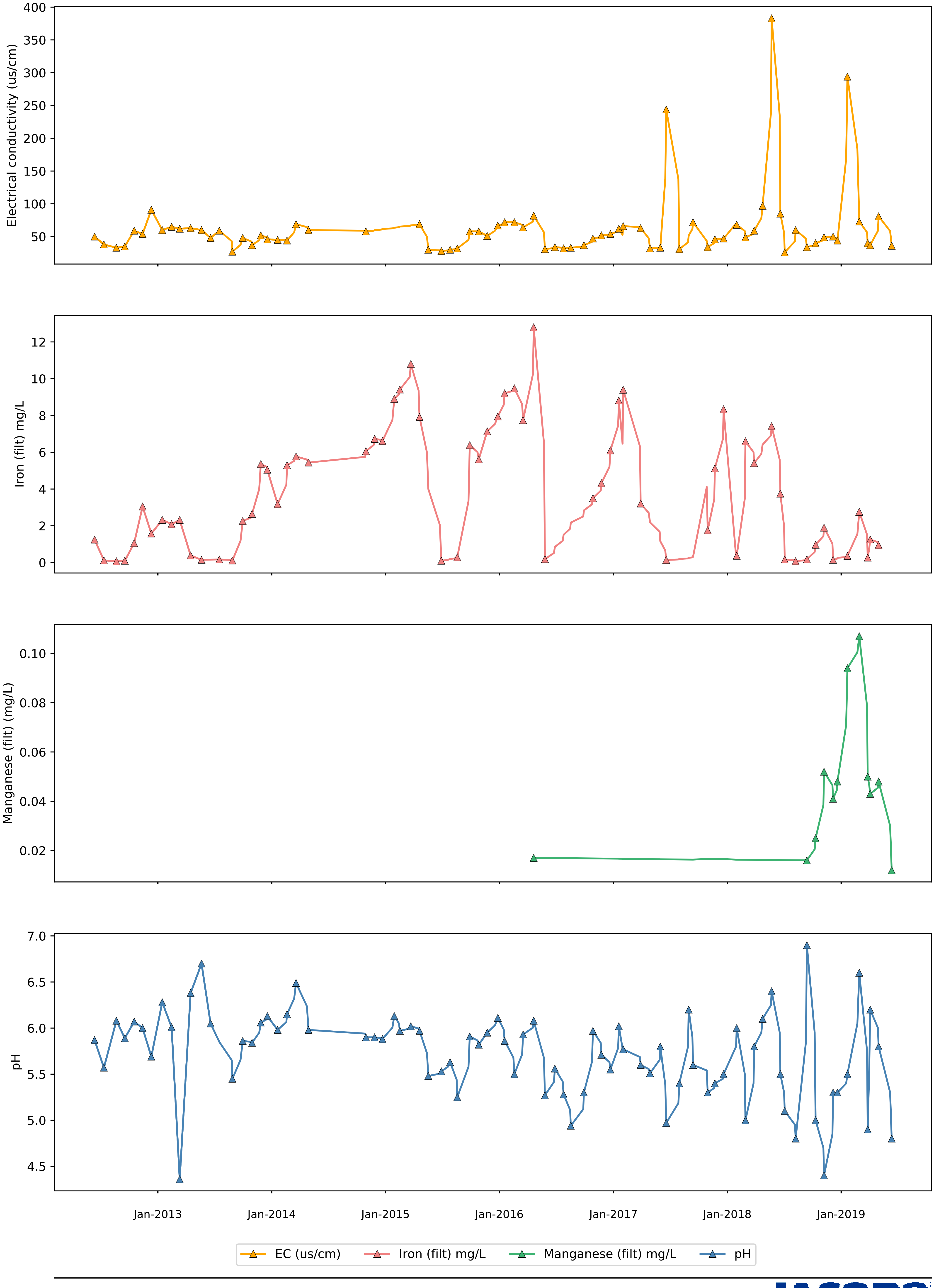


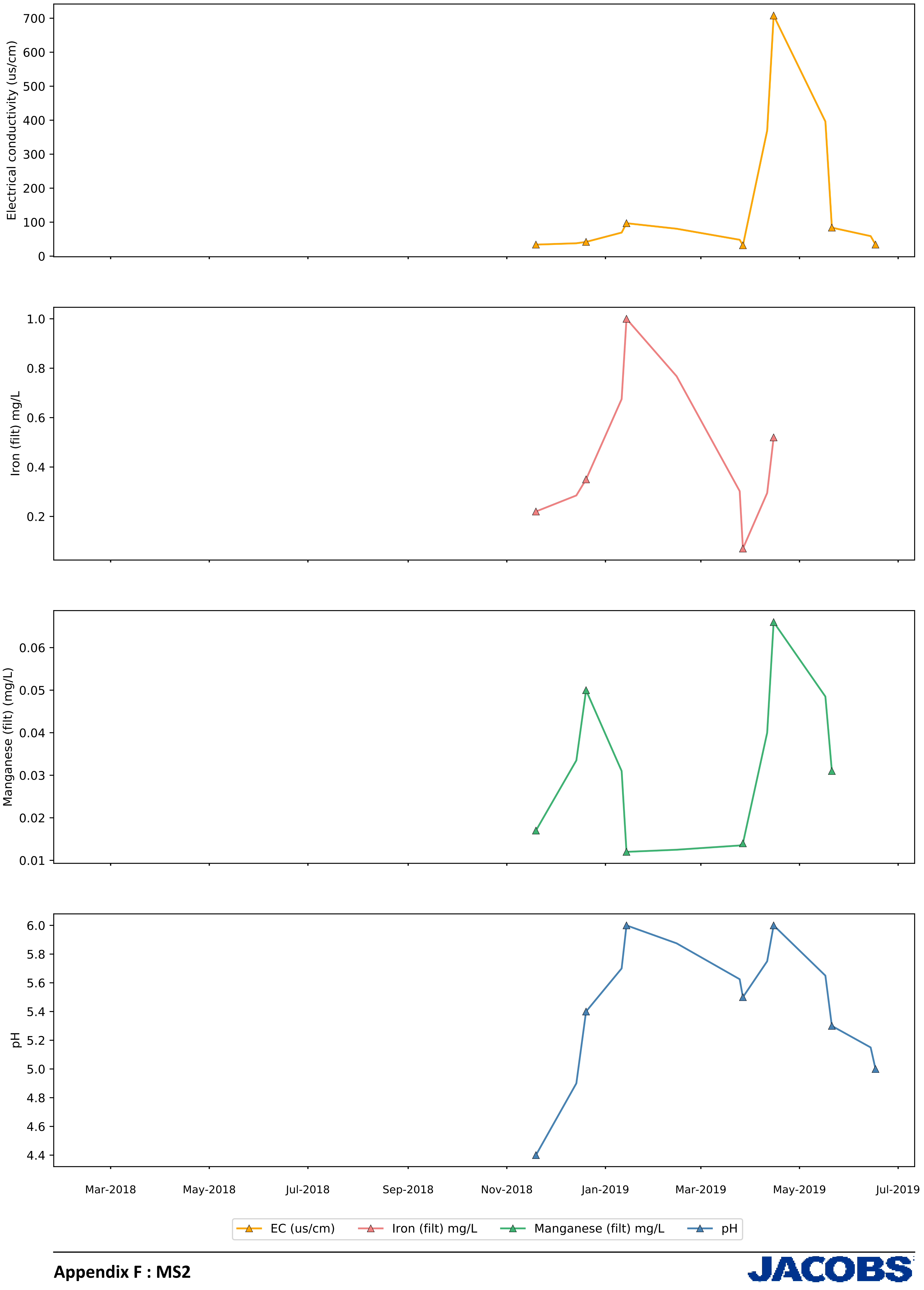
Appendix F : GG1



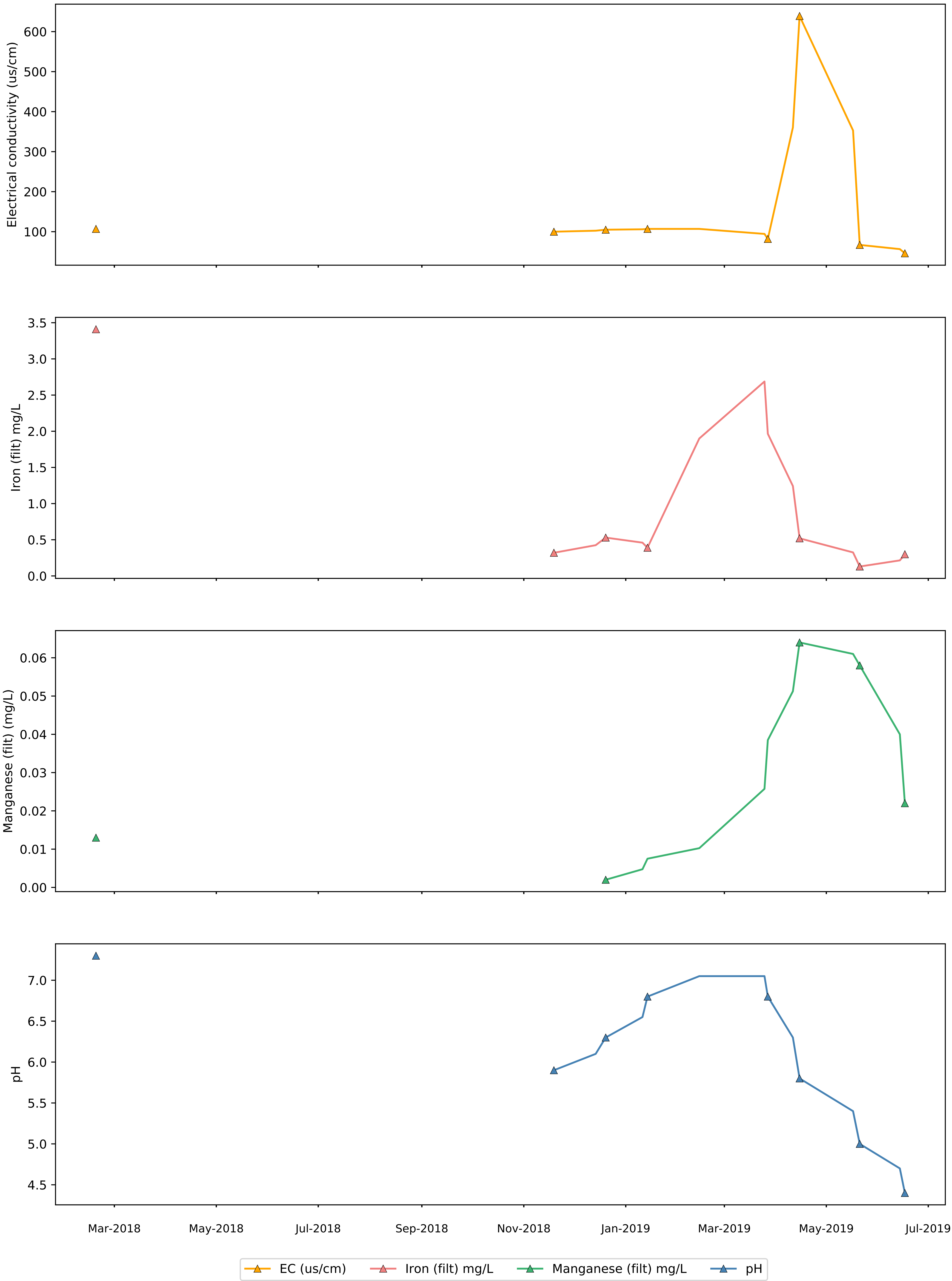
Electrical conductivity (us/cm)
80
70
60
50
40
Iron (filt) mg/L
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Manganese (filt) (mg/L)
0.04
0.02
0.00
−0.02
−0.04
pH
8.0
7.5
7.0
6.5
6.0
5.5
5.0
Jan-2013
Jul-2013
Jan-2014
Jul-2014
Jan-2015
Jul-2015
Jan-2016
Jul-2016
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH


70
60
50
40
30
Electrical conductivity (us/cm)
8
6
4
2
0
Iron (filt) mg/L
0.04
0.02
0.00
−0.02
−0.04
Manganese (filt) (mg/L)
7.5
7.0
6.5
6.0
5.5
5.0
4.5
pH
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

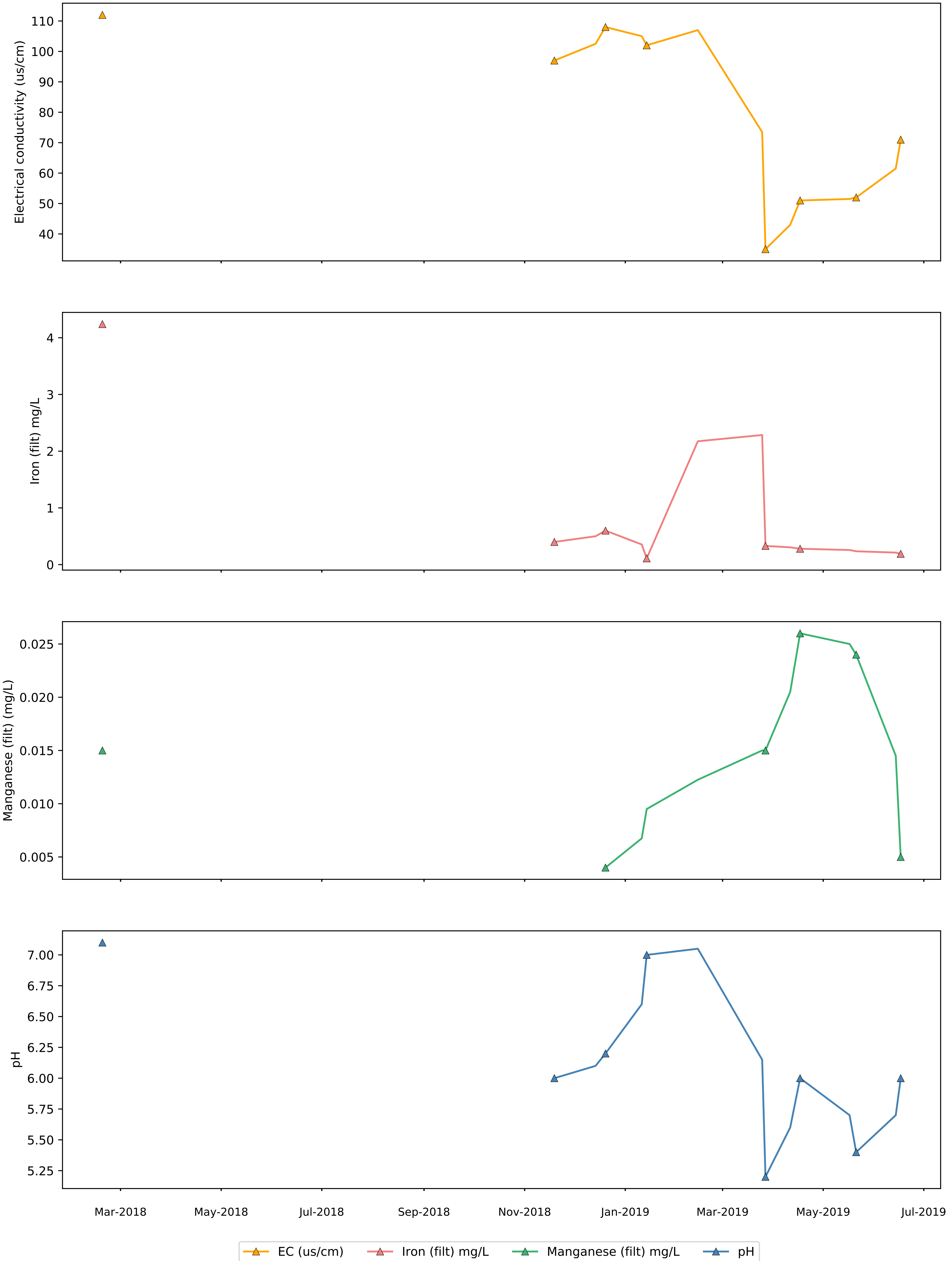

Electrical conductivity (us/cm)
Iron (filt) mg/L
Manganese (filt) (mg/L)
pH
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH



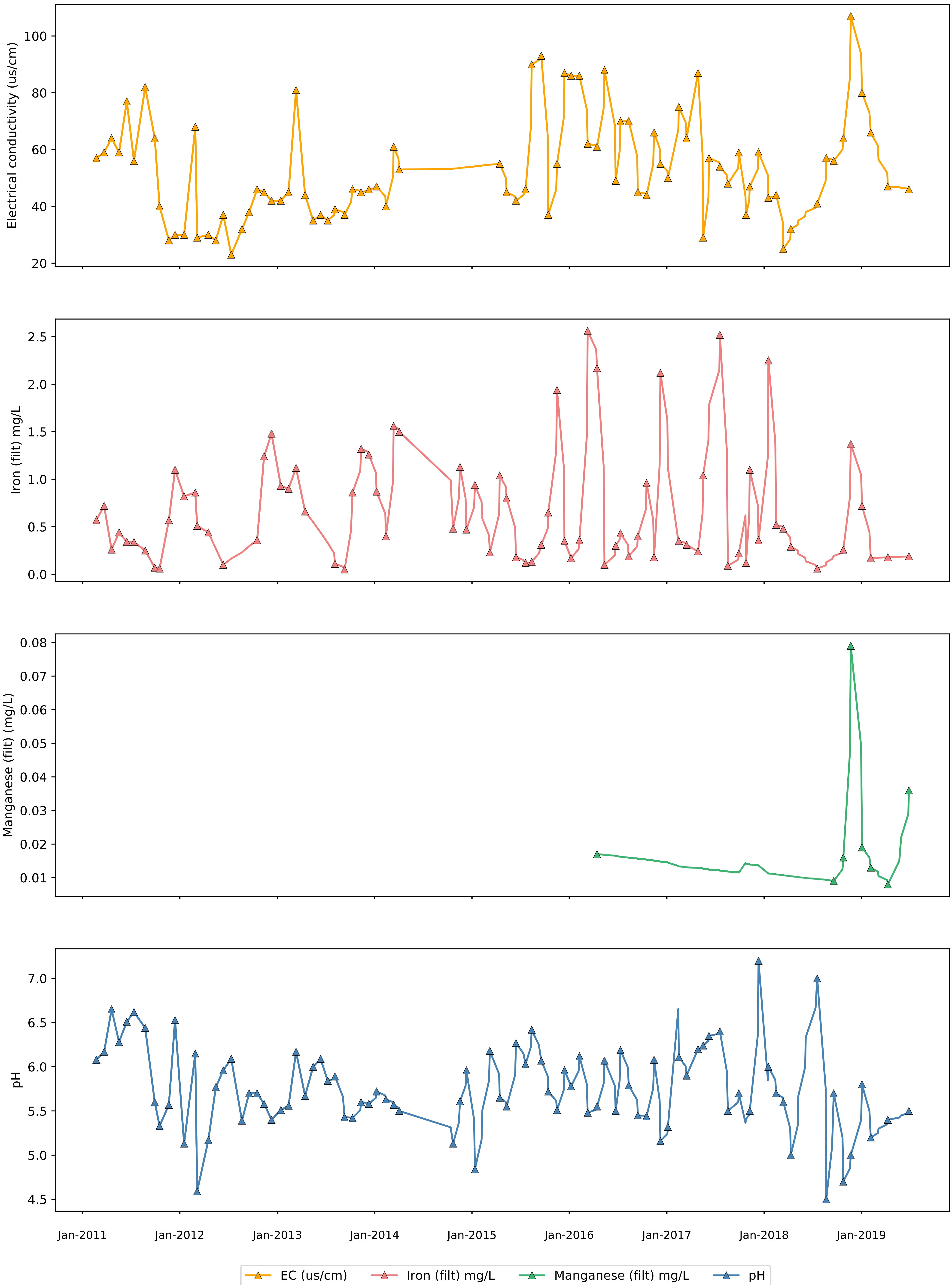
Electrical conductivity (us/cm)
Iron (filt) mg/L
Manganese (filt) (mg/L)
pH
Mar-2018
May-2018
Jul-2018
Sep-2018
Nov-2018
Jan-2019
Mar-2019
May-2019
Jul-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH



Appendix F : PC1

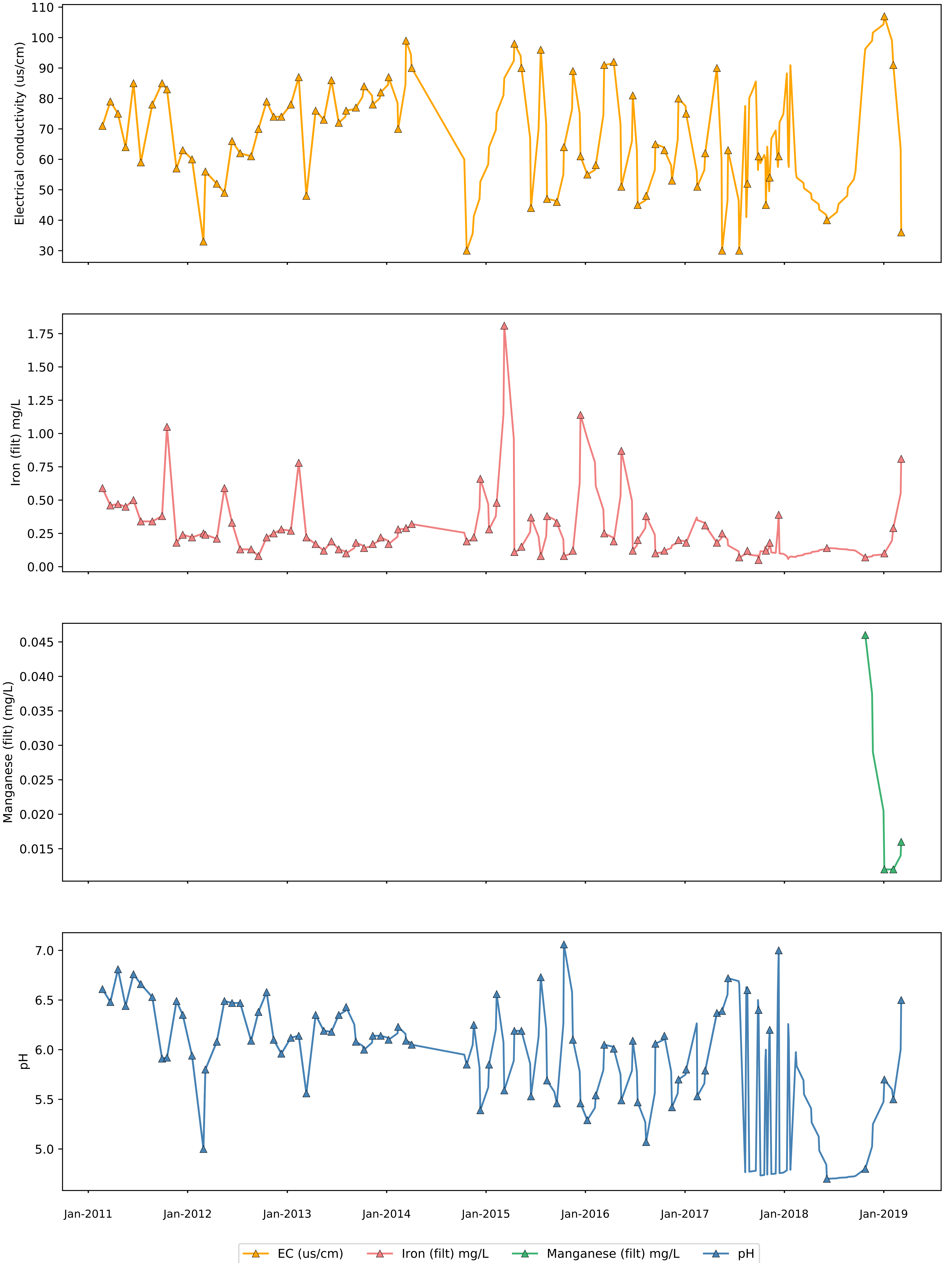


Appendix F : PC2

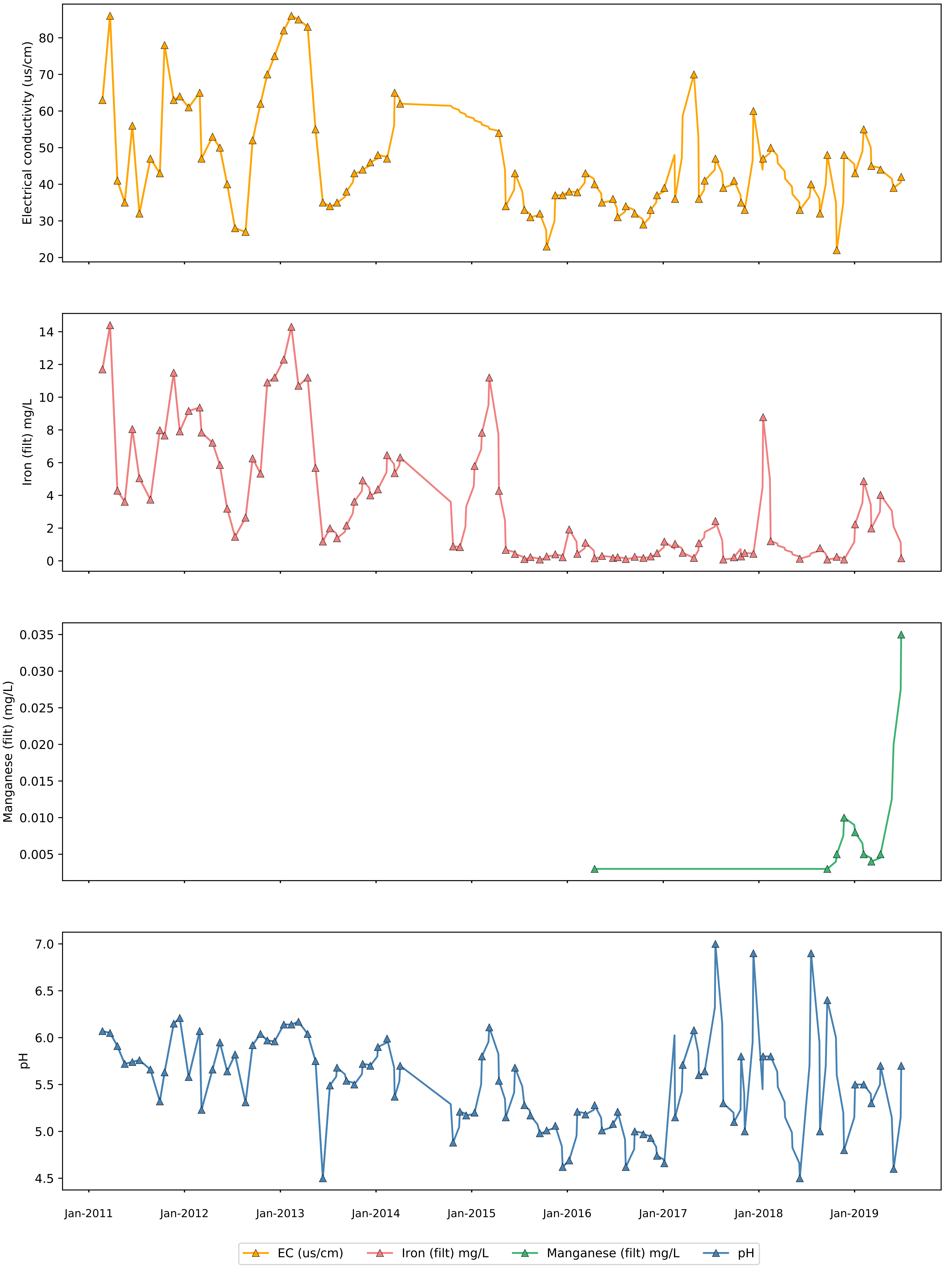


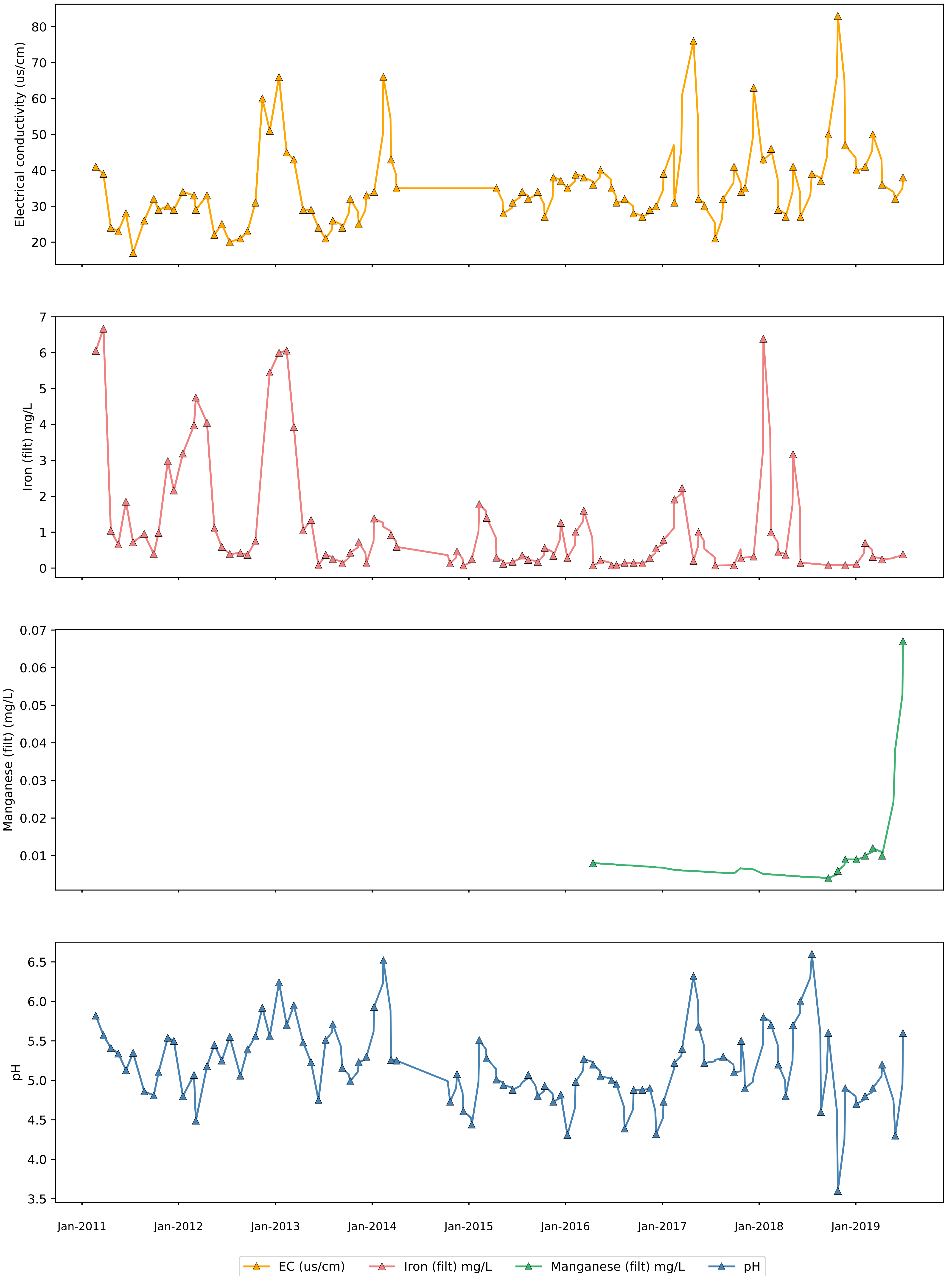
Appendix F : SS1

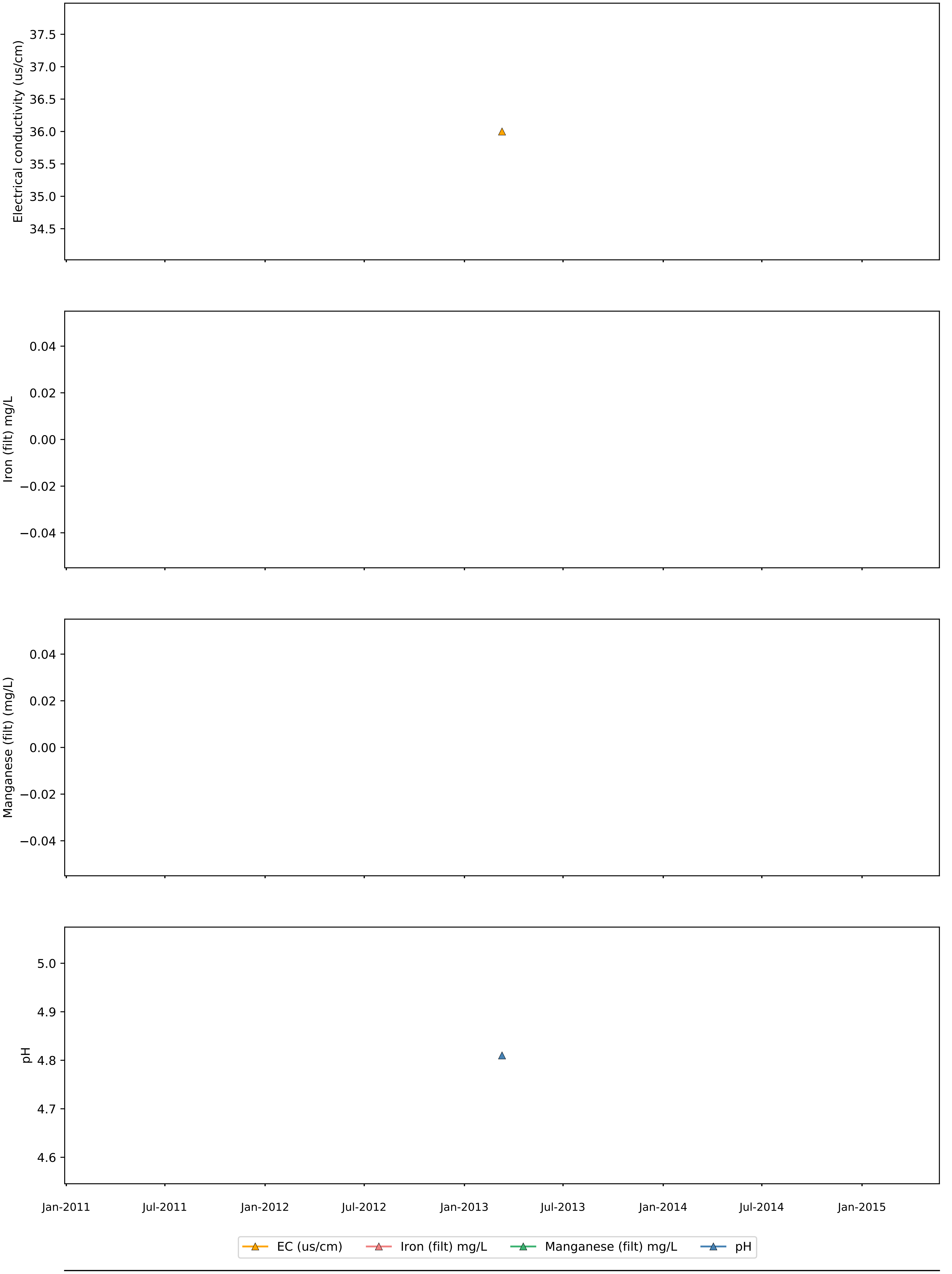
JACOBS



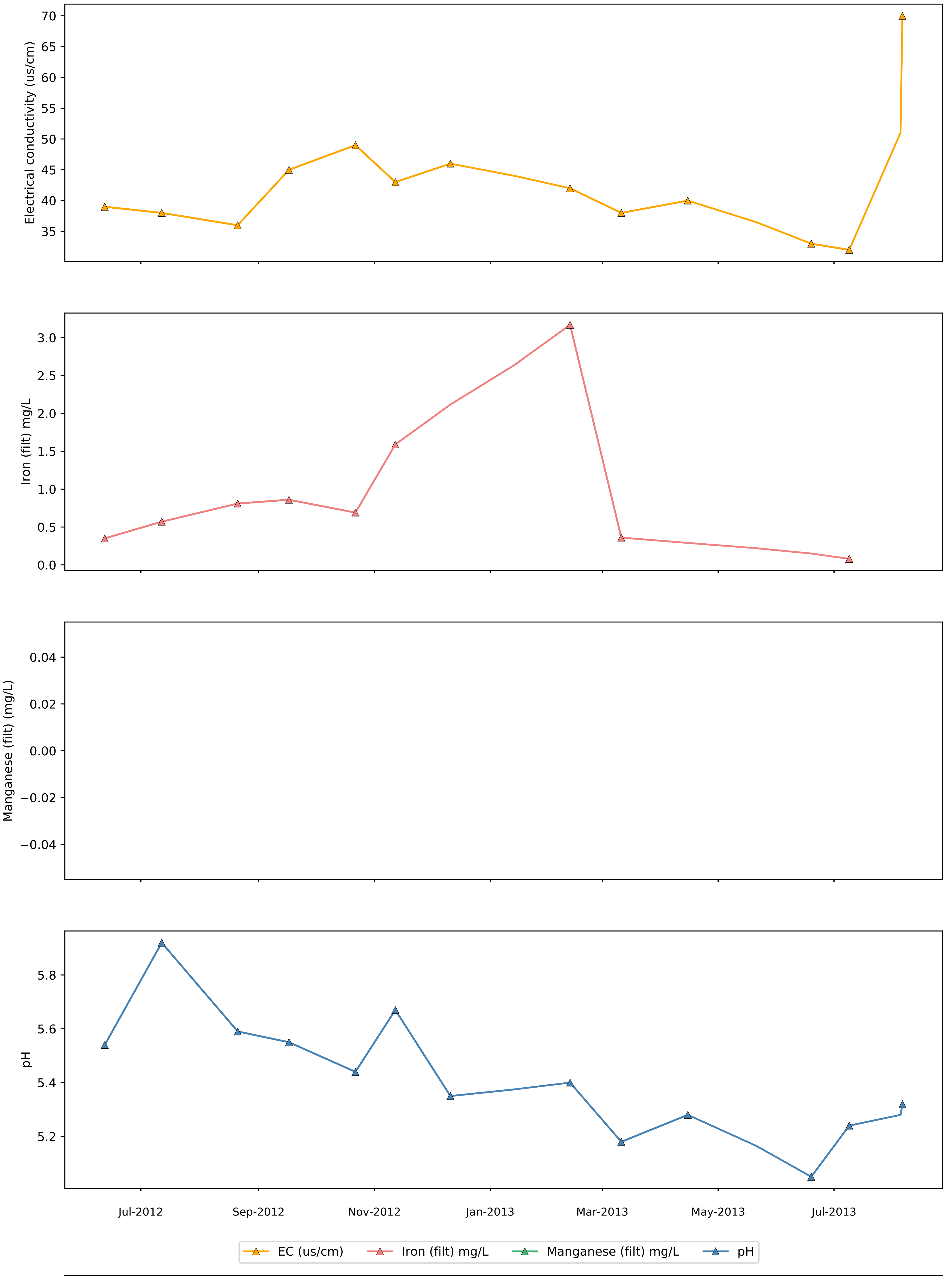
Electrical conductivity (us/cm)
Iron (filt) mg/L
Manganese (filt) (mg/L)
pH
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

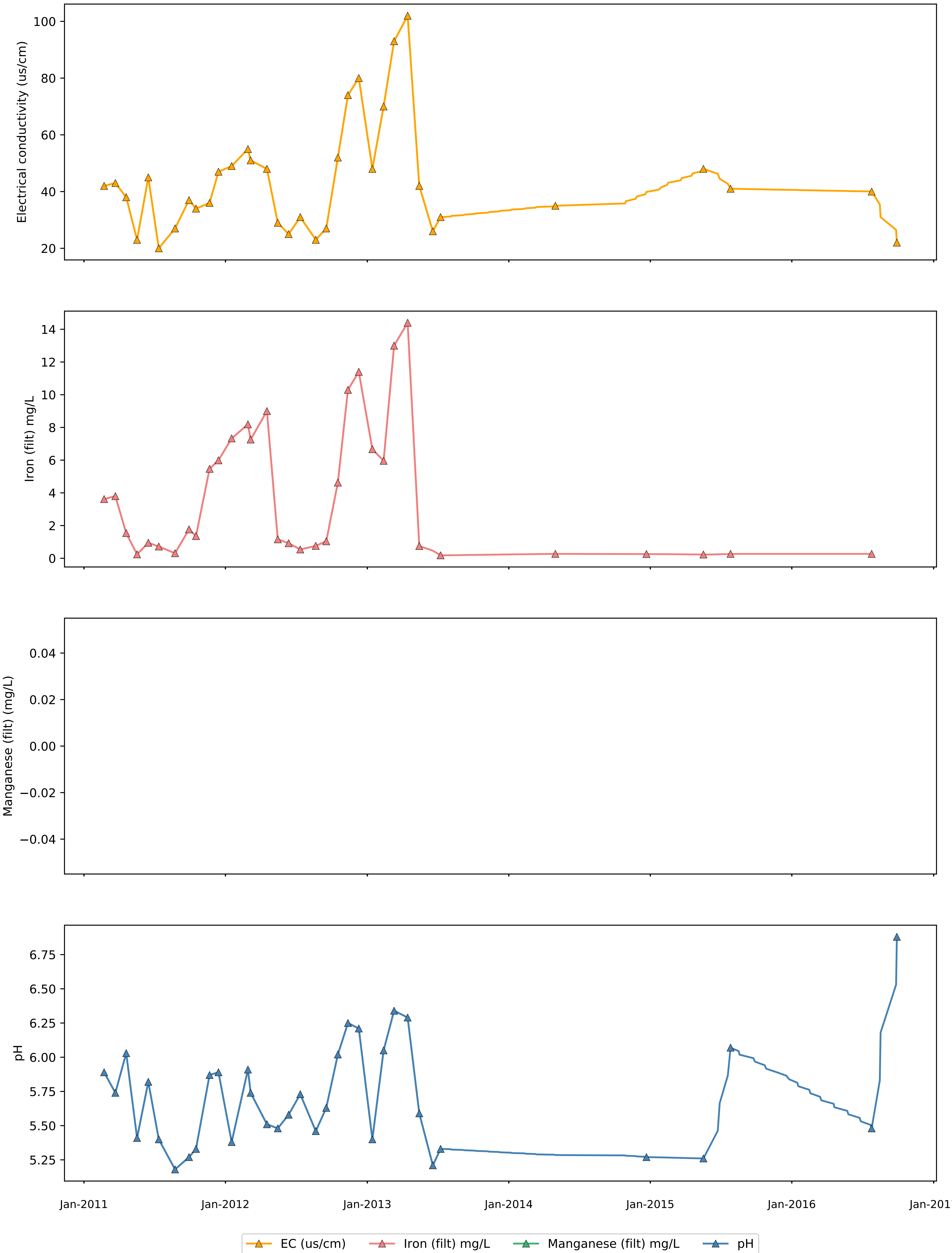

Electrical conductivity (us/cm)
Iron (filt) mg/L
Manganese (filt) (mg/L)
pH
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

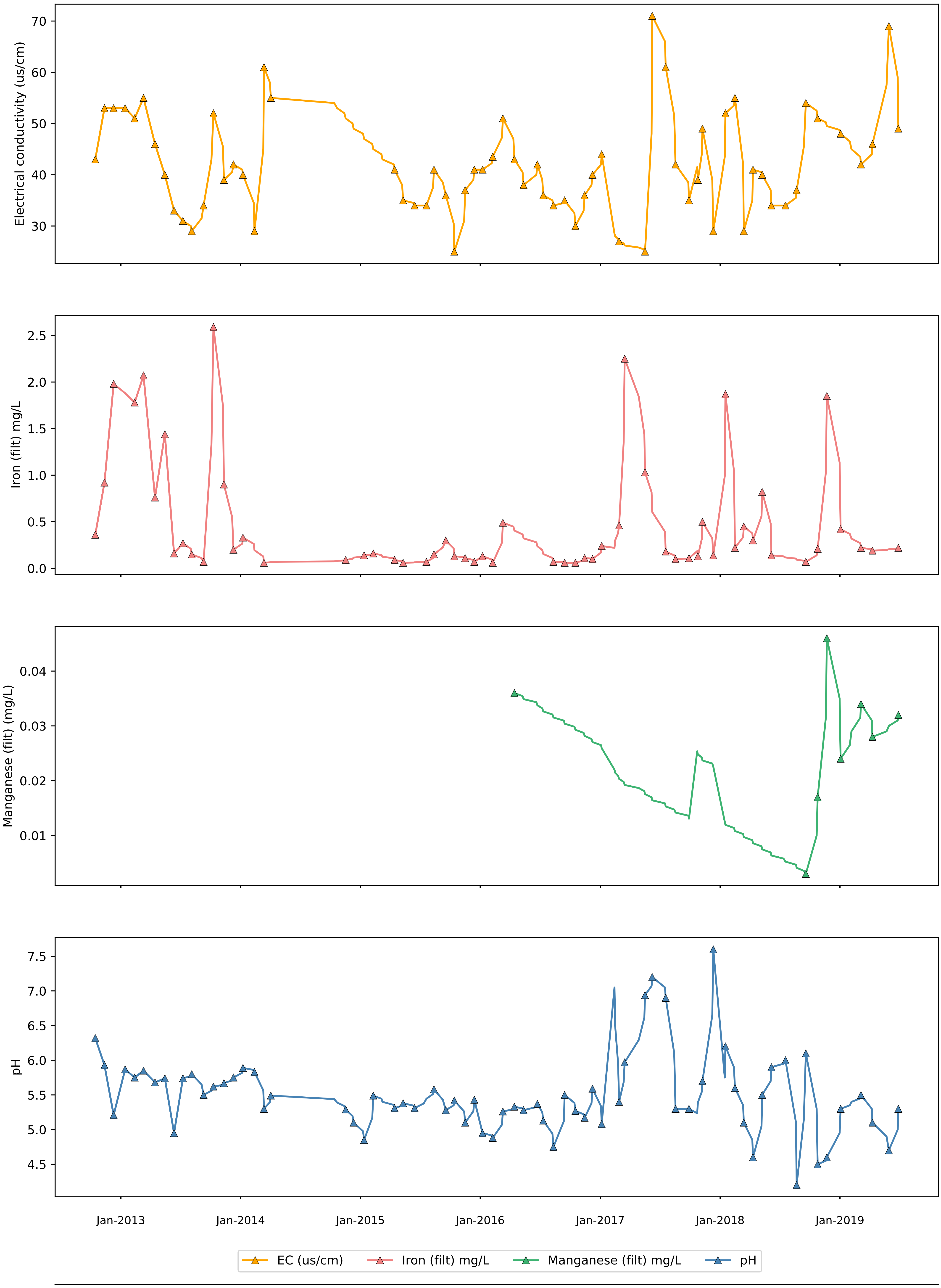

Electrical conductivity (us/cm)
Iron (filt) mg/L
Manganese (filt) (mg/L)
pH
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

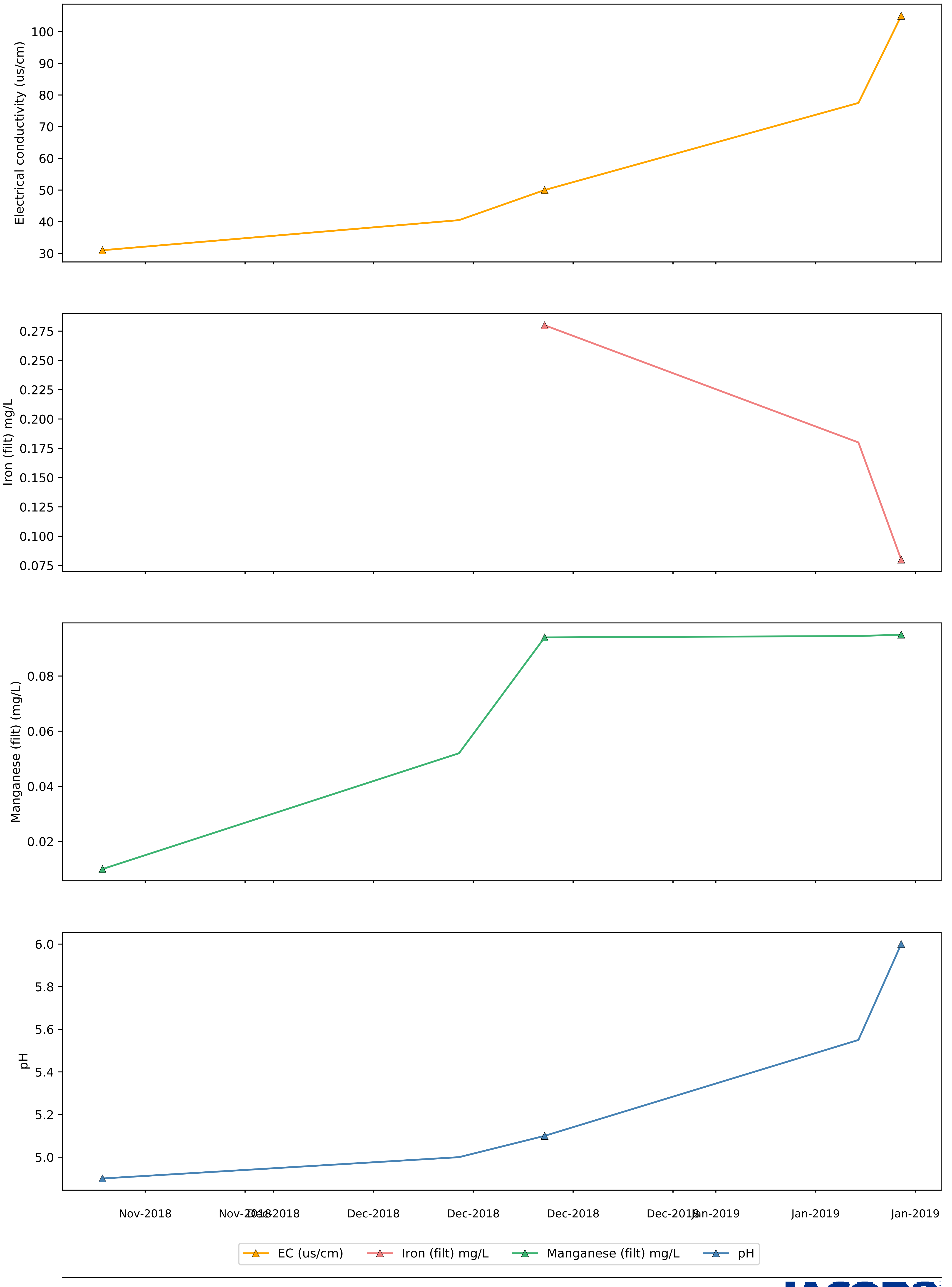


Electrical conductivity (us/cm)
37.5
37.0
36.5
36.0
35.5
35.0
34.5
Iron (filt) mg/L
0.04
0.02
0.00
−0.02
−0.04
Manganese (filt) (mg/L)
0.04
0.02
0.00
−0.02
−0.04
pH
5.0
4.9
4.8
4.7
4.6
Jan-2011
Jul-2011
Jan-2012
Jul-2012
Jan-2013
Jul-2013
Jan-2014
Jul-2014
Jan-2015
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

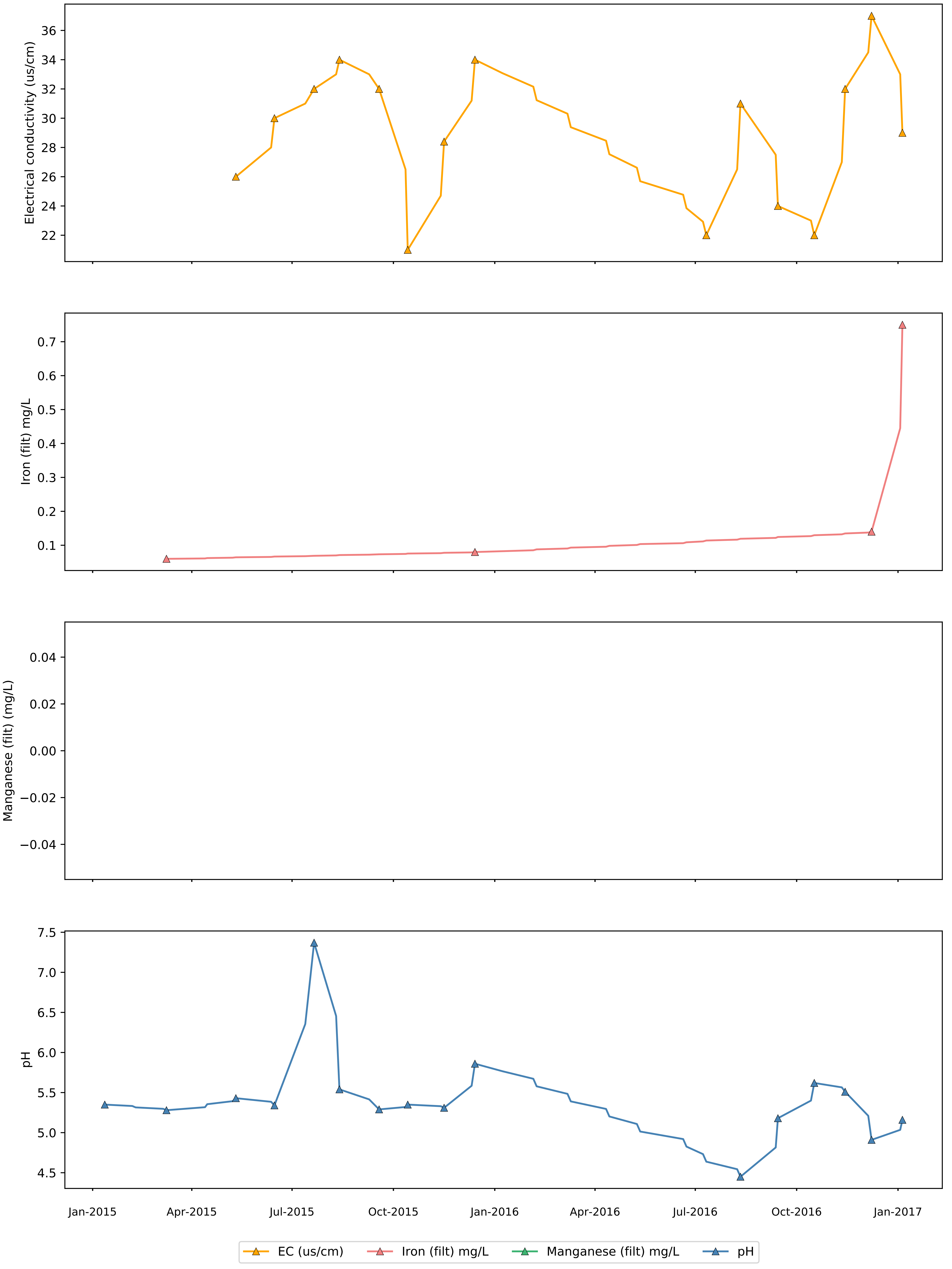

Electrical conductivity (us/cm)
70
65
60
55
50
45
40
35
Iron (filt) mg/L
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Manganese (filt) (mg/L)
0.04
0.02
0.00
−0.02
−0.04
pH
5.8
5.6
5.4
5.2
Jul-2012
Sep-2012
Nov-2012
Jan-2013
Mar-2013
May-2013
Jul-2013
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

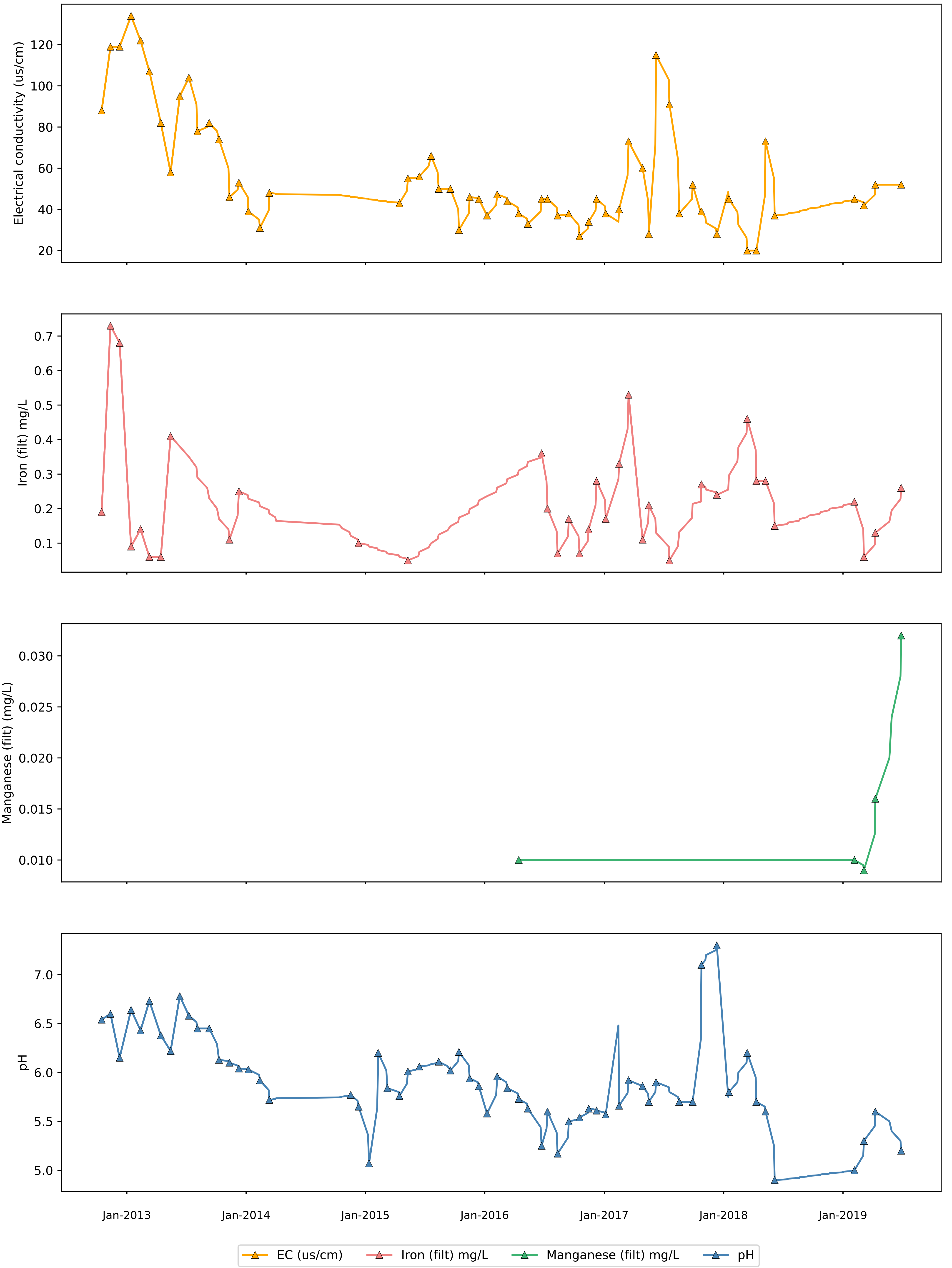

Electrical conductivity (us/cm)
Iron (filt) mg/L
Manganese (filt) (mg/L)
pH
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH

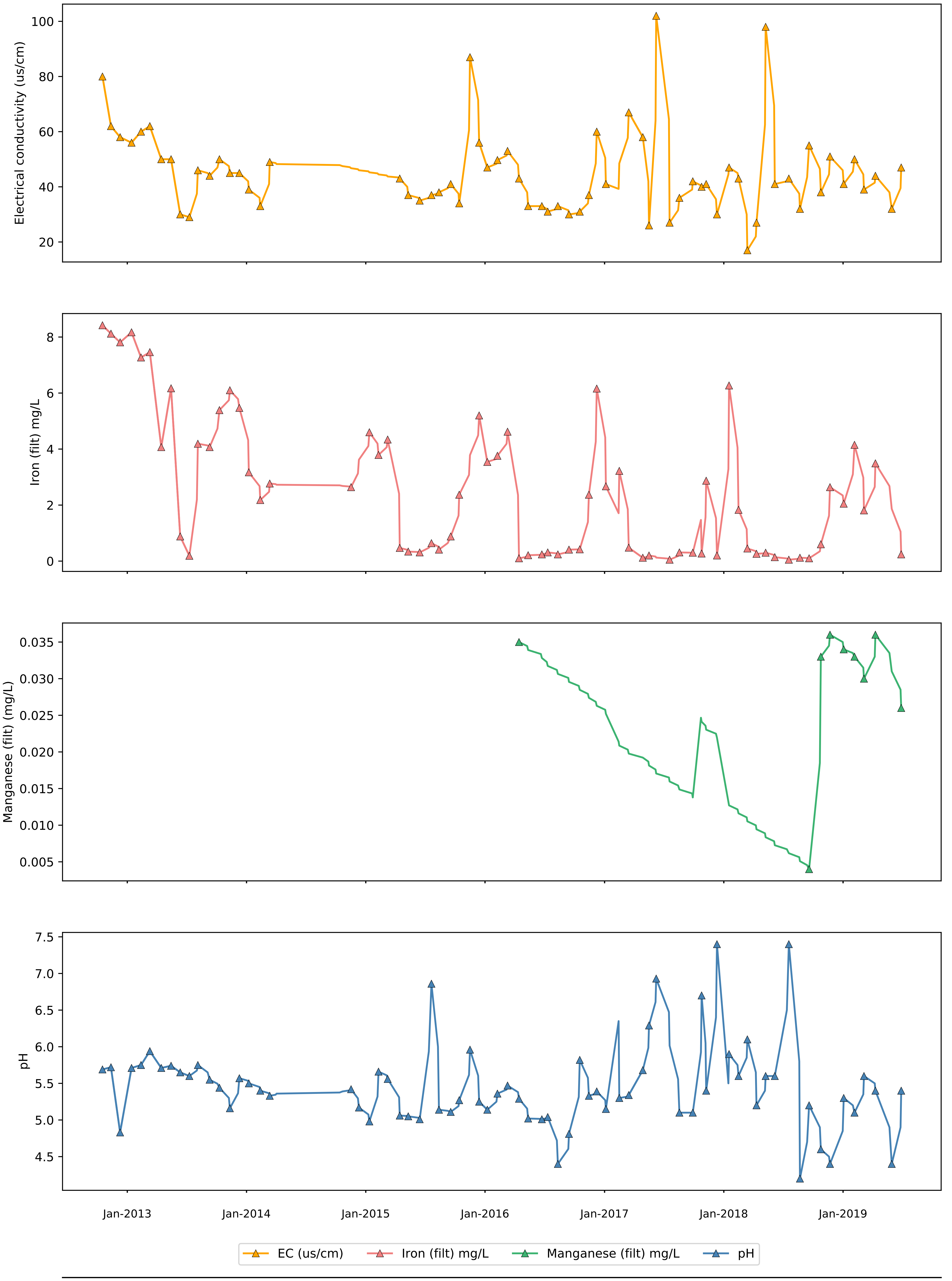

Electrical conductivity (us/cm)
Iron (filt) mg/L
Manganese (filt) (mg/L)
pH
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH



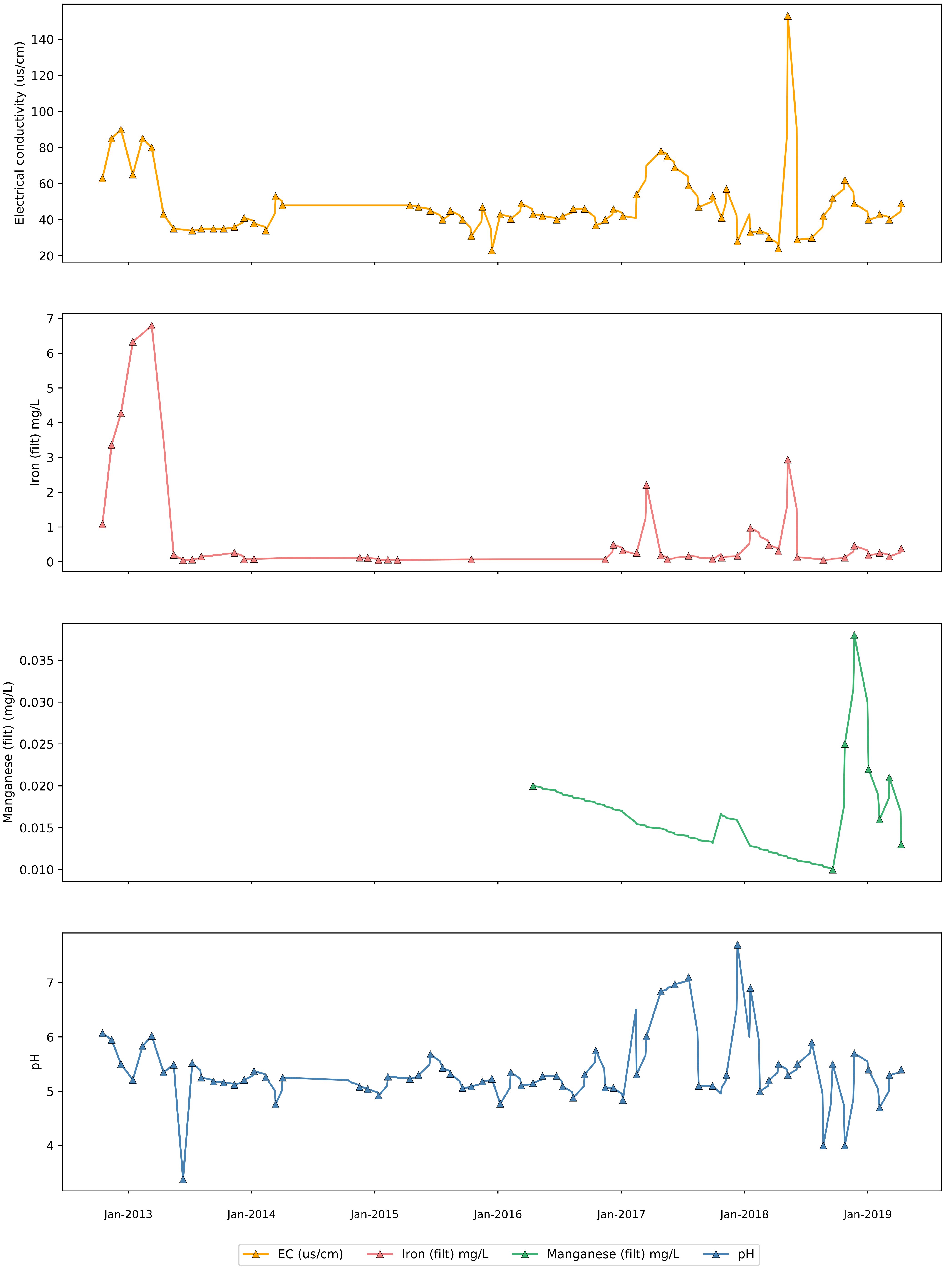
Electrical conductivity (us/cm)
Iron (filt) mg/L
Manganese (filt) (mg/L)
pH
Nov-2018
Nov-2018
Dec-2018
Dec-2018
Dec-2018
Dec-2018
Dec-2018
Jan-2019
Jan-2019
Jan-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH


Electrical conductivity (us/cm)
Iron (filt) mg/L
Manganese (filt) (mg/L)
pH
Jan-2015
Apr-2015
Jul-2015
Oct-2015
Jan-2016
Apr-2016
Jul-2016
Oct-2016
Jan-2017
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH


Electrical conductivity (us/cm)
120
100
80
60
40
20
Iron (filt) mg/L
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Manganese (filt) (mg/L)
0.030
0.025
0.020
0.015
0.010
pH
7.0
6.5
6.0
5.5
5.0
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH



Electrical conductivity (us/cm)
100
80
60
40
20
Iron (filt) mg/L
8
6
4
2
0
Manganese (filt) (mg/L)
0.035
0.030
0.025
0.020
0.015
0.010
0.005
pH
7.5
7.0
6.5
6.0
5.5
5.0
4.5
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
EC (us/cm)
Iron (filt) mg/L
Manganese (filt) mg/L
pH



Appendix F : XS1

JACOBS

location l	Date of Sample	Comments	omments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
BA1	18/03/2018			Cloudy	13.4	5.1	56	0.03	<1	<1	4	8	<1	1	0.016	0.32	0.057	<0.05
BA1	25/02/2019			Cloudy	13.1	5.2	41	0.05	<1	<1	7	8	<1	<1	0.016	0.67	0.057	<0.05
BA1	30/04/2019			Cloudy	12.4	5	40	0.04	<1	<1	4	8	<1	<1	0.013	0.16	0.025	<0.05
BA1	29/05/2019			Clear	11.1	6.1	54	0.06	<1	<1	4	7	<1	4	0.033	0.25	0.018	<0.05
BA2	18/03/2018			Cloudy	14.4	6.1	182	1.2	<1	<1	43	7	<1	<5	0.006	1.07	<0.005	<0.05
BA2	25/02/2019	orTDS, LOR raised due to sample mi		Cloudy	13.9	6.3	178	1.33	<1	<1	37	35	<1	<10	0.006	1.88	<0.005	<0.05
BA2	30/04/2019			Cloudy	12.4	6.4	184	0.47	<1	<1	41	<10	<1	<10	<0.001	1.23	<0.005	<0.05
BA2	29/05/2019			Slightly cloudy	8.3	5.5	48	0.1	<1	<1	6	8	1	<1	0.045	0.15	0.047	<0.05
BA3	18/03/2018			Cloudy	14	5.8	103	0.85	<1	<1	23	4	<1	<1	0.001	0.27	<0.005	<0.05
BA3	25/02/2019	orTDS, LOR raised due to sample mi		Cloudy	13.5	6.2	102	0.95	<1	<1	24	36	<1	<10	0.002	0.3	<0.005	<0.05
BA3	30/04/2019			Cloudy	12.4	6	106	3.94	<1	<1	9	19	<1	<10	0.004	1.22	0.272	0.28
BA3	29/05/2019			Slightly cloudy	9.1	5.1	45	0.12	<1	<1	4	7	<1	<1	0.052	0.25	0.044	<0.05
BE1	18/03/2018			Slightly cloudy	13.8	5.5	46	0.05	<1	<1	5	6	<1	3	0.018	0.21	0.03	<0.05
BE1	25/02/2019			Cloudy	13	5.1	41	0.26	<1	<1	5	7	<1	2	0.019	0.63	0.024	<0.05
BE1	30/04/2019			Cloudy	12.5	4.7	47	0.96	1	<1	5	7	<1	4	0.027	0.24	0.029	<0.05
BE1	29/05/2019			Cloudy	8.5	5.6	51	0.42	2	<1	4	6	<1	<1	0.046	0.23	0.02	<0.05
BE2	18/03/2018			Cloudy	14.4	4.8	42	0.03	<1	<1	4	6	<1	<1	0.02	<0.05	0.022	<0.05
BE2	25/02/2019			Cloudy	13.4	4.7	39	0.58	<1	<1	5	7	<1	2	0.026	0.37	0.008	<0.05
BE2	30/04/2019			Cloudy	12.6	4.7	38	0.32	<1	<1	4	7	<1	<1	0.028	0.2	0.008	<0.05
BE2	29/05/2019			Clear	10.6	5.3	46	0.1	<1	<1	3	7	<1	<1	0.049	0.24	<0.005	<0.05
BS1	16/10/2012		Cloudy, black, 0.76 m		10.8	5.78	39	0.24	<1	<1	4	9	<1			0.38	0.018	
BS1	13/11/2012		Cloudy, 1.16 m		14	5.31	37	0.08	<1	<1	5	9	<1			0.2	0.06	
BS1	11/12/2012		Slightly cloudy, 1.11 m		12.3	5.42	39	0.07	<1	<1	4	9	<1			0.45	0.074	
BS1	15/01/2013		Slightly cloudy, 1.34 m		13.9	5.64	44	0.09	<1	<1	4	8	<1			2.27	0.07	
BS1	14/02/2013		Slightly cloudy, 1.09 m		14.5	5.79	47	0.07	<1	<1	5	8	<1			1.76	0.115	
BS1	12/03/2013		Clear, 1.08 m		14.6	6.04	41	0.08	<1	<1	3	8	<1			0.77	0.071	
BS1	16/04/2013		Cloudy, 1.06		12.6	5.55	32	0.08	<1	<1	4	7	<1			0.14	0.061	
BS1	21/05/2013		Clear, 1.30 m			5.67	31	0.06	<1	<1	4	7	<1			0.23	0.051	
BS1	19/06/2013		Clear, 0.98 m		8	4.39	31	0.05	<1	<1	4	7	<1			0.18	0.045	
BS1	17/07/2013		Slightly cloudy, 1.07 m		9.1	9.02	31	0.08	<1	<1	5	12	<1			0.3	0.129	
BS1	28/08/2013		Clear, 1.09 m		9.5	5.24	35	0.07	<1	<1	4	7	<1			0.2	0.081	
BS1	30/09/2013		Clear, 1.31 m		12.1	5.47	49	0.06	<1	<1	5	10	4			0.21	0.103	
BS1	30/10/2013		Clear, 1.11 m		13.3	5.51	45	0.08	<1	<1	5	8	<1			1.38	0.07	
BS1	27/11/2013		Clear, 1.12 m		16.3	5.73	58	0.05	<1	<1	5	9	<1			2.53	0.06	
BS1	18/12/2013		Clear, 1.14m		17.5	5.87	57	0.1	<1	<1	6	10	<1			2.63	0.114	
BS1	20/01/2014		Clear, 1.14 m, not purged			5.9	54	0.1	<1	<1	5	18	<1			3.9	0.103	
BS1	19/02/2014		Clear, 1.30 m		16.9	6.03	74	0.14	1	1	6	7	<1			8.23	0.072	
BS1	20/03/2014		Clear, 1.10 m		17.2	6.12	65	0.08	<1	<1	5	7	<1			2.07	0.114	
BS1	29/04/2014		Clear, 1.20 m		15.4	5.98	52	0.04	1	<1	6	5	<1			0.23	0.099	
BS1	20/04/2015			Clear	13.1	5.5	29	0.03	1	<1	3	2	<1	<1		0.17	0.059	
BS1	18/05/2015			Clear	11.5	5.46	27	0.02	<1	<1	2	4	<1	<1		0.14	0.034	
BS1	29/06/2015			Clear	8.6	5.51	29	0.02	<1	<1	2	4	<1	<1		0.06	0.036	
BS1	27/07/2015			Clear	7.4	5.66	32	0.02	<1	<1	2	4	<1	<1		<0.05	0.026	
BS1	19/08/2015			Clear	8.1	5.12	31	0.02	<1	<1	2	4	<1	<1		<0.05	0.028	
BS1	27/10/2015			Clear	12.9	5.33	40	0.02	1	<1	3	6	<1	<1		<0.05	0.032	
BS1	23/11/2015			Clear	17.7	5.11	33	0.01	1	<1	4	7	<1	<1		<0.05	0.033	
BS1	30/12/2015			Slightly cloudy	15	5.96	58		<1	<1	5	8	1	<1		2.51	0.028	
BS1	18/02/2016			Clear	17.7	5.06	39	0.02	<1	<1	3	6	<1	<1		0.13	0.03	
BS1	17/03/2016			Clear	17.8	5.87	61	0.02	1	<1	4	6	<1	4		3.48	0.029	
BS1	20/04/2016			Clear	15.1	5.31	40	0.09	1	<1	4	6	<1	<1	0.056	0.25	0.034	<0.05
BS1	26/05/2016			Clear	10.2	5.28	38	0.01	<1	<1	3	5	<1	<1		<0.05	0.018	
BS1	27/06/2016			Clear	7.8	5.47	32	0.01	<1	<1	3	6	<1	4		<0.05	0.015	
BS1	25/07/2016			Clear	9	5.15	32	0.02	<1	<1	3	6	<1	<1		<0.05	0.019	
BS1	17/08/2016			Clear	8.9	4.99	38	0.03	<1	<1	3	6	<1	<1		<0.05	0.022	
BS1	28/09/2016				11.8	5.19	37											
BS1	27/10/2016			Clear	14.3	5.46	35	0.02	<1	<1	4	6	<1	<1		<0.05	0.018	
BS1	23/11/2016			Clear	16.7	5.31	40	0.03	<1	<1	4	6	<1	<1		<0.05	0.024	
BS1	22/12/2016			Clear	16.4	5.1	43	0.03	<1	<1	4	8	<1	<1		<0.05	0.022	
BS1	18/01/2017			Clear	20.3	5.18	45	0.02	<1	<1	4	8	<1	<1		0.3	0.026	
BS1	1/02/2017			Clear	18.3	5.3	56	0.02	1	<1	6	7	<1	<1		2.05	0.044	
BS1	27/02/2017			Slightly Cloudy	17	5.75	61	0.05	1	<1	4	10	<1	<1		4.46	0.03	
BS1	29/03/2017			Cloudy	19.4	5.39	64	0.06	1	<1	3	8	<1	<1		4.65	0.032	
BS1	28/04/2017			Slightly Cloudy	12.9	5.76	106	0.04	1	<1	8	10	1	2		3.82	0.022	
BS1	31/05/2017			Cloudy	8.1	5.82	40	0.07	<1	<1	5	8	<1	2		0.26	0.01	
BS1	19/06/2017			Cloudy	8.6	4.9	94	0.08	2	<1	11	123	114	2		<0.05	0.054	
BS1	31/07/2017			Slightly Cloudy	8.6	5.3	43	0.04	<1	<1	4	7	<1			0.06	0.02	

location I	Date of Sample	Comments	omments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium m	Sodium mg/L	Chloride mg/L	Potassium mg	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
BS1	30/08/2017			Slightly Cloudy	8.5	5.4	30	0.03	<1	<1	4	7	<1	<1		0.06	0.008	
BS1	13/09/2017			Slightly Cloudy	10.8	5.5	37	0.02	<1	<1	4	7	<1	<1		<0.05	0.015	
BS1	30/10/2017			Clear	17.5	5.1	32	0.03	<1	<1	4	9	<1	<1		0.05	0.016	
BS1	22/11/2017			Clear	12.8	5	48	0.14	<1	<1	4	8	<1	<1		1.33	0.02	
BS1	20/12/2017			Clear	14.3	5.4	53	0.18	<1	<1	5	9	<1	2		0.92	0.024	
BS1	31/01/2018			Clear	14.2	5.1	39	0.08	<1	<1	4	8	<1	5		0.38	<0.005	
BS1	28/02/2018			Clear	15.3	5.6	54	0.08	<1	<1	4	8	<1	2		7.45	0.016	
BS1	28/03/2018			Clear	16.7	5.7	67	0.08	1	<1	8	7	<1	<1		4.28	0.031	
BS1	24/04/2018			Clear	13.5	5.3	53	0.02	1	<1	4	6	<1			1.16	0.029	
BS1	23/05/2018			Clear	8.7	6.6	100	0.02	<1	<1	4	19	13	<1		<0.05	0.025	
BS1	20/06/2018			Clear	7.3	4.8	45	0.03	<1	<1	4	6	<1			<0.05	0.018	
BS1	4/07/2018			Clear	6.6	5.4	43	0.14	<1	<1	5	6	<1	<1		0.24	0.029	
BS1	8/08/2018			Slightly Cloudy	8	5.3	49	0.02	<1	<1	4	5	<1	<1		<0.05	0.026	
BS1	13/09/2018			Clear	5.8	6.8	40	0.06	<1	<1	3	8	<1	<1	0.015	0.16	0.006	<0.05
BS1	11/10/2018			Clear	6	5.8	35	0.27	<1	<1	4	8	<1	<1	0.021	0.68	0.007	<0.05
BS1	7/11/2018			Clear	11	4.6	52	0.04	1	<1	4	8	1	1	0.036	0.19	0.048	<0.05
BS1	6/12/2018			Clear	10.8	5.2	45	0.03	<1	<1	4	8	<1	1	0.03	<0.05	0.041	<0.05
BS1	20/12/2018			Slightly cloudy	13.7	5.2	55	0.02	1	<1	4	10	<1	2	0.055	<0.05	0.064	<0.05
BS1	21/01/2019			Clear	14.2	6.8	279	0.21	<1	<1	4	4	<1	2	0.042	0.71	<0.005	<0.05
BS1	28/02/2019			Cloudy	14.9	7.1	801	0.05	1	<1	5	10	1	2	0.082	1.04	0.046	<0.05
BS1	27/03/2019			Clear	11.9	6.1	70	0.08	<1	<1	5	10	<1	1	0.061	0.3	0.071	<0.05
BS1	4/04/2019			Clear	14.8	5.5	44	0.04	<1	<1	6	10	<1	3	0.029	0.06	0.081	<0.05
BS1	1/05/2019	nsufficent sample		Clear	13.8	5.6	54	0.03	2	<1	8	9	1	<1	0.032	<0.05	0.072	<0.05
BS2	15/10/2012		Cloudy brown, 0.40 m		11	5.52	54	0.46	4	2	4	9	<1			0.26	0.017	
BS2	13/11/2012		Cloudy, brown, 0.37 m		14.5	6.12	70	0.32	2	<1	10	8	<1			0.42	0.019	
BS2	11/12/2012		Cloudy, brown, 0.35 m		13.2	5.5	65	0.13	2	<1	5	7	<1			1.72	0.064	
BS2	15/01/2013		Brown, cloudy, 0.33 m		14.4	6.14	71	0.13	3	<1	9	7	<1			3.8	0.051	
BS2	14/02/2013		Brown, cloudy, 0.36 m		15	5.91	64	0.06	2	<1	6	7	<1			2.39	0.062	
BS2	12/03/2013		Slightly cloudy, 0.32 m		14.8	5.23	56	0.07	<1	<1	4	7	<1			1.36	0.055	
BS2	16/04/2013		Slightly Cloudy, 0.32		12.8	5.94	40	0.26	1	<1	5	6	1			0.7	0.044	
BS2	21/05/2013		Clear, 0.30 m			6.15	33	0.08	<1	<1	4	6	<1			0.14	0.028	
BS2	19/06/2013		Slightly cloudy, 0.38 m		8.5	5.21	31	<0.01	<1	<1	5	6	<1			<0.05	0.007	
BS2	17/07/2013		Clear, 0.36 m		9.6	7.82	32	0.04	<1	<1	5	7	<1			0.05	0.074	
BS2	28/08/2013		Slightly cloudy, 0.31 m		9.1	5.55	36	0.04	<1	<1	5	7	<1			0.06	0.08	
BS2	30/09/2013		Slightly cloudy, 0.36 m		12.1	5.68	47	0.04	<1	<1	6	9	2			0.47	0.088	
BS2	30/10/2013		Clear, 0.33 m		14	5.69	44	0.05	<1	<1	5	8	<1			0.31	0.043	
BS2	27/11/2013		Clear, 0.34 m		14.1	5.74	43	0.08	<1	<1	5	7	<1			1.23	0.06	
BS2	18/12/2013		Slightly cloudy, 0.33m		16	5.74	45	0.06	<1	<1	5	7	<1			0.47	0.065	
BS2	20/01/2014		Clear, 1.34 m, not purged			6	46	0.07	1	<1	5	14	<1			3.4	0.058	
BS2	19/02/2014		Clear, 0.33 m		16.6	5.65	38	0.07	<1	<1	5	7	<1			0.73	0.046	
BS2	20/03/2014		Clear, 0.30 m		16.1	6.12	54	0.05	<1	<1	5	6	<1			1.22	0.08	
BS2	29/04/2014		Clear, 0.30 m		14.4	5.76	49	0.04	1	<1	6	6	<1			0.14	0.105	
BS2	20/04/2015			Clear	11.8	5.38	41	0.04	1	<1	4	7	<1	<1		0.13	0.039	
BS2	18/05/2015			Clear	12	5.45	37	0.03	<1	<1	4	6	<1	<1		0.11	0.022	
BS2	29/06/2015			Clear	9.7	5.51	35	0.02	<1	<1	4	6	<1	<1		0.07	0.022	
BS2	27/07/2015			Clear	8.5	5.59	37	0.03	<1	<1	3	6	<1	<1		0.08	0.016	
BS2	19/08/2015			Clear	8.8	5.27	38	0.03	<1	<1	4	5	<1	<1		0.07	0.018	
BS2	27/10/2015			Clear	11.8	5.41	38	0.02	<1	<1	4	7	<1	<1		0.32	0.025	
BS2	23/11/2015			Clear	15.7	5.52	31	0.02	<1	<1	4	6	<1	<1		0.62	0.015	
BS2	28/12/2015			Clear	16.6	5.7	49		1	<1	4	8	2	<1		1.09	0.027	
BS2	18/02/2016			Clear	15.8	5.2	45	0.03	<1	<1	4	6	<1	<1		1.65	0.019	
BS2	17/03/2016			Clear	16.9	5.48	48	0.03	<1	<1	5	6	<1	3		1.46	0.017	
BS2	20/04/2016			Clear	14.7	5.33	86	0.15	1	<1	4	6	<1	<1	0.056	0.97	0.03	<0.05
BS2	26/05/2016			Clear	10.6	5.16	38	0.02	<1	<1	3	5	<1	<1		<0.05	0.008	
BS2	27/06/2016			Clear	9.2	5.39	33	0.02	<1	<1	3	7	<1	<1		<0.05	0.008	
BS2	25/07/2016			Clear	9.9	5.12	33	0.04	<1	<1	3	6	<1	<1		<0.05	0.006	
BS2	17/08/2016			Clear	10.2	4.69	38	0.03	<1	<1	4	6	<1	<1		0.06	0.011	
BS2	27/10/2016			Clear	15	5.67	37	0.04	<1	<1	4	6	<1	<1		0.09	0.012	
BS2	23/11/2016			Clear	15.5	5.91	75	0.03	<1	<1	6	6	<1	<1		0.27	0.027	
BS2	22/12/2016			Clear	15.8	5.22	36	0.02	<1	<1	5	6	<1	<1		0.62	0.022	
BS2	18/01/2017			Clear	18.3	5.48	45	0.03	<1	<1	4	8	<1	<1		2.22	0.018	
BS2	1/02/2017			Clear	16.7	5.68	59	0.09	<1	<1	5	5	<1	<1		4.93	0.034	
BS2	27/02/2017			Clear	16.3	5.96	53	0.1	<1	<1	4	6	<1	<1		4.64	0.017	
BS2	29/03/2017			Cloudy	19	5.42	70	0.06	1	<1	3	8	<1	<1		4.67	0.034	
BS2	28/04/2017			Clear	13.4	5.22	33	0.05	<1	2	7	5	<1	<1		0.07	0.016	
BS2	31/05/2017			Cloudy	7.8	6.21	38	0.08	<1	<1	5	7	<1	<1		0.29	0.008	

location I	Date of Sample	Comments	Comments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
BS2	19/06/2017			Cloudy	9	5.11	107	0.13	2	<1	10	71	88	5		0.06	0.048	
BS2	31/07/2017			Slightly Cloudy	9.2	5.3	34	0.04	<1	<1	3	6	<1			<0.05	0.008	
BS2	30/08/2017			Slightly Cloudy	7.9	5.6	33	0.03	<1	<1	4	7	<1	1		0.06	0.01	
BS2	13/09/2017			Clear	10.5	5.5	35	0.04	<1	<1	4	7	<1	<1		<0.05	0.013	
BS2	30/10/2017			Clear	16.8	5.6	35	0.04	<1	<1	4	8	<1	<1		2.34	0.012	
BS2	22/11/2017			Clear	12.6	5	36	0.21	<1	<1	4	6	<1	<1		1.68	0.013	
BS2	20/12/2017			Clear	13.9	5.3	43	0.02	1	<1	5	6	<1	<1		0.58	0.025	
BS2	31/01/2018			Clear	13.8	5.3	47	0.08	<1	<1	5	8	<1	7		0.32	<0.005	
BS2	28/02/2018			Clear	14.3	5.7	46	0.08	<1	<1	4	8	<1	<1		4.88	0.008	
BS2	28/03/2018			Clear	13.8	5.8	78	0.09	1	1	12	8	<1	1		3.11	0.019	
BS2	24/04/2018			Clear	12.5	5.4	53	0.03	<1	<1	5	8	<1			1.53	0.025	
BS2	23/05/2018			Clear	9.3	5.8	61	0.03	<1	<1	5	19	13	<1		0.06	0.054	
BS2	20/06/2018			Clear	6.9	4.8	48	0.06	<1	<1	4	8	<1			<0.05	0.011	
BS2	4/07/2018			Cloudy	7	5	49	0.1	<1	<1	7	9	<1	<1		<0.05	0.023	
BS2	8/08/2018			Clear	7.9	4.6	67	0.06	<1	<1	6	9	<1	3		0.08	0.016	
BS2	13/09/2018			Clear	6.5	7	32	0.07	<1	<1	4	7	<1	<1	0.019	0.18	0.008	<0.05
BS2	11/10/2018			Clear	6.9	5.7	37	0.14	<1	<1	4	8	<1	<1	0.021	0.56	0.007	<0.05
BS2	7/11/2018			Clear	11.2	4.6	48	0.04	<1	<1	6	10	<1	<1	0.042	1.17	0.05	<0.05
BS2	6/12/2018			Clear	10.7	5.1	47	0.04	<1	<1	5	7	<1	<1	0.033	0.12	0.046	<0.05
BS2	20/12/2018			Cloudy	13.1	5.4	66	0.18	3	<1	4	7	1	2	0.045	0.25	0.027	<0.05
BS2	21/01/2019			Clear	20.1	5.2	224	0.1	<1	<1	4	4	1	<1	0.093	0.29	0.028	<0.05
BS2	28/02/2019			Slightly cloudy	17.2	6.9	78	0.06	<1	<1	5	8	<1	<1	0.081	0.79	0.039	<0.05
BS2	27/03/2019			Clear	12.4	5.8	49	0.08	<1	<1	4	8	<1	<1	0.055	0.25	0.057	<0.05
BS2	4/04/2019			Clear	14.3	6.1	66	0.05	1	1	8	7	1	4	0.065	0.58	0.076	<0.05
BS3	15/10/2012		Cloudy brown, 0.75 m		10.4	5.76	69	0.53	2	<1	10	8	<1			0.32	0.031	
BS3	11/12/2012		Cloudy brown, 0.53 m		11.6	5.44	87	0.08	5	2	4	9	<1			1.65	0.053	
BS3	15/01/2013		Brown, cloudy, 0.63 m		13.5	5.8	81	0.12	4	1	4	8	<1			4.39	0.074	
BS3	14/02/2013		Brown, cloudy, 0.65 m		13.7	5.58	67	0.09	2	1	5	8	<1			4.27	0.053	
BS3	12/03/2013		Cloudy, 0.67 m		13.9	5.55	70	0.1	2	<1	4	8	<1			3.01	0.092	
BS3	16/04/2013		Cloudy, 0.60		11.9	5.92	57	0.1	3	1	4	7	<1			0.82	0.024	
BS3	21/05/2013		Brown, cloudy, 0.70			5.86	44	0.07	2	<1	4	9	<1			0.05	0.028	
BS3	19/06/2013		Brown, cloudy, 0.69 m		8.1	4.32	40	0.04	2	<1	4	8	<1			<0.05	0.043	
BS3	17/07/2013		Cloudy, 0.71 m		9.1	8.51	40	0.08	2	<1	5	8	<1			0.06	0.056	
BS3	28/08/2013		Slightly cloudy, 0.67 m		9.5	5.43	48	0.05	2	<1	4	8	<1			0.07	0.051	
BS3	30/09/2013		Slightly cloudy, 0.68 m		11.5	5.26	65	0.08	2	<1	5	12	5			0.19	0.124	
BS3	30/10/2013		Cloudy, 72 m		12.5	5.55	52	0.06	2	<1	4	8	<1			0.52	0.056	
BS3	27/11/2013		Brown,cloudy, 0.67 m		13.5	5.3	49	0.08	2	<1	4	9	<1			0.11	0.111	
BS3	18/12/2013		Cloudy, 0.65m		16	5.44	51	0.07	1	<1	5	10	<1			0.18	0.096	
BS3	20/01/2014		Clear, 0.66 m, not purged			5.49	50	0.05	1	<1	5	16	<1			2.88	0.204	
BS3	19/02/2014		Clear, 0.68 m		15.6	5.17	58	0.09	2	<1	5	8	<1			0.52	0.13	
BS3	20/03/2014		Cloudy, 0.62 m		15.6	5.5	66	0.09	1	<1	5	9	<1			2.96	0.092	
BS3	29/04/2014		Slightly cloudy, 0.70 m		14.1	5.26	56	0.08	2	<1	6	7	<1			<0.05	0.149	
BS3	20/04/2015			Clear	13.3	4.88	59	0.29	1	<1	4	7	<1	6		1.68	0.061	
BS3	18/05/2015			Clear	11.6	4.52	54	0.27	<1	<1	3	7	<1	4		0.12	0.045	
BS3	29/06/2015			Slightly Cloudy	9	4.62	57	0.24	1	<1	3	8	<1	5		0.08	0.046	
BS3	27/07/2015			Slightly Cloudy	7.5	4.88	55	0.27	<1	<1	3	6	<1	4		0.12	0.03	
BS3	19/08/2015			Slightly Cloudy	7.8	4.67	54	0.25	1	<1	4	6	<1	5		0.13	0.024	
BS3	27/10/2015			Clear	12.1	4.84	57	0.23	1	<1	4	8	<1	4		0.55	0.029	
BS3	23/11/2015			Clear	17.1	4.76	47	0.16	1	<1	6	10	2	5		0.73	0.027	
BS3	29/12/2015			Slightly cloudy	18.2	5.06	60		1	<1	5	9	<1	5		1.21	0.031	
BS3	18/02/2016			Slightly Cloudy	15.8	5.17	69	0.07	<1	<1	4	7	<1	6		5.23	0.044	
BS3	17/03/2016			Slightly Cloudy	16.3	4.8	58	0.17	1	<1	4	7	<1	8		0.8	0.022	
BS3	20/04/2016			Slightly Cloudy	14.3	4.9	110	0.29	2	<1	4	7	<1	5	0.066	0.14	0.047	<0.05
BS3	26/05/2016			Slightly Cloudy	10.2	4.81	50	0.17	1	<1	3	6	<1	12		0.06	0.017	
BS3	27/06/2016			Cloudy	8.4	5.01	49	0.17	1	<1	4	8	<1	4		0.07	0.024	
BS3	25/07/2016			Slightly Cloudy	9.3	4.72	44	0.21	1	<1	3	6	<1	4		0.08	0.011	
BS3	17/08/2016			Clear	9.2	4.63	52	0.23	1	<1	3	6	<1	5		0.1	0.013	
BS3	28/09/2016				10.7	4.73	46											
BS3	27/10/2016			Slightly Cloudy	13.9	5.15	45	0.18	<1	<1	4	6	<1	3		1.29	0.02	
BS3	23/11/2016			Slightly Cloudy	15.1	4.77	51	0.19	1	<1	4	6	<1	4		0.31	0.022	
BS3	22/12/2016			Slightly Cloudy	14.9	4.89	54	0.14	1	<1	4	8	<1	5		1.96	0.023	
BS3	18/01/2017			Cloudy	18.1	5.19	56	0.11	1	<1	4	7	<1	3		3.09	0.018	
BS3	1/02/2017			Cloudy	16.4	4.88	66	0.1	1	<1	5	6	<1	7		2.39	0.065	
BS3	27/02/2017			Cloudy	16	5.3	60	0.12	<1	<1	3	7	<1	3		5.38	0.019	
BS3	29/03/2017			Cloudy	17.4	5.33	51	0.13	1	<1	2	6	<1	2		4.16	0.019	
BS3	28/04/2017			Cloudy	13	5.13	45	0.17	1	<1	3	5	<1	11		0.18	0.027	

location	Date of Sample	Comments	Comments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium m	Sodium mg/L	Chloride mg/L	Potassium mg	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
BS3	31/05/2017			Cloudy	7.5	5.91	45	0.08	<1	<1	5	8	<1	2		0.28	0.008	
BS3	19/06/2017			Cloudy	8.9	5.01	99	0.08	2	<1	11	159	149	2		<0.05	0.057	
BS3	31/07/2017			Slightly Cloudy	8.1	5	42	0.19	<1	<1	3	6	<1			0.1	0.017	
BS3	30/08/2017			Cloudy	7.1	5.2	32	0.17	1	<1	3	7	<1	2		0.12	0.009	
BS3	13/09/2017			Slightly Cloudy	9.7	4.8	44	0.26	<1	<1	3	7	<1	2		0.27	0.018	
BS3	30/10/2017			Clear	16.2	5	47	0.1	<1	<1	4	9	<1	3		5.18	0.014	
BS3	22/11/2017			Clear	11.1	4.6	48	0.62	1	<1	4	8	<1	1		1.96	0.021	
BS3	20/12/2017			Clear	13.4	4.9	55	0.03	<1	<1	5	7	<1	<1		0.89	0.013	
BS3	31/01/2018			Clear	14.6	4.9	58	0.06	<1	<1	4	7	<1	8		0.22	<0.005	
BS3	28/02/2018			Clear	14	5.2	47	0.13	<1	<1	3	8	<1	2		5.31	0.012	
BS3	28/03/2018			Clear	13.7	5.4	62	0.12	<1	<1	8	6	<1	2		3.01	0.02	
BS3	24/04/2018			Clear	11.5	4.9	44	0.16	<1	<1	4	6	<1			0.14	0.024	
BS3	23/05/2018			Clear	8	6.5	109	0.11	<1	<1	4	26	21	2		0.11	0.02	
BS3	20/06/2018			Clear	6.4	4.4	45	0.16	<1	<1	3	6	<1			0.06	0.017	
BS3	4/07/2018			Slightly Cloudy	7.6	5.2	44	0.2	<1	<1	5	6	<1	<1		0.12	0.028	
BS3	8/08/2018			Cloudy	6.5	5	54	0.15	<1	<1	4	7	<1	2		0.25	0.026	
BS3	13/09/2018			Slightly cloudy	7.4	6.7	41	0.15	<1	<1	3	8	<1	2	0.033	0.17	0.042	<0.05
BS3	11/10/2018			Slightly Cloudy	6.8	5	41	0.14	<1	<1	4	8	<1	<1	0.027	1.42	0.018	<0.05
BS3	7/11/2018			Clear	10.4	4.5	55	0.14	<1	<1	4	10	<1	2	0.034	2.95	0.061	<0.05
BS3	6/12/2018			Clear	9.6	4.8	52	0.17	1	<1	4	8	<1	1	0.05	0.24	0.048	<0.05
BS3	20/12/2018			Slightly cloudy	13.4	5.1	57	0.04	1	<1	4	9	<1	2	0.058	<0.05	0.075	<0.05
BS3	21/01/2019			Cloudy	15.6	7.4	250	0.11	1	<1	7	22	14	2	0.068	1.72	0.049	<0.05
BS3	28/02/2019			Cloudy	14.8	6	808	0.1	2	<1	5	10	<1	6	0.05	0.83	0.075	<0.05
BS3	27/03/2019			Slightly cloudy	12.8	5.3	49	0.11	<1	<1	4	7	<1	3	0.049	0.28	0.025	<0.05
BS3	4/04/2019			Clear	13.5	5.8	45	0.16	<1	<1	5	8	<1	4	0.041	0.34	0.078	<0.05
BS3	1/05/2019			Clear	12.4	5.3	43	0.07	1	1	6	6	<1	2	0.061	<0.05	0.04	<0.05
CC1	12/06/2012		Brown, cloudy		8.6	6.14	90	0.09	9	2	6	4	<1	<1		0.27	0.056	
CC1	12/07/2012		Clear-43cm			6.36	69	0.03	6	2	5	4	<1			0.47	0.034	
CC1	21/08/2012		Slighlty cloudy 55cm			6.48	66	0.03	7		4	4	<1			0.33	0.058	
CC1	17/09/2012		Cloudy, 59cm		12.2	6.26	78	0.04	7	2	4	5	<1			0.54	0.034	
CC1	17/10/2012		Slightly cloudy, 0.56 m		12.1	6.51	77	0.03	6	2	4	6	<1			0.22	0.031	
CC1	13/11/2012		Slightly cloudy, 0.62 m		15.5	6.53	121	0.04	10	2	4	5	<1			5.77	0.045	
CC1	11/12/2012		Cloudy, 0.40 m		12.7	6.48	145	0.09	9	2	4	6	<1			9.51	0.057	
CC1	15/01/2013		Light brown, cloudy, 0.68 m		14.5	6.58	166	0.04	12	3	4	5	<1			11.3	0.037	
CC1	14/02/2013		Slightly cloudy, 0.58 m		15.1	6.54	167	0.03	12	3	6	6	<1			13.2	0.038	
CC1	12/03/2013		Slightly cloudy, 0.55 m		15.2	5.42	170	0.02	10	2	4	5	<1			4.03	0.032	
CC1	16/04/2013		Cloudy Orange, 0.57		13.1	6.47	108	<0.01	13	3	4	4	<1			0.47	0.031	
CC1	21/05/2013		Slightly cloudy, 0.59 m			6.67	140	0.03	15	3	3	4	<1			3.73	0.034	
CC1	19/06/2013		Slightly cloudy, 0.55 m		8.1	5.97	99	0.02	12	3	4	4	<1			0.55	0.013	
CC1	17/07/2013		Clear, 0.63 m		8.9	7.41	97	0.03	10	3	4	4	<1			0.75	0.063	
CC1	28/08/2013		Clear, 0.57 m		9.5	6.35	143	0.05	12	3	3	4	<1			7.94	0.089	
CC1	30/09/2013		Slightly cloudy, 0.58 m		14.7	6.47	147	0.03	12	2	3	9	8			4.69	0.081	
CC1	30/10/2013		Clear, 0.61 m		13.6	6.38	126	0.02	9	2	3	5	<1			1.07	0.009	
CC1	27/11/2013		Clear, 0.59 m		14.6	6.34	131	0.02	11	2	3	5	<1			7.83	0.044	
CC1	18/12/2013		Clear, 0.68m		15.7	6.37	104	0.02	6	2	3	5	<1			3.79	0.063	
CC1	20/01/2014		Clear, 0.79 m, not purged			6.4	127	0.02	10	2	3	11	<1			15	0.07	
CC1	19/02/2014		Clear, 0.68 m		16.1	6.35	92	0.04	7	2	3	4	<1			5.19	0.062	
CC1	20/03/2014		Slightly cloudy, 0.60 m		15.9	6.6	108	0.04	8	2	4	4	<1			1.4	0.073	
CC1	29/04/2014		Slightly cloudy, 0.63 m		14.7	6.61	137	0.13	11	2	4	4	<1			9.48	0.132	
CC1	30/10/2014			Clear	14	6.15	105	0.05	6	1	4	5	1	<10		4.8	0.089	
CC1	20/04/2015			Clear	12.4	6.37	156	0.11	11	2	3	5	<1	<1		9.86	0.046	
CC1	18/05/2015			Clear	11.2	6.31	143	0.02	12	2	3	4	<1	<1		8.12	0.064	
CC1	29/06/2015			Slightly Cloudy	9.3	6.2	134	0.02	11	3	6	4	<1	1		7.47	0.03	
CC1	27/07/2015			Slightly Cloudy	8.1	6.46	122	0.03	10	2	3	4	<1	<1		5.59	0.025	
CC1	19/08/2015			Slightly Cloudy	9	6.12	144	0.04	10	2	3	4	<1	2		10.2	0.023	
CC1	28/09/2015			Clear	11.5	6.24	130	0.02	8	2	3	4	<1	<1		8.19	0.009	
CC1	27/10/2015			Clear	12.9	6.43	142	0.03	9	2	3	5	<1	<1		11.5	0.024	
CC1	23/11/2015			Clear	18.4	5.9	107	0.03	9	2	4	6	2	<1		7.76	0.025	
CC1	26/12/2015			Clear	18	6.34	100		5	1	4	6	<1	<1		5.35	0.023	
CC1	18/01/2016			Clear	16.1	6.34	144	0.03	10	2	4	5	<1	<1		10.9	0.015	
CC1	18/02/2016			Clear	18.6	5.92	133	0.03	8	2	7	5	<1	<1		9.73	0.016	
CC1	17/03/2016			Clear	16.9	6.01	102	0.03	5	<1	5	5	<1	2		6.85	0.012	
CC1	20/04/2016			Clear	14.6	6.01	74	0.16	4	<1	3	4	<1	<1	0.083	4.68	0.034	<0.05
CC1	26/05/2016			Slightly Cloudy	10.8	5.6	34	0.02	2	<1	2	4	<1	<1		0.08	0.025	
CC1	27/06/2016			Clear	7.6	6.16	59	<0.01	4	<1	3	4	<1	<1		0.06	0.015	
CC1	25/07/2016			Clear	9.4	5.89	54	0.01	5	<1	2	4	<1	<1		0.12	0.01	

location I	Date of Sample	Comments	Comments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium m	Sodium mg/L	Chloride mg/L	Potassium mg	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
CC1	17/08/2016			Clear	9.2	5.47	58	0.02	5	<1	2	4	<1	<1		0.16	0.011	
CC1	28/09/2016				11.8	5.88	75											
CC1	27/10/2016			Slightly Cloudy	18	6.58	48	0.04	6	<1	3	4	<1	<1		7.57	0.017	
CC1	23/11/2016			Slightly Cloudy	17.8	6.29	105	0.03	6	1	4	4	1	<1		10.9	0.04	
CC1	22/12/2016			Clear	15.1	5.95	121	0.03	7	1	4	4	<1	<1		16	0.015	
CC1	18/01/2017			Slightly Cloudy	21	6.53	156	0.02	6	1	4	5	<1	<1		29.8	0.023	
CC1	1/02/2017			Clear	16.6	6.35	160	0.05	6	1	5	4	<1	<1		29.6	0.052	
CC1	27/02/2017			Clear	17.7	5.97	102	0.03	4	<1	3	3	<1	2		21.1	0.018	
CC1	29/03/2017			Clear	16.1	6.33	173	0.03	5	1	3	4	<1	<1		31.5	0.02	
CC1	28/04/2017			Clear	14.6	5.34	39	0.1	<1	<1	4	4	<1	8		0.14	0.05	
CC1	31/05/2017			Cloudy	10.2	6.18	71	0.03	4	1	3	4	<1	<1		4.44	0.026	
CC1	19/06/2017			Cloudy	9.2	6.11	42	0.02	1	<1	4	6	<1	1		<0.05	0.029	
CC1	31/07/2017			Slightly Cloudy	9.2	6	50	<0.01	3	<1	3	4	<1			0.23	0.018	
CC1	30/08/2017			Cloudy	8.4	5.4	55	<0.01	3	<1	3	5	<1	<1		2.51	0.023	
CC1	13/09/2017			Cloudy	12.8	6	56	<0.01	3	<1	3	5	<1	<1		3.76	0.012	
CC1	30/10/2017			Clear	17.3	6.1	98	0.03	3	<1	4	6	<1	<1		20.1	0.021	
CC1	22/11/2017			Clear	11.4	6.1	105	0.45	4	<1	4	4	<1	<1		23.4	0.036	
CC1	20/12/2017	nount available to complete all anal		Clear	15.9	6.3	8.3											
CC1	31/01/2018			Clear	14.2	5.9	59	0.07	<1	<1	7	8	<1	6		0.28	<0.005	
CC1	13/09/2018	y - Insufficient sample for lab analys		Slightly Cloudy	7	6.5	46											
CC1	11/10/2018	y - Insufficient sample for lab analys		Clear	7	5.3	39											
CC1	4/04/2019	icient water all anaylsis		Clear	14.6	6.5	72											
CW1	22/02/2011		Cloudy		17.2	5.06	19	0.48	<1	<1	3	5	<1	<1		0.23	0.064	
CW1	23/03/2011		Cloudy		18.4	4.7	21	0.24	<1	<1	3	6	<1	<1		0.56	0.129	
CW1	23/03/2011		Cloudy		18.4	4.7	21	0.24	<1	<1	3	6	<1	<1		0.56	0.129	
CW1	20/04/2011		Cloudy, brown		13	5.25	21	0.23	<1	<1	3	6	<1	<1		0.25	0.052	
CW1	20/04/2011		Cloudy, brown		13	5.25	21	0.23	<1	<1	3	6	<1	<1		0.25	0.052	
CW1	18/05/2011		Cloudy		12.1	5.09	20	0.06	<1	<1	3	6	<1	<1		0.32	0.126	
CW1	18/05/2011		Cloudy		12.1	5.09	20	0.06	<1	<1	3	6	<1	<1		0.32	0.126	
CW1	16/06/2011		Cloudy		10.7	5.21	22	1.27	<1	<1	2	5	<1	<1		0.37	0.201	
CW1	16/06/2011		Cloudy		10.7	5.21	22	1.27	<1	<1	2	5	<1	<1		0.37	0.201	
CW1	13/07/2011		Cloudy		9.1	5.1	15	0.13	<1	<1	2	5	<1	<1		0.16	0.151	
CW1	13/07/2011		Cloudy		9.1	5.1	15	0.13	<1	<1	2	5	<1	<1		0.16	0.151	
CW1	24/08/2011		Cloudy		11.7	5.05	23	0.36	<1	<1	3	5	<1	<1		0.12	0.084	
CW1	24/08/2011		Cloudy		11.7	5.05	23	0.36	<1	<1	3	5	<1	<1		0.12	0.084	
CW1	29/09/2011		Brown, cloudy		12	4.81	26	0.08	<1	<1	3	5	1	<1		<0.05	0.068	
CW1	29/09/2011		Brown, cloudy		12	4.81	26	0.08	<1	<1	3	5	1	<1		<0.05	0.068	
CW1	17/10/2011		Cloudy		11.5	4.85	30	0.17	<1	<1	3	6	<1	<1		0.06	0.18	
CW1	17/10/2011		Cloudy		11.5	4.85	30	0.17	<1	<1	3	6	<1	<1		0.06	0.18	
CW1	21/11/2011		Cloudy		14.4	5.17	18	0.19	<1	<1	3	5	<1	<1		0.32	0.198	
CW1	21/11/2011		Cloudy		14.4	5.17	18	0.19	<1	<1	3	5	<1	<1		0.32	0.198	
CW1	14/12/2011		Cloudy		14.1	5.3	19	0.09	<1	<1	2	6	<1	1		0.1	0.13	
CW1	14/12/2011		Cloudy		14.1	5.3	19	0.09	<1	<1	2	6	<1	1		0.1	0.13	
CW1	17/01/2012		Cloudy		13.5	3.95	19	0.32	<1	<1	3	6	<1	1		0.15	0.103	
CW1	28/02/2012		Cloudy		16.2	4.56	18	0.11	<1	<1	3	5	<1	<1		0.24	0.069	
CW1	6/03/2012		Brown, cloudy		14.4	4.73	17	0.1	<1	<1	2	4	<1	<1		0.19	0.084	
CW1	17/04/2012		Brown, cloudy		12.7	4.76	18	0.14	<1	<1	3	4	<1	<1		0.22	0.074	
CW1	15/05/2012		Brown, cloudy		10.7	4.9	16	0.45	<1	<1	2	4	<1	<1		0.2	0.068	
CW1	12/06/2012		Dark brown, cloudy		9.5	4.84	23	0.07	<1	<1	2	5	<1	<1		<0.05	0.065	
CW1	12/07/2012		Cloudy - 93cm			5.08	16	0.18	<1	<1	2	5	<1			<0.05	0.038	
CW1	21/08/2012		Cloudy brown 89cm			4.44	18	0.08	<1		2	5	<1			<0.05	0.107	
CW1	17/09/2012		Cloudy, 90cm		11.7	4.81	24	0.04	<1	<1	2	5	<1			0.06	0.067	
CW1	17/10/2012		Slightly cloudy, 0.86 m		11.8	5.17	26	0.04	<1	<1	2	6	<1			0.3	0.058	
CW1	13/11/2012		Slightly cloudy, 0.88 m		14.9	4.92	25	0.04	<1	<1	4	5	<1			0.05	0.053	
CW1	11/12/2012				12.7	5.01	24	0.06	<1	<1	2	5	<1			<0.05	0.048	
CW1	15/01/2013		Slightly cloudy, 0.96 m		14.9	5.14	22	0.02	<1	<1	2	4	<1			0.06	0.063	
CW1	14/02/2013		Slightly cloudy, 0.95 m		15.4	5	23	0.02	<1	<1	4	4	<1			0.06	0.071	
CW1	12/03/2013		Brown, cloudy, 0.94 m		15.1	6.87	25	0.02	<1	<1	2	5	<1			0.06	0.051	
CW1	16/04/2013		Cloudy Brown, 0.89		12.7	5.06	22	0.03	<1	<1	3	4	<1			<0.05	0.107	
CW1	21/05/2013		Sligthly cloudy, 0.92 m			5.35	21	0.14	<1	<1	2	4	<1			0.18	0.062	
CW1	19/06/2013		Slightly cloudy, 0.92 m		9.2	5.13	22	0.07	<1	<1	3	4	<1			0.06	0.08	
CW1	17/07/2013		Slightly cloudy, 1.02 m		10.1	8.77	20	0.03	<1	<1	3	5	<1			<0.05	0.1	
CW1	28/08/2013		Cloudy, 0.94 m		10.3	5.11	22	0.03	<1	<1	4	4	<1			0.09	0.062	
CW1	30/09/2013		Slightly cloudy, 0.98 m		12.5	5.16	82	0.02	<1	<1	4	20	18			<0.05	0.111	
CW1	30/10/2013		Slightly cloudy, 0.97 cm		11.9	5.29	23	0.04	<1	<1	2	5	<1			<0.05	0.102	
CW1	27/11/2013		Clear, 0.97 m		12.5	5.15	23	0.02	<1	<1	2	4	<1			<0.05	0.054	

location	Date of Sample	Comments	omments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
CW1	18/12/2013		Clear, 0.98m		14.6	5.47	25	0.05	<1	<1	3	5	<1			<0.05	0.14	
CW1	20/01/2014		Clear, 1.10 m, not purged			5.18	20	0.01	<1	<1	3	12	<1			<0.05	0.091	
CW1	19/02/2014		Slightly cloudy, 1.21 m		14.8	5.1	23	0.02	<1	<1	3	5	<1			<0.05	0.113	
CW1	20/03/2014		Slightly cloudy, 1.13 m		14.3	4.97	41	0.03	<1	<1	3	5	<1			<0.05	0.093	
CW1	29/04/2014		Slightly cloudy, 1.29 m		14.1	5.44	39	0.02	<1	<1	4	4	<1			<0.05	0.13	
CW2	22/02/2011		Slightly cloudy		16	5.42	16	0.07	<1	<1	2	4	<1	<1		0.09	0.152	
CW2	23/03/2011		Slightly cloudy		18.3	4.66	28	0.14	<1	<1	3	5	<1	<1		0.62	0.187	
CW2	23/03/2011		Slightly cloudy		18.3	4.66	28	0.14	<1	<1	3	5	<1	<1		0.62	0.187	
CW2	20/04/2011		Cloudy, brown		13.1	5.71	15	0.04	<1	<1	3	6	<1	<1		0.07	0.069	
CW2	20/04/2011		Cloudy, brown		13.1	5.71	15	0.04	<1	<1	3	6	<1	<1		0.07	0.069	
CW2	18/05/2011		Slightly cloudy		11.9	5.35	15	0.08	<1	<1	2	5	<1	<1		<0.05	0.09	
CW2	18/05/2011		Slightly cloudy		11.9	5.35	15	0.08	<1	<1	2	5	<1	<1		<0.05	0.09	
CW2	16/06/2011		Cloudy		10.8	5.54	18	0.1	<1	<1	2	4	<1	<1		0.06	0.185	
CW2	16/06/2011		Cloudy		10.8	5.54	18	0.1	<1	<1	2	4	<1	<1		0.06	0.185	
CW2	13/07/2011		Slightly cloudy		8.8	5.27	15	0.06	<1	<1	2	4	<1	<1		<0.05	0.236	
CW2	13/07/2011		Slightly cloudy		8.8	5.27	15	0.06	<1	<1	2	4	<1	<1		<0.05	0.236	
CW2	24/08/2011		Slightly cloudy		12.8	5.38	21	0.14	<1	<1	2	4	<1	<1		0.07	0.067	
CW2	24/08/2011		Slightly cloudy		12.8	5.38	21	0.14	<1	<1	2	4	<1	<1		0.07	0.067	
CW2	29/09/2011		Slightly cloudy		10.6	4.99	21	0.06	<1	<1	2	4	<1	<1		<0.05	0.061	
CW2	29/09/2011		Slightly cloudy		10.6	4.99	21	0.06	<1	<1	2	4	<1	<1		<0.05	0.061	
CW2	17/10/2011		Slightly cloudy		11.8	4.98	20	0.06	<1	<1	2	4	<1	<1		<0.05	0.173	
CW2	17/10/2011		Slightly cloudy		11.8	4.98	20	0.06	<1	<1	2	4	<1	<1		<0.05	0.173	
CW2	21/11/2011		Slightly cloudy		13.4	5.05	15	0.28	<1	<1	2	4	<1	<1		0.3	0.177	
CW2	21/11/2011		Slightly cloudy		13.4	5.05	15	0.28	<1	<1	2	4	<1	<1		0.3	0.177	
CW2	14/12/2011		Slightly cloudy		12.9	5.24	17	0.05	<1	<1	2	4	<1	<1		<0.05	0.179	
CW2	14/12/2011		Slightly cloudy		12.9	5.24	17	0.05	<1	<1	2	4	<1	<1		<0.05	0.179	
CW2	17/01/2012		Clear		13.9	4.15	18	0.09	<1	<1	2	5	<1	<1		0.11	0.139	
CW2	28/02/2012		Clear		15.3	4.69	18	0.04	<1	<1	2	4	<1	<1		0.07	0.049	
CW2	6/03/2012		Cloudy		13.7	4.88	17	0.07	<1	<1	2	4	<1	<1		0.31	0.102	
CW2	17/04/2012		brown, slightly cloudy		12.7	5.1	16	0.06	<1	<1	2	4	<1	<1		0.06	0.083	
CW2	15/05/2012		brown, slightly cloudy		10.6	5.28	16	0.06	<1	<1	2	4	<1	<1		<0.05	0.074	
CW2	12/06/2012		Clear		9.6	5.25	20	0.06	<1	<1	2	4	<1	<1		0.07	0.07	
CW2	12/07/2012		Clear-114cm			5.5	12	0.16	<1	<1	2	4	<1			<0.05	0.048	
CW2	21/08/2012		Clear 108cm			5.23	19	0.08	<1		3	3	<1			0.05	0.13	
CW2	17/09/2012		Clear, 115cm		10.1	4.68	21	0.07	<1	<1	2	5	<1			0.44	0.06	
CW2	17/10/2012		Clear, 1.15 m		11.8	5.42	27	0.04	<1	<1	3	6	<1			0.17	0.093	
CW2	13/11/2012		Clear, 1.17 m		15.1	4.7	22	0.04	<1	<1	3	4	<1			<0.05	0.054	
CW2	11/12/2012		Clear, 1.20 mt		12.3	5.24	23	0.05	<1	<1	2	5	<1			0.13	0.06	
CW2	15/01/2013		Clear, 1.21 m		14.6	5.24	22	0.1	<1	<1	2	4	<1			0.09	0.089	
CW2	14/02/2013		Clear, 1.15 m		14.6	5.27	23	0.02	<1	<1	3	4	<1			<0.05	0.076	
CW2	12/03/2013		Clear, 1.13 m		15.2	5.72	25	0.02	<1	<1	2	4	<1			0.06	0.069	
CW2	16/04/2013		Clear, 1.05		12.7	5.4	21	0.01	<1	<1	2	4	<1			<0.05	0.072	
CW2	21/05/2013		Clear, 1.18 m			5.65	20	0.03	<1	<1	2	4	<1			<0.05	0.062	
CW2	19/06/2013		Clear, 1.12 m		9.3	5.34	19	<0.01	<1	<1	2	4	<1			<0.05	<0.005	
CW2	17/07/2013		Clear, 1.22 m		10.1	8.28	21	0.04	<1	<1	3	4	<1			<0.05	0.119	
CW2	28/08/2013		Clear, 1.16 m		10.4	5.29	21	0.03	<1	<1	3	4	<1			<0.05	0.07	
CW2	30/09/2013		Clear, 1.09 m		12.2	5.53	44	0.03	<1	<1	3	7	6			<0.05	0.128	
CW2	30/10/2013		Clear, 1.17 m		11.7	5.4	23	0.02	<1	<1	2	5	<1			<0.05	0.028	
CW2	27/11/2013		Clear, 1.17 m		12.3	5.44	25	0.03	<1	<1	2	4	<1			<0.05	0.094	
CW2	18/12/2013		Clear, 1.19m		13.7	5.67	30	0.04	<1	<1	2	4	<1			<0.05	0.094	
CW2	20/01/2014		Clear, 1.22 m, not purged			5.38	21	0.04	<1	<1	2	11	<1			<0.05	0.109	
CW2	19/02/2014		Clear, 1.23 m		14.5	5.45	21	0.03	<1	<1	2	4	<1			<0.05	0.07	
CW2	20/03/2014		Clear, 1.20 m		13.8	4.86	30	0.04	<1	<1	3	3	<1			<0.05	0.094	
CW2	29/04/2014		Slightly cloudy, 1.29 m		13.3	5.88	40	0.02	<1	<1	3	4	<1			<0.05	0.321	
CW2	18/05/2015			Clear	11.8	5.31	40	0.09	<1	<1	3	1	<1	10		<0.05	0.083	
CW2	25/07/2016			Clear	10.2	4.81	44	0.41	<1	<1	2	2	1	8		<0.05	0.069	
CW3	12/03/2013		Light brown, cloudy, 1.30 m		15.8	7.17	29											
CW4	16/10/2012		Cloudy brown, 0.82 m		13.6	6.14	52	0.16	3	<1	4	8	3			0.13	0.032	
CW4	13/11/2012		Cloudy, brown, 1.33 m		15.2	6.07	60	0.14	4	<1	5	4	<1			0.05	0.019	
CW4	11/12/2012		Brown, cloudy, 1.58 m		13.1	5.78	57	0.06	3	<1	4	5	<1			0.21	0.035	
CW4	14/02/2013		Cloudy, 1.72 m		15.8	5.94	45	0.05	2	<1	5	5	<1			0.06	0.028	
CW4	12/03/2013		Cloudy, 0.98 m		14.5	5.08	43	0.09	2	<1	3	2	<1			<0.05	0.017	
CW4	16/04/2013		Cloudy, 1.15		12.6	5.89	52	0.06	5	1	4	3	<1			<0.05	0.02	
CW4	21/05/2013		Dry, 2.02			6.17	39											
FT1	18/03/2018			Cloudy	15	4.7	43	0.1	<1	<1	4	7	<1	2	0.01	0.07	0.024	<0.05
FT1	25/02/2019			Cloudy	13.9	5.3	44	0.06	<1	<1	4	7	<1	3	0.008	0.12	0.03	<0.05

location	Date of Sample	Comments	Comments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
FT1	30/04/2019			Cloudy	13	4.6	43	0.34	<1	<1	4	6	<1	2	0.008	<0.05	0.023	<0.05
FT1	29/05/2019			Slightly cloudy	8.9	6	43	0.1	<1	<1	5	8	1	<1	0.049	0.18	0.037	<0.05
FT2	29/05/2019			Slightly cloudy	9.5	5.3	48	0.08	<1	<1	4	7	<1	5	0.067	0.32	0.024	<0.05
GG1	16/10/2012		Slightly cloudy, 0.78 m		10.7	4.81	33	0.6	1	<1	3	8	<1			0.75	0.098	
GG1	13/11/2012		Slightly cloudy, 0.72 m		12.8	5.71	53	0.43	1	<1	4	8	<1			5.13	0.069	
GG1	11/12/2012		Cloudy, brown, 0.71 m		11.5	5.69	56	0.32	1	<1	3	9	<1			6.03	0.079	
GG1	15/01/2013		Light brown, cloudy, 0.85 m		13.1	5.44	35	1.32	1	<1	4	7	<1			0.96	0.064	
GG1	14/02/2013		Slightly cloudy, brown, 0.73 m		14.3	5.66	142	0.12	1	<1	4	7	<1			2.25	0.055	
GG1	12/03/2013		Cloudy, 0.64 m		14.3	4.56	46	0.15	<1	<1	3	7	<1			2.56	0.06	
GG1	16/04/2013		Cloudy, 0.55		12.2	5.57	36	0.12	1	<1	4	6	<1			0.59	0.052	
GG1	21/05/2013		Brown, cloudy, 0.72			5.67	31	0.12	1	<1	3	6	<1			0.11	0.05	
GG1	19/06/2013		Slightly cloudy, 0.66 m		8.6	4.94	31	0.08	2	<1	4	7	<1			0.18	0.043	
GG1	17/07/2013		Cloudy, 0.59 m		9.7	8.12	31	0.21	1	<1	5	7	<1			0.31	0.075	
GG1	28/08/2013		Cloudy, 0.68 m		9.4	5.56	38	0.16	<1	<1	4	6	<1			1.77	0.09	
GG1	30/09/2013		Cloudy, 0.69 m		12.8	5.39	56	0.14	1	<1	5	10	5			1.98	0.102	
GG1	27/11/2013		Brown,cloudy, 0.23 m		13.6	5.44	47	0.54	1	<1	8	9	<1			2.34	0.061	
GG1	18/12/2013		Cloudy, 0.28m		15.8	5.81	57	0.65	<1	<1	5	9	<1			4.64	0.082	
GG1	20/01/2014		Clear, 0.31 m, not purged			5.83	52	0.7	1	<1	5	15	<1			7.01	0.093	
GG1	19/02/2014		Cloudy, 0.30 m		16.5	5.46	38	0.39	1	<1	5	8	<1			1.28	0.061	
GG1	20/03/2014		Cloudy, 0.26 m		16.9	5.67	55	0.88	1	<1	5	7	<1			3.62	0.079	
GG1	29/04/2014		Cloudy, 0.22 m		14.6	5.48	53	0.72	2	<1	8	6	<1			3.8	0.092	
GG1	30/10/2014			Clear	14.7	5.06	43	0.14	<1	<1	5	6	<1	<10		0.33	0.08	
GG1	20/04/2015			Clear	13.6	5.38	42	0.09	<1	<1	4	7	<1	<1		0.26	0.04	
GG1	18/05/2015			Clear	11.9	5.31	36	0.07	<1	<1	4	6	<1	<1		<0.05	0.036	
GG1	29/06/2015			Clear	10.4	5.38	35	0.07	<1	<1	3	6	<1	<1		<0.05	0.031	
GG1	27/07/2015			Clear	8.8	5.4	40	0.08	<1	<1	3	6	<1	<1		<0.05	0.033	
GG1	19/08/2015			Clear	9.1	5.03	37	0.08	<1	<1	4	5	<1	<1		<0.05	0.018	
GG1	28/09/2015			Clear	11.7	5.04	38	0.06	<1	<1	4	6	<1	<1		0.13	0.015	
GG1	27/10/2015			Clear	14	5.08	39	0.07	<1	<1	3	6	<1	<1		0.29	0.033	
GG1	23/11/2015			Clear	18.1	5.14	32	0.06	<1	<1	4	7	1	<1		0.18	0.026	
GG1	31/12/2015			Clear	18.2	5.17	45		<1	<1	5	8	<1	<1		0.79	0.027	
GG1	18/01/2016			Clear	17.2	4.93	38	0.05	<1	<1	4	6	<1	<1		1	0.022	
GG1	18/02/2016			Clear	16.9	4.93	40	0.06	<1	<1	4	7	<1	<1		0.46	0.025	
GG1	17/03/2016			Clear	17.6	5.03	46	0.04	<1	<1	4	6	<1	3		0.5	0.022	
GG1	20/04/2016			Clear	15.5	5.07	40	0.2	1	<1	4	6	<1	1	0.016	0.28	0.033	<0.05
GG1	26/05/2016			Slightly Cloudy	11.6	5.24	42	0.06	<1	<1	4	6	<1	<1		<0.05	0.018	
GG1	27/06/2016			Clear	9	5.18	34	0.13	<1	<1	4	6	<1	<1		<0.05	0.014	
GG1	25/07/2016			Clear	10.2	4.82	32	0.12	<1	<1	3	5	<1	<1		<0.05	0.013	
GG1	17/08/2016			Clear	9.8	4.74	39	0.11	<1	<1	3	5	<1	1		0.06	0.014	
GG1	28/09/2016				12.3	5.01	38											
GG1	27/10/2016	enough sample for TOG		Clear	18.6	5.45	38	0.05	<1	<1	5	6	4	<1		1.19	0.026	
GG1	23/11/2016			Clear	17	5.34	50	0.1	<1	<1	4	5	<1	<1		3.04	0.038	
GG1	22/12/2016			Clear	15.6	5.2	45	0.09	<1	<1	4	6	<1	<1		2.55	0.022	
GG1	18/01/2017			Clear	19.2	5.55	46	0.14	<1	<1	5	13	<1	<1		1.56	0.025	
GG1	1/02/2017			Clear	16.9	5.15	79	0.1	<1	<1	17	18	<1	<1		1.29	0.062	
GG1	29/03/2017			Clear	16.8	5.63	50	0.06	<1	<1	4	9	<1	2		0.17	0.006	
GG1	28/04/2017			Clear	14.3	5.07	37	0.11	<1	<1	4	4	<1	4		0.17	0.044	
GG1	31/05/2017			Cloudy	8.7	6.1	25	0.04	<1	<1	3	4	<1	<1		0.1	<0.005	
GG1	19/06/2017			Cloudy	9.1	5	230	0.27	<1	<1	4	10	3	5		<0.05	0.02	
GG1	31/07/2017			Slightly Cloudy	9.7	5	38	0.09	<1	<1	4	6	<1			0.11	0.013	
GG1	30/08/2017			Clear	6.1	5	22	0.03	<1	<1	3	5	<1	1		<0.05	<0.005	
GG1	13/09/2017			Slightly Cloudy	13.2	5.4	35	0.03	<1	<1	4	7	<1	2		0.13	0.034	
GG1	30/10/2017			Clear	16.4	6.1	148	0.19	<1	<1	31	45	<1	8		11.2	0.041	
GG1	22/11/2017			Clear	11.5	5	83	1.09	<1	<1	5	6	2	3		1.92	0.071	
GG1	31/01/2018			Clear	13.6	4.8	45	0.08	<1	<1	4	8	<1	<1		0.31	<0.005	
GW1	13/11/2012		Cloudy, 1.33 m		17.1	6.2	53	0.14	3	<1	5	7	<1			0.2	0.022	
GW1	11/12/2012		Brown, cloudy, 1.5 m		12.3	6.44	78	0.2	6	<1	5	6	<1			0.36	0.026	
GW1	15/01/2013		Clear, 1.31 m		14.5	5.98	43	0.12	2	<1	4	7	<1			1.02	0.09	
GW1	14/02/2013		Slightly cloudy, 1.35 m		14.9	6.16	55	0.03	4	<1	5	9	<1			0.27	0.034	
GW1	12/03/2013		Clear, 0.70 m		15.4	6.46	47											
GW1	16/04/2013		Slightly Cloudy, 1.15		12.4	6.49	71	0.14	8	<1	4	5	<1			0.62	0.034	
GW1	21/05/2013		Clear, 1.72 m			6.5	56	0.02	5	<1	4	6	<1			0.05	0.036	
GW1	19/06/2013		Clear, 1.33 m		7.7	6.36	59	0.02	7	<1	4	6	<1			<0.05	0.025	
GW1	17/07/2013		Clear, 1.39 m		9	7.84	46	0.03	3	<1	4	6	<1			<0.05	0.091	
GW1	28/08/2013		Slightly cloudy, 0.73 m		10.1	5.72	40	0.01	2	<1	4	6	<1			0.07	0.061	
GW1	30/09/2013		Clear, 1.40 m		11.7	5.85	51	0.02	3	<1	5	8	2			0.13	0.116	

location	Date of Sample	Comments	Comments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
GW1	27/11/2013		Clear, 0.20 m		13.8	5.9	46	0.02	2	<1	4	6	<1			0.06	0.062	
GW1	18/12/2013		Clear, 0.20m		16.1	6	45	0.03	1	<1	4	6	<1			0.35	0.061	
GW1	20/01/2014		Clear, 0.23 m, not purged			6.01	49	0.08	4	<1	5	12	<1			0.14	0.062	
GW1	19/02/2014		Slighlty cloudy, 0.21		16.8	5.91	53	0.26	3	<1	5	8	<1			0.99	0.09	
GW1	20/03/2014		Clear, 0.21 m		17	6.33	86	0.18	6	<1	5	6	<1			0.22	0.091	
GW1	29/04/2014		Clear, 0.20 m		14.6	6.6	83	0.16	8	<1	6	5	<1			0.22	0.112	
GW1	27/06/2016			Clear	8.3	5.24	47	0.18	<1	1	3	4	<1	11		<0.05	0.01	
GW1	25/07/2016			Clear	9.9	5.11	38	0.24	<1	<1	3	2	<1	8		<0.05	0.006	
GW1	28/09/2016				11.8	4.74	39											
GW2	16/10/2012		Cloudy black, 0.61 m		12.5	6.11	51	0.22	4	<1	4	7	<1			1.98	0.019	
GW2	13/11/2012		Slightly cloudy, 0.70 m		15.7	6.2	54	0.39	1	<1	8	7	<1			4.22	0.025	
GW2	11/12/2012		Brown, cloudy, 0.71 m		12.5	5.96	44	0.23	<1	<1	3	8	<1			3.2	0.032	
GW2	15/01/2013		Slightly brown, 0.82 m		15.1	6.09	47	0.78	1	<1	4	6	<1			6.3	0.054	
GW2	14/02/2013		Slightly cloudy, 0.75 m		15.1	6.03	48	0.38	1	<1	4	8	<1			4.13	0.062	
GW2	12/03/2013		Clear, 1.32 m		15.3	5.2	68	0.02	5	<1	4	6	<1			0.11	0.056	
GW2	16/04/2013		Cloudy, 0.66		13.3	5.74	43	0.13	1	<1	4	6	<1			1.3	0.08	
GW2	21/05/2013		Brown, cloudy, 0.76 m			5.83	33	0.02	<1	<1	4	7	<1			0.06	0.038	
GW2	19/06/2013		Brown, cloudy, 0.72 m, not enough water for analysis		8.3	5.18	27											
GW2	17/07/2013		Cloudy, black		9.2	6.48	28	0.19	<1	<1	4	6	<1			0.68	0.05	
GW2	28/08/2013		Brown, 0.73		9.5	5.77	35	0.17	<1	<1	3	5	<1			1.74	0.111	
GW2	30/09/2013		Slightly cloudy, 0.74 m		13	5.92	66	0.21	<1	<1	4	11	8			3.08	0.062	
GW2	27/11/2013		Brown, cloudy, 0.27 m		14.6	5.9	45	0.31	<1	<1	6	7	<1			2.72	0.057	
GW2	18/12/2013		Slightly cloudy, 0.30m		17.5	6.18	51	0.44	<1	<1	4	6	<1			5.2	0.058	
GW2	20/01/2014		Slighlty cloudy, 0.31 m, not purged			6.11	50	0.52	<1	<1	4	14	<1			6.18	0.057	
GW2	19/02/2014		Cloudy, 0.28 m		17.1	6.25	48	0.4	<1	<1	4	6	<1			4.31	0.08	
GW2	20/03/2014		Cloudy, 0.25 m		17.2	6.48	54	0.38	<1	<1	4	5	<1			2.33	0.061	
GW2	29/04/2014		Cloudy, 0.29 m		15.1	6.6	44	0.27	<1	<1	5	4	<1			1.78	0.159	
GW2	20/04/2015			Clear	12.9	7.73	63	0.23	1	<1	2	5	<1	<1		5.94	0.044	
GW2	18/05/2015			Cloudy	12	5.5	44	0.09	<1	<1	2	5	<1	9		3.42	0.032	
GW2	29/06/2015			Cloudy	10.4	5.56	36	0.07	<1	<1	2	5	<1	<1		1.92	0.023	
GW2	27/07/2015			Cloudy	8.5	5.62	40	0.04	<1	<1	2	5	1	<1		0.81	0.026	
GW2	19/08/2015			Slightly Cloudy	8.6	5.2	33	0.05	<1	<1	3	4	<1	<1		0.86	0.022	
GW2	28/09/2015			Slightly Cloudy	11.6	5.67	40	0.06	<1	<1	2	5	<1	<1		2.66	0.01	
GW2	27/10/2015			Clear	13.1	5.92	48	0.12	<1	<1	3	6	<1	<1		4.33	0.022	
GW2	23/11/2015			Clear	18	5.68	51	0.16	<1	<1	4	10	6	<1		4.82	0.025	
GW2	18/01/2016			Slightly cloudy	16.2	5.85	50	0.17	<1	<1	4	4	<1	<1		4.69	0.022	
GW2	18/02/2016			Slightly Cloudy	17.7	5.49	55	0.23	<1	<1	3	5	<1	<1		5.4	0.021	
GW2	27/06/2016			Slightly Cloudy	8.8	4.8	54	0.23	<1	<1	4	4	<1	11		0.12	0.023	
GW2	25/07/2016			Clear	9.9	4.48	39	0.16	<1	<1	3	3	<1	5		0.24	0.018	
GW2	17/08/2016			Clear	9.7	7.73	43	0.14	<1	<1	3	4	<1	5		0.44	0.014	
GW2	28/09/2016				12.5	4.9	38											
GW2	27/10/2016			Clear	16.1	5.39	33	0.16	<1	<1	3	5	<1	1		2.22	0.019	
GW2	23/11/2016			Clear	16.2	5.33	40	0.17	<1	<1	3	4	<1	2		2.94	0.025	
GW2	22/12/2016			Slightly Cloudy	15.8	5.73	43	0.11	<1	<1	4	4	<1	5		2.09	0.025	
GW2	29/03/2017			Clear	16.5	5.32	42	0.06	<1	<1	4	9	<1	3		0.16	0.008	
MS1	12/06/2012		Dark brown, cloudy		8.7	5.87	50	0.17	<1	<1	6	5	<1	<1		1.25	0.065	
MS1	12/07/2012		Cloudy - 140cm			5.57	38	0.12	<1	<1	5	6	<1			0.12	0.024	
MS1	21/08/2012		Cloudy brown 119cm			6.08	33	0.06	<1		6	8	<1			0.07	0.041	
MS1	17/09/2012		Clear, 120cm		12.1	5.89	35	0.02	1	<1	4	8	<1			0.1	0.085	
MS1	17/10/2012		Slightly cloudy, 1.20 m		10.3	6.07	59	0.03	1	<1	4	8	1			1.06	0.044	
MS1	13/11/2012		Cloudy, 1.45 m		15.8	6	54	0.05	2	<1	6	7	<1			3.05	0.059	
MS1	11/12/2012		Slightly cloudy, 1.55 m		13.4	5.69	91	0.03	1	<1	5	7	<1			1.58	0.16	
MS1	15/01/2013		Clear, 1.61 m		13.9	6.28	60	0.04	2	<1	5	6	<1			2.32	0.064	
MS1	14/02/2013		Clear, 1.37 m		14.9	6.01	65	<0.01	2	<1	6	6	<1			2.09	0.073	
MS1	12/03/2013		Clear, 1.23 m		15.1	4.36	62	0.02	<1	<1	4	6	<1			2.32	0.053	
MS1	16/04/2013		Clear, 1.27		13.9	6.38	63	0.02	2	1	5	6	<1			0.39	0.039	
MS1	21/05/2013		Clear, 1.31 m			6.7	60	0.06	4	2	4	6	<1			0.15	0.054	
MS1	19/06/2013		Clear, 1.49 m		8.8	6.05	48	<0.01	2	<1	4	6	<1			<0.05	0.01	
MS1	17/07/2013		Clear, 1.32 m		10.6	7.52	59	0.08	2	<1	5	6	<1			0.17	0.102	
MS1	28/08/2013		Slightly cloudy, 1.75 m		10.1	5.45	27	0.02	<1	<1	3	5	<1			0.11	0.093	
MS1	30/09/2013		Clear, 1.48 m		12.4	5.86	48	0.02	<1	<1	4	8	3			2.26	0.1	
MS1	30/10/2013		Clear, 1.75 m		12.4	5.84	37	0.02	<1	<1	4	6	<1			2.65	0.073	
MS1	27/11/2013		Clear, 1.28 m		14.8	6.06	52	0.03	<1	<1	4	5	<1			5.36	0.098	
MS1	18/12/2013		Clear, 1.72m		16	6.13	46	0.02	<1	<1	4	6	<1			5.05	0.073	
MS1	20/01/2014		Clear, 1.42 m, not purged			5.98	45	0.02	1	<1	4	12	<1			3.18	0.086	
MS1	19/02/2014		Clear, 1.74 m		15.8	6.15	44	0.02	<1	<1	4	5	<1			5.29	0.075	

location I	Date of Sample	Comments	:omments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
MS1	20/03/2014		Clear, 1.40 m		17.2	6.49	69	0.02	<1	<1	4	5	<1			5.77	0.091	
MS1	29/04/2014		Clear, 1.38 m		14.5	5.98	60	0.01	<1	<1	5	3	<1			5.44	0.133	
MS1	30/10/2014			Clear	14.8	5.9	58	0.02	<1	<1	4	4	<1	<1		6.06	0.166	
MS1	20/04/2015			Clear	13.7	5.97	69	0.02	<1	<1	3	4	<1	<1		7.92	0.055	
MS1	18/05/2015			Clear	12	5.48	30	0.02	<1	<1	3	3	<1	<1		<0.05	0.038	
MS1	29/06/2015			Clear	9.8	5.53	28	0.02	<1	<1	4	4	<1	2		0.1	0.03	
MS1	27/07/2015			Clear	8.2	5.63	30	0.01	<1	<1	3	3	<1	<1		<0.05	0.026	
MS1	19/08/2015			Slightly Cloudy	9.2	5.25	32	0.01	<1	<1	3	4	<1	<1		0.29	0.035	
MS1	28/09/2015			Clear	11.9	5.91	58	<0.01	<1	<1	3	4	<1	<1		6.39	0.016	
MS1	27/10/2015			Clear	13.3	5.82	58	0.01	<1	<1	3	5	<1	<1		5.62	0.033	
MS1	23/11/2015			Clear	17.6	5.95	51	<0.01	<1	<1	4	5	1	<1		7.14	0.035	
MS1	27/12/2015			Slightly cloudy	15.9	6.11	67		<1	<1	4	6	<1	1		7.95	0.033	
MS1	18/01/2016			Clear	18	5.86	72	<0.01	<1	<1	4	4	<1	<1		9.21	0.03	
MS1	18/02/2016			Clear	17.8	5.5	72	0.01	<1	<1	5	5	<1	<1		9.48	0.038	
MS1	17/03/2016			Clear	18	5.93	64	<0.01	<1	<1	4	5	<1	2		7.75	0.025	
MS1	20/04/2016			Clear	15.9	6.08	82	0.14	<1	<1	4	5	<1	<1	0.017	12.8	0.051	<0.05
MS1	26/05/2016			Clear	11.2	5.27	31	<0.01	<1	<1	3	4	<1	<1		0.19	0.033	
MS1	27/06/2016			Clear	8.6	5.56	34	0.01	1	<1	3	5	<1	<1		<0.05	0.019	
MS1	25/07/2016			Clear	9.7	5.28	32	0.02	<1	<1	3	5	<1	<1		<0.05	0.019	
MS1	17/08/2016			Clear	9.8	4.94	33	0.02	<1	<1	3	5	<1	<1		<0.05	0.023	
MS1	28/09/2016				12.5	5.3	37											
MS1	27/10/2016			Clear	16.6	5.97	47	0.01	<1	<1	4	5	<1	<1		3.5	0.021	
MS1	23/11/2016			Clear	16.9	5.71	52	0.01	<1	<1	4	4	<1	1		4.32	0.03	
MS1	22/12/2016			Clear	16.6	5.55	54	<0.01	<1	<1	4	5	<1	8		6.1	0.016	
MS1	18/01/2017			Clear	18.9	6.02	62	<0.01	<1	<1	4	6	<1	<1		8.82	0.029	
MS1	1/02/2017			Clear	17.7	5.77	66	<0.01	<1	<1	5	5	<1	4		9.4	0.046	
MS1	29/03/2017			Slightly Cloudy	17.8	5.6	63	0.2	<1	<1	3	6	<1	1		3.21	0.022	
MS1	28/04/2017			Clear	13.4	5.51	32	0.03	<1	<1	6	8	<1	<1		<0.05	0.034	
MS1	31/05/2017			Clear	8.8	5.8	33	0.01	1	<1	3	4	<1	<1		<0.05	0.019	
MS1	19/06/2017			Cloudy	8.7	4.97	244	0.22	<1	<1	4	8	4	2		0.14	0.019	
MS1	31/07/2017			Clear	8.6	5.4	31	0.02	<1	<1	3	7	<1			<0.05	0.011	
MS1	30/08/2017			Clear	12	6.2	1310	0.03	9	3	141	328	156	24		<0.05	0.024	
MS1	13/09/2017			Clear	10.7	5.6	72	0.02	<1	<1	10	20	<1	1		<0.05	0.017	
MS1	30/10/2017			Clear	11.7	5.3	34	0.02	1	<1	4	7	<1	<1		1.76	0.013	
MS1	22/11/2017			Clear	11.7	5.4	46	0.23	<1	<1	4	5	<1	<1		5.13	0.026	
MS1	20/12/2017			Clear	14.4	5.5	47	0.02	2	<1	5	6	2	<1		8.34	0.025	
MS1	31/01/2018			Clear	12.9	6	68	0.07	<1	<1	5	7	<1	13		0.37	<0.005	
MS1	28/02/2018			Clear	13.4	5	49	0.05	<1	<1	3	5	<1	5		6.6	0.016	
MS1	28/03/2018			Clear	16.14	5.8	59	0.04	<1	<1	4	3	<1	<1		5.41	0.011	
MS1	24/04/2018			Clear	12.8	6.1	97	0.01	<1	<1	5	4	<1			17.1	0.047	
MS1	23/05/2018			Clear	9.5	6.4	383	<0.01	1	<1	9	59	57	<1		7.42	0.042	
MS1	20/06/2018			Clear	7.4	5.5	85	0.01	2	<1	6	7	1			3.75	0.053	
MS1	4/07/2018			Slightly Cloudy	7.7	5.1	26	0.16	<1	<1	7	<1	<1	<1		0.17	0.024	
MS1	8/08/2018			Slightly Cloudy	5.9	4.8	60	0.06	<1	<1	5	9	<1	<1		0.08	0.015	
MS1	13/09/2018			Slightly Cloudy	5	6.9	34	0.06	<1	<1	3	7	<1	<1	0.016	0.18	<0.005	<0.05
MS1	11/10/2018			Slightly Cloudy	7.1	5	40	0.17	<1	<1	4	8	<1	<1	0.025	0.97	0.013	<0.05
MS1	7/11/2018			Clear	10.7	4.4	49	0.06	1	<1	5	7	<1	3	0.052	1.9	0.051	<0.05
MS1	6/12/2018			Clear	9.8	5.3	50	0.03	<1	<1	4	5	<1	2	0.041	0.15	0.03	<0.05
MS1	20/12/2018			Clear	13.7	5.3	44	0.02	<1	<1	4	6	<1	2	0.048	<0.05	0.034	<0.05
MS1	21/01/2019			Cloudy	17.5	5.5	294	0.18	<1	<1	5	4	1	<1	0.094	0.36	0.027	0.06
MS1	28/02/2019			Slightly cloudy	16.4	6.6	73	0.57	1	1	6	8	2	1	0.107	2.76	0.119	<0.05
MS1	27/03/2019			Clear	13.1	4.9	40	0.08	<1	<1	4	8	<1	4	0.05	0.27	0.024	<0.05
MS1	4/04/2019			Slightly cloudy	13.8	6.2	37	0.02	<1	<1	5	7	<1	4	0.043	1.26	0.05	<0.05
MS1	1/05/2019	nsufficent sample		Clear	13.6	5.8	81	<0.01	2	1	10	6	<1	4	0.048	0.95	0.045	<0.05
MS2	19/11/2018			Cloudy	10.7	4.4	34	0.14	<1	<1	3	5	<1	4	0.017	0.22	0.019	<0.05
MS2	20/12/2018			Clear	10.9	5.4	42	0.03	<1	<1	4	6	<1	2	0.05	0.35	0.029	<0.05
MS2	14/01/2019			Slightly cloudy	14.9	6	97	0.35	<1	<1	3	6	<1	<1	0.012	1	<0.005	<0.05
MS2	27/03/2019	icient water all anaylsis			14.1	5.5	32	0.03	<1	<1	4	7	<1	<1	0.014	0.07	0.098	<0.05
MS2	15/04/2019	ple amount to conduct all analysis		Cloudy	14	6	708	0.08	2	<1	10	63	<1	24	0.066	0.52	0.354	<0.05
MS2	21/05/2019				14.2	5.3	84	0.05	<1	<1	6	16	11	4	0.031	<0.05	0.114	<0.05
NMSS	18/02/2018			Cloudy	15.3	6.3	53	0.17	<1	<1	3	7	<1	4	0.047	0.06	0.028	<0.05
NMSS	19/11/2018			Cloudy	10.1	5.4	53	0.38	1	<1	3	5	<1	<1	0.037	0.16	<0.005	<0.05
NMSS	20/12/2018			Cloudy	13.4	6	93	0.07	7	<1	6	7	<1	3	0.078	5.62	0.055	<0.05
NMSS	14/01/2019			Cloudy	14.7	5.7	52	0.64	1	<1	7	7	<1	<1	0.008	0.24	0.011	0.11
NMSS	27/03/2019			Cloudy	12.9	5.2	41	0.06	<1	<1	3	6	<1	3	0.055	2.7	0.025	<0.05
NMSS	15/04/2019			Clear	13.3	6	485	0.05	1	<1	5	6	<1	2	0.044	0.12	0.059	<0.05

location	Date of Sample	Comments	omments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium m	Sodium mg/L	Chloride mg/L	Potassium mg	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
NMSS	21/05/2019				11.1	5.5	66	0.17	4	<1	5	8	2	2	0.099	0.54	0.023	<0.05
PC1	18/02/2018			Cloudy	14.8	7.3	107	14.6	4	2	53	31	2	14	0.013	3.41	1.13	1.19
PC1	19/11/2018			Cloudy	11.6	5.9	100	0.96	2	<1	43	5	1	<1	<0.001	0.32	0.033	0.68
PC1	20/12/2018			Cloudy	14.5	6.3	105	1.4	<1	<1	39	6	<1	46	0.002	0.53	0.012	0.2
PC1	14/01/2019			Cloudy	13.8	6.8	107	0.5				6		18	<0.001	0.39	0.024	0.54
PC1	27/03/2019			Cloudy	14.3	6.8	82	0.68	4	1	38	<1	1	<1	<0.010	<0.50	0.097	<0.50
PC1	15/04/2019			Slightly cloudy	13	5.8	639	0.11	<1	<1	4	9	<1	<1	0.064	0.52	0.027	<0.05
PC1	21/05/2019				11.6	5	67	0.1	1	<1	6	8	3	8	0.058	0.13	0.041	<0.05
PC2	18/02/2018			Cloudy	15.1	7.1	112	18	4	2	56	31	2	14	0.015	4.24	1.16	1.08
PC2	19/11/2018			Cloudy	11.9	6	97	1.12	1	<1	41	5	1	<1	<0.001	0.4	0.069	0.7
PC2	20/12/2018			Cloudy	14.9	6.2	108	1.66	<1	<1	31	6	<1	20	0.004	0.6	0.014	0.13
PC2	14/01/2019			Cloudy	14	7	102	0.27	<1	<1	24	10	<1	5	<0.001	0.11	<0.005	0.16
PC2	27/03/2019			Cloudy	14	5.2	35	0.05	<1	<1	4	6	<1	<1	0.015	0.33	0.03	<0.05
PC2	17/04/2019			Cloudy brown	13.7	6	51	0.04	2	<1	4	6	<1	<1	0.026	0.28	1.62	<0.05
PC2	21/05/2019				13.5	5.4	52	0.03	<1	<1	4	11	4	2	0.024	<0.05	0.149	<0.05
PSS	18/02/2018			Cloudy	15.9	6.6	133	0.14	5	1	7	10	<1	7	0.104	0.36	0.016	<0.05
PSS	19/11/2018			Cloudy	10	5.4	80	0.67	3	<1	6	8	<1	2	0.037	0.22	<0.005	<0.05
PSS	20/12/2018			Cloudy	13.5	5.9	107	0.06	7	1	6	7	<1	3	0.082	5.94	0.059	<0.05
PSS	14/01/2019			Cloudy	14.2	6.1	104	0.12	5	1	5	9	<1	<1	0.091	0.06	0.006	<0.05
PSS	27/03/2019			Cloudy	13.4	6.1	117	0.01	6	1	5	8	<1	<1	0.122	9.68	0.054	<0.05
PSS	15/04/2019			Cloudy	12.5	6.8	737	0.08	5	<1	5	7	<1	<1	0.166	1.59	0.029	<0.05
PSS	21/05/2019				13	5.4	39	0.04	<1	<1	4	7	2	3	0.029	<0.05	0.139	<0.05
SS1	22/02/2011		Cloudy		14.2	6.08	57	0.91	<1	<1	15	6	<1	<1		0.57	0.092	
SS1	23/03/2011		Cloudy		18.8	6.17	59	0.54	<1	<1	16	7	<1	<1		0.72	0.05	
SS1	23/03/2011		Cloudy		18.8	6.17	59	0.54	<1	<1	16	7	<1	<1		0.72	0.05	
SS1	20/04/2011		Cloudy, brown		12.9	6.65	64	0.5	<1	<1	17	9	<1	<1		0.26	0.018	
SS1	20/04/2011		Cloudy, brown		12.9	6.65	64	0.5	<1	<1	17	9	<1	<1		0.26	0.018	
SS1	18/05/2011		Cloudy		10.6	6.28	59	0.86	<1	<1	17	8	<1	<1		0.44	0.032	
SS1	18/05/2011		Cloudy		10.6	6.28	59	0.86	<1	<1	17	8	<1	<1		0.44	0.032	
SS1	16/06/2011		Cloudy		9.9	6.51	77	0.58	<1	<1	16	7	<1	1		0.34	0.233	
SS1	16/06/2011		Cloudy		9.9	6.51	77	0.58	<1	<1	16	7	<1	1		0.34	0.233	
SS1	13/07/2011		Cloudy		8.3	6.62	56	0.67	<1	<1	18	7	<1	3		0.34	0.074	
SS1	13/07/2011		Cloudy		8.3	6.62	56	0.67	<1	<1	18	7	<1	3		0.34	0.074	
SS1	24/08/2011		Cloudy		11.6	6.44	82	2.03	<1	<1	18	7	2	2		0.25	0.038	
SS1	24/08/2011		Cloudy		11.6	6.44	82	2.03	<1	<1	18	7	2	2		0.25	0.038	
SS1	29/09/2011		Brown, cloudy		9.5	5.6	64	0.09	<1	<1	6	7	<1	3		0.07	0.078	
SS1	29/09/2011		Brown, cloudy		9.5	5.6	64	0.09	<1	<1	6	7	<1	3		0.07	0.078	
SS1	17/10/2011		Cloudy		10.2	5.33	40	0.12	<1	<1	6	6	<1	2		0.06	0.064	
SS1	17/10/2011		Cloudy		10.2	5.33	40	0.12	<1	<1	6	6	<1	2		0.06	0.064	
SS1	21/11/2011		Cloudy		13.2	5.57	28	0.11	<1	<1	7	6	<1	<1		0.57	0.09	
SS1	21/11/2011		Cloudy		13.2	5.57	28	0.11	<1	<1	7	6	<1	<1		0.57	0.09	
SS1	14/12/2011		Slightly cloudy		12.1	6.53	30	0.46	<1	<1	6	6	<1	<1		1.1	0.078	
SS1	14/12/2011		Slightly cloudy		12.1	6.53	30	0.46	<1	<1	6	6	<1	<1		1.1	0.078	
SS1	17/01/2012		Clear		14.1	5.13	30	0.04	<1	<1	7	mg/L	<1	<1		0.82	0.074	
SS1	28/02/2012		Clear		15	6.15	68	0.07	<1	<1	7	6	<1	<1		0.86	0.048	
SS1	6/03/2012		Clear		13.6	4.59	29	0.06	<1	<1	7	6	<1	<1		0.51	0.062	
SS1	17/04/2012		Clear		12.8	5.17	30	0.08	<1	<1	7	6	<1	<1		0.44	0.054	
SS1	15/05/2012		Clear		10.2	5.77	28	0.03	<1	<1	5	6	<1	<1		<0.05	0.063	
SS1	12/06/2012		Clear		9.9	5.96	37	0.06	1	<1	6	7	<1	<1		0.1	0.06	
SS1	12/07/2012		Clear-45cm			6.09	23	0.06	<1	<1	5	7	<1			<0.05	0.041	
SS1	21/08/2012		Clear 55cm			5.39	32	0.01	<1		6	7	<1			<0.05	0.072	
SS1	17/09/2012		Clear, 63 cm		11.6	5.7	38	0.02	<1	<1	6	8	<1			<0.05	0.053	
SS1	17/10/2012		Clear, 0.91 m		11.5	5.7	46	0.02	<1	<1	7	9	1			0.36	0.074	
SS1	12/11/2012		Clear, 0.62 m		13.5	5.58	45	0.02	<1	<1	6	7	<1			1.24	0.109	
SS1	10/12/2012		Clear, 0.65 m		12.1	5.4	42	0.06	<1	<1	7	7	<1			1.48	0.058	
SS1	14/01/2013		Clear, 0.58 m		14.3	5.51	42	0.02	<1	<1	8	6	<1			0.93	0.061	
SS1	12/02/2013		Clear, 0.53 m		15.2	5.56	45	0.02	<1	<1	9	7	<1			0.9	0.054	
SS1	12/03/2013		Clear. 0.67 m		15.4	6.17	81	0.01	<1	<1	6	6	<1			1.12	0.05	
SS1	15/04/2013		Clear, 0.47		13.5	5.67	44	0.01	<1	<1	8	5	1			0.66	0.043	
SS1	15/05/2013	ly cloudy, 1.72 m, not enough water for additional analysis				6	35											
SS1	12/06/2013		Clear, 0.60 m		9.4	6.09	37	<0.01	<1	<1	7	6	<1			<0.05	0.047	
SS1	9/07/2013		Clear, 0.51 m			5.84	35	0.01	<1	<1	7	6	<1			<0.05	0.031	
SS1	5/08/2013		Clear, 1.17 m		8.9	5.89	39	0.02	<1	<1	7	6	<1			0.11	0.067	
SS1	10/09/2013		Clear, 0.84 m		11	5.43	37	0.02	<1	<1	7	6	<1			0.05	0.056	
SS1	10/10/2013		Clear, 0.85 m		12	5.42	46	0.02	<1	<1	8	6	1			0.86	0.053	
SS1	11/11/2013		Clear, 1.16 m		10.8	5.6	45	0.05	<1	<1	6	6	<1			1.32	0.098	

location I	Date of Sample	Comments	:omments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
SS1	10/12/2013		Clear, 1.00m		13	5.58	46	0.04	<1	<1	7	6	<1			1.26	0.069	
SS1	8/01/2014		Clear, 1.43 m		12.1	5.72	47	0.05	<1	<1	8	6	<1			0.87	0.068	
SS1	12/02/2014		Clear, 1.45m		15.4	5.63	40	0.05	<1	<1	7	7	<1			0.4	0.068	
SS1	13/03/2014		Clear, 1.28 m		15.2	5.57	61	0.05	<1	<1	8	5	<1			1.56	0.178	
SS1	3/04/2014		Clear, 1.11 m		14.7	5.5	53	0.03	<1	<1	7	5	<1			1.5	0.374	
SS1	22/10/2014			Clear	20.18	5.13	<10	0.03	<1	<1	6	5	<1	<1		0.48	0.112	
SS1	15/04/2015			Clear	14.4	5.65	55	0.03	<1	<1	7	6	<1	<1		1.04	0.041	
SS1	11/05/2015			Clear	11.7	5.55	45	0.03	<1	<1	8	5	<1	<1		0.8	0.027	
SS1	15/06/2015			Cloudy	9.3	6.27	42	0.27	<1	<1	14	4	<1	<1		0.18	0.014	
SS1	21/07/2015			Clear	9.3	6.03	46	0.02	<1	<1	7	5	<1	<1		0.12	0.024	
SS1	13/08/2015			Cloudy	7	6.42	90	0.23	<1	<1	18	4	<1	<1		0.13	0.02	
SS1	18/09/2015			Cloudy	8.1	6.07	93	0.49	<1	<1	20	6	<1	<1		0.31	0.014	
SS1	14/10/2015			Clear	12	5.72	37	0.03	<1	<1	6	5	<1	<1		0.65	0.023	
SS1	16/11/2015			Clear	11.7	5.51	55	0.03	<1	<1	7	5	<1	<1		1.94	0.036	
SS1	14/12/2015			Cloudy	15.3	5.96	87	0.89	<1	<1	22	7	<1	<1		0.35	0.009	
SS1	8/01/2016			Cloudy	14.4	5.78	86	0.15	<1	<1	17	6	<1	<1		0.17	0.007	
SS1	8/02/2016			Cloudy	14.8	6.12	86	1.3	<1	<1	25	5	<1	<1		0.36	<0.005	
SS1	10/03/2016			Clear	14.7	5.48	62	0.05	<1	<1	8	6	<1	1		2.56	0.012	
SS1	14/04/2016			Clear	13.1	5.55	61	0.07	<1	<1	8	5	<1	1	0.017	2.17	0.015	<0.05
SS1	12/05/2016			Cloudy	11.6	6.07	88	0.11	<1	<1	18	5	<1	<1		0.1	<0.005	
SS1	23/06/2016			Clear	10	5.5	49	0.31	<1	<1	6	5	<1	1		0.3	0.009	
SS1	11/07/2016			Clear	8.5	6.19	70	0.02	<1	<1	6	5	<1	1		0.43	0.015	
SS1	11/08/2016			Cloudy	7.9	5.79	70	0.24	<1	<1	12	4	<1	3		0.19	0.006	
SS1	14/09/2016			Clear	10.1	5.45	45	0.04	<1	<1	6	5	<1	1		0.4	0.026	
SS1	17/10/2016			Slightly Cloudy	9.4	5.44	44	0.04	<1	<1	7	5	<1	<1		0.96	0.011	
SS1	14/11/2016			Cloudy	11.4	6.08	66	0.26	<1	<1	14	5	<1	2		0.18	0.006	
SS1	8/12/2016			clear	13.5	5.16	55	0.04	<1	<1	8	5	<1	<1		2.12	0.012	
SS1	5/01/2017			Slightly Cloudy	13.9	5.32	50	0.06	<1	<1	6	5	<1	<1		2.64	0.023	
SS1	15/02/2017			Cloudy	16	6.11	75	0.74	<1	<1	17	4	<1	5		0.35	<0.005	
SS1	16/03/2017			Cloudy	15.1	5.9	64	0.27	<1	<1	17	4	<1	<1		0.31	0.008	
SS1	28/04/2017			Cloudy	11.8	6.2	87	0.08	<1	<1	18	3	<1	<1		0.24	0.094	
SS1	17/05/2017			Cloudy	11.6	6.24	29	0.08	<1	<1	4	5	<1	4		1.04	0.011	
SS1	8/06/2017			Cloudy	7.5	6.35	57	0.15	<1	<1	12	8	<1	<1			0.005	
SS1	19/07/2017			Cloudy	6.3	6.4	54	0.11	<1	<1	4	6	<1	<1		2.52	<0.005	
SS1	18/08/2017			Clear	7.8	5.5	48	0.03	1	1	14	6	<1	1		0.09	0.016	
SS1	28/09/2017			Clear	6.5	5.7	59	0.08	<1	<1	7	4	<1	5		0.22	0.023	
SS1	25/10/2017			Slightly Cloudy	12.7	7.5	37	0.05	<1	<1	5	4	<1	9		0.12	<0.005	
SS1	8/11/2017			Clear	9.4	5.5	47	0.06	<1	<1	6	5	<1	2		1.1	0.018	
SS1	11/12/2017			Clear	13	7.2	59	0.14	<1	<1	3	7	<1			0.36	<0.005	
SS1	17/01/2018			Slightly Cloudy	11.6	6	43	0.07	<1	<1	8	5	<1	<1		2.25	0.01	
SS1	15/02/2018			Slightly Cloudy	15	5.7	44	0.15	<1	<1	7	6	<1	<1		0.52	0.014	
SS1	14/03/2018			Clear	14.3	5.6	25	0.12	<1	<1	4	3	1	<1		0.48	0.008	
SS1	11/04/2018			Clear	12.2	5	32	0.1	<1	<1	3	6	<1	<1		0.29	<0.005	
SS1	19/07/2018			Slightly Cloudy	4.7	7	41	0.14	<1	<1	7	4	<1	10		0.06	0.038	
SS1	22/08/2018			Slightly Cloudy	6.2	4.5	57	0.03	<1	<1	5	4	<1	12		<0.05	0.025	
SS1	19/09/2018			Clear	7.5	5.7	56	0.03	<1	<1	6	4	<1	9	0.009	<0.05	0.031	<0.05
SS1	25/10/2018			Clear	9.2	4.7	64	0.04	<1	<1	12	6	1	9	0.016	0.26	0.05	<0.05
SS1	22/11/2018			Cloudy	10.7	5	107	0.05	4	<1	7	7	<1	2	0.079	1.37	0.018	<0.05
SS1	3/01/2019			Clear	13.6	5.8	80	0.07	<1	<1	10	12	2	10	0.019	0.72	0.126	<0.05
SS1	5/02/2019			Slightly cloudy	13.6	5.2	66	0.12	<1	<1	7	8	<1	9	0.013	0.17	0.037	<0.05
SS1	10/04/2019			Cloudy	12.7	5.4	47	0.06	<1	<1	15	4	<1	18	0.008	0.18	0.074	0.07
SS3	22/02/2011		Cloudy		15.7	6.61	71	0.8	<1	<1	20	7	1	<1		0.59	0.093	
SS3	23/03/2011		Cloudy		18.9	6.48	79	0.65	<1	<1	22	7	1	<10		0.46	0.02	
SS3	23/03/2011		Cloudy		18.9	6.48	79	0.65	<1	<1	22	7	1	<10		0.46	0.02	
SS3	20/04/2011		Cloudy, brown		12.5	6.81	75	0.51	<1	<1	20	8	1	<1		0.47	0.018	
SS3	20/04/2011		Cloudy, brown		12.5	6.81	75	0.51	<1	<1	20	8	1	<1		0.47	0.018	
SS3	18/05/2011		Cloudy		9.1	6.44	64	0.44	<1	<1	21	8	1	<1		0.45	0.03	
SS3	18/05/2011		Cloudy		9.1	6.44	64	0.44	<1	<1	21	8	1	<1		0.45	0.03	
SS3	16/06/2011		Cloudy		8.6	6.76	85	0.75	<1	<1	17	7	<1	<1		0.5	0.057	
SS3	16/06/2011		Cloudy		8.6	6.76	85	0.75	<1	<1	17	7	<1	<1		0.5	0.057	
SS3	13/07/2011		Cloudy		7.3	6.66	59	0.42	<1	<1	18	7	<1	<1		0.34	0.038	
SS3	13/07/2011		Cloudy		7.3	6.66	59	0.42	<1	<1	18	7	<1	<1		0.34	0.038	
SS3	24/08/2011		Cloudy		10.8	6.53	78	0.52	<1	<1	18	7	<1	<1		0.34	0.019	
SS3	24/08/2011		Cloudy		10.8	6.53	78	0.52	<1	<1	18	7	<1	<1		0.34	0.019	
SS3	29/09/2011		Cloudy		9.8	5.91	85	0.57	<1	<1	19	7	<1	2		0.38	0.048	
SS3	29/09/2011		Cloudy		9.8	5.91	85	0.57	<1	<1	19	7	<1	2		0.38	0.048	

location l	Date of Sample	Comments	:omments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
SS3	17/10/2011		Cloudy		10.1	5.92	83	4.81	<1	<1	23	8	<1	8		1.05	0.078	
SS3	17/10/2011		Cloudy		10.1	5.92	83	4.81	<1	<1	23	8	<1	8		1.05	0.078	
SS3	21/11/2011		Cloudy		14.2	6.49	57	0.31	<1	<1	18	6	<1	<1		0.18	0.058	
SS3	21/11/2011		Cloudy		14.2	6.49	57	0.31	<1	<1	18	6	<1	<1		0.18	0.058	
SS3	14/12/2011		Cloudy		12.3	6.35	63	0.57	<1	<1	18	8	<1	2		0.24	0.055	
SS3	14/12/2011		Cloudy		12.3	6.35	63	0.57	<1	<1	18	8	<1	2		0.24	0.055	
SS3	17/01/2012		Cloudy		13.7	5.94	60	0.45	<1	<1	16	5	<1	<1		0.22	0.034	
SS3	28/02/2012		Cloudy		14.8	5	33	0.43	<1	<1	18	6	<1	<1		0.25	0.019	
SS3	6/03/2012		Cloudy		13.9	5.8	56	0.48	<1	<1	16	6	<1	1		0.24	0.017	
SS3	17/04/2012		Cloudy		12.7	6.08	52	0.38	<1	<1	16	5	<1	<1		0.21	0.054	
SS3	15/05/2012		Light brown, cloudy		10.1	6.49	49	1.97	<1	<1	13	5	<1	<1		0.59	0.052	
SS3	12/06/2012		Brown, cloudy		9.7	6.47	66	1.16	<1	<1	14	5	<1	1		0.33	0.048	
SS3	12/07/2012		Cloudy - 72cm			6.47	62	0.32	<1	<1	14	6	<1			0.13	0.018	
SS3	21/08/2012		Cloudy brown 73cm			6.09	61	0.33	<1		14	5	<1			0.13	0.059	
SS3	17/09/2012		Cloudy, 81 cm		11.7	6.38	70	0.28	<1	<1	12	6	<1			0.08	0.028	
SS3	17/10/2012		Cloudy, 0.81 m		13.5	6.58	79	0.51	<1	<1	16	7	<1			0.22	0.028	
SS3	12/11/2012		Cloudy, light brown, 0.84 m		13	6.1	74	0.63	<1	<1	16	6	<1			0.25	0.075	
SS3	10/12/2012		Cloudy, brown, 0.84 m		12.2	5.96	74	0.66	<1	<1	18	7	<1			0.28	0.038	
SS3	14/01/2013		Cloudy, 0.83 m		15.5	6.12	78	0.28	<1	<1	17	6	<1			0.27	0.059	
SS3	12/02/2013		Cloudy, 0.69 m		15.5	6.14	87	1.45	<1	<1	24	7	<1			0.78	0.077	
SS3	12/03/2013		Cloudy, 0.78 m		15.3	5.56	48	0.17	<1	<1	18	6	<1			0.22	0.031	
SS3	15/04/2013		Cloudy, 0.65		13.7	6.35	76	0.3	<1	<1	18	5	<1			0.17	0.03	
SS3	15/05/2013		Cloudy, brown, 0.79 m			6.19	73	0.26	<1	<1	16	6	<1			0.12	0.017	
SS3	12/06/2013		Cloudy, 0.78 m		8.8	6.18	86	0.62	<1	<1	17	6	<1			0.19	0.013	
SS3	9/07/2013		Cloudy, 0.73 m			6.35	72	0.32	<1	<1	20	6	<1			0.13	0.018	
SS3	5/08/2013		Cloudy, 0.75 m		8.3	6.43	76	0.21	<1	<1	16	6	<1			0.1	0.032	
SS3	10/09/2013		Cloudy, 0.78 m		10.7	6.08	77	0.19	<1	<1	16	6	<1			0.18	0.05	
SS3	10/10/2013		Cloudy, 0.81 m		12.8	6	84	0.21	<1	<1	18	7	<1			0.14	0.037	
SS3	11/11/2013		Cloudy, 0.78 m		11.1	6.14	78	0.18	<1	<1	13	6	<1			0.17	0.032	
SS3	10/12/2013		Cloudy, 0.88m		13.2	6.14	82	0.34	<1	<1	18	6	<1			0.22	0.021	
SS3	8/01/2014		Cloudy, 0.89 m		13.5	6.1	87	0.26	<1	<1	18	7	<1			0.17	0.023	
SS3	12/02/2014		Cloudy, 1.09m		16.2	6.23	70	0.31	<1	<1	18	6	<1			0.28	0.027	
SS3	13/03/2014		Cloudy, 0.82 m		15.1	6.09	99	0.28	<1	<1	19	5	<1			0.29	0.165	
SS3	3/04/2014		Cloudy, 0.81 m		14.9	6.05	90	0.35	<1	<1	18	4	<1			0.32	0.144	
SS3	22/10/2014			Clear	14.55	5.85	30	0.26	<1	<1	13	5	<1	<1		0.19	0.098	
SS3	15/04/2015			Cloudy	13.8	6.19	98	0.17	<1	<1	18	5	<1	<1		0.11	0.018	
SS3	11/05/2015			Cloudy	11	6.19	90	0.2	<1	<1	20	4	<1	<1		0.15	0.024	
SS3	15/06/2015			Clear	10.4	5.53	44	0.04	<1	<1	5	5	<1	<1		0.37	0.021	
SS3	21/07/2015			Cloudy	8.4	6.73	96	0.13	<1	<1	18	5	<1	<1		0.08	0.014	
SS3	13/08/2015			Clear	8.5	5.69	47	0.03	<1	<1	6	4	<1	<1		0.38	0.033	
SS3	18/09/2015			Clear	8.7	5.46	46	0.02	<1	<1	6	6	<1	<1		0.33	0.017	
SS3	14/10/2015			Cloudy	10.6	7.06	64	0.13	<1	<1	15	5	<1	<1		0.08	<0.005	
SS3	16/11/2015			Cloudy	11.8	6.1	89	0.1	<1	<1	20	6	<1	<1		0.12	<0.005	
SS3	14/12/2015			Clear	14.3	5.46	61	0.04	<1	<1	8	6	1	2		1.14	0.036	
SS3	8/01/2016			Clear	14	5.29	55	0.05	<1	<1	7	6	<1	1		1.99	0.011	
SS3	8/02/2016			Clear	14.8	5.54	58.1	0.05	<1	<1	8	5	<1	1		2.44	0.019	
SS3	10/03/2016			Cloudy	15.2	6.05	91	0.18	<1	<1	17	5	<1	<1		0.25	<0.005	
SS3	14/04/2016			Cloudy	13.2	6.01	92	0.51	<1	<1	19	4	<1	<1	<0.001	0.19	<0.005	<0.05
SS3	12/05/2016			Clear	11.8	5.49	51	0.04	<1	<1	7	5	<1	2		0.87	0.007	
SS3	23/06/2016			Cloudy	8.7	6.09	81	0.2	<1	<1	14	5	<1	<1		0.12	0.016	
SS3	11/07/2016			Cloudy	9.9	5.47	45	0.29	<1	<1	13	5	<1	2		0.2	0.008	
SS3	11/08/2016			Clear	9	5.07	48	0.04	<1	<1	6	4	<1	<1		0.38	0.009	
SS3	14/09/2016			Clear	9.3	6.06	65	0.21	<1	<1	12	5	<1	3		0.1	0.007	
SS3	17/10/2016			Clear	8.7	6.14	63	0.2	<1	<1	14	5	<1	2		0.12	0.01	
SS3	14/11/2016			Clear	12	5.42	53	0.02	<1	<1	7	4	<1	<1		2.84	0.009	
SS3	8/12/2016			cloudy	14.2	5.7	80	0.28	<1	<1	16	7	2	3		0.2	0.017	
SS3	5/01/2017			Cloudy	15.1	5.8	75	0.18	<1	<1	13	4	<1	4		0.18	0.008	
SS3	15/02/2017			Cloudy	15.6	5.53	51	0.06	<1	<1	8	5	<1	<1		1.99	0.019	
SS3	16/03/2017			Cloudy	15.6	5.79	62	0.3	<1	<1	17	4	<1	<1		0.31	<0.005	
SS3	28/04/2017			Cloudy	11.7	6.37	90	0.08	<1	<1	18	4	<1	<1		0.18	0.026	
SS3	17/05/2017			Cloudy	11.3	6.39	30	0.04	<1	<1	2	4	<1	5		0.25	0.011	
SS3	8/06/2017			Cloudy	7.9	6.72	63	0.17	<1	<1	12	8	<1	<1			0.005	
SS3	19/07/2017			Clear	8	7.9	30	0.03	<1	<1	3	5	<1	3		0.07	<0.005	
SS3	18/08/2017			Cloudy	7.2	6.6	52	0.15	<1	<1	11	8	<1	4		0.12	0.007	
SS3	28/09/2017			Cloudy	5.6	6.4	61	0.07	<1	<1	10	5	<1	<1		0.05	0.007	
SS3	25/10/2017			Clear	13	7.9	45	0.06	<1	<1	3	4	<1	8		0.12	<0.005	

location I	Date of Sample	Comments	omments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
SS3	8/11/2017			Cloudy	9.4	6.2	54	0.14	<1	<1	9	6	<1	1		0.18	0.017	
SS3	11/12/2017			Slightly Cloudy	13.7	7	61	0.17	<1	<1	3	7	<1			0.39	<0.005	
SS3	6/06/2018			Clear	6.3	4.7	40	0.06	<1	<1	6	6	<1	<1		0.14	0.005	
SS3	25/10/2018			Cloudy	10	4.8	128	0.08	<1	2	18	9	1	26	0.046	0.07	0.067	<0.05
SS3	3/01/2019			Cloudy	14.3	5.7	107	0.11	<1	<1	17	6	<1	29	0.012	0.1	0.033	<0.05
SS3	5/02/2019			Cloudy	22.2	5.5	91	0.26	<1	<1	14	6	<1	20	0.012	0.29	0.032	<0.05
SS3	6/03/2019			Cloudy	13.2	6.5	36	0.04	<1	<1	9	8	1	8	0.016	0.81	0.084	<0.05
SS4	22/02/2011		Cloudy		20.2	6.07	63	0.46	<1	<1	4	7	<1	<1		11.7	0.099	
SS4	23/03/2011		Cloudy		19.3	6.05	86	0.38	<1	<1	5	5	<1	<1		14.4	0.082	
SS4	23/03/2011		Cloudy		19.3	6.05	86	0.38	<1	<1	5	5	<1	<1		14.4	0.082	
SS4	20/04/2011		Cloudy, brown		12.3	5.91	41	0.14	<1	<1	4	8	<1	<1		4.29	0.066	
SS4	20/04/2011		Cloudy, brown		12.3	5.91	41	0.14	<1	<1	4	8	<1	<1		4.29	0.066	
SS4	18/05/2011		Cloudy		10.6	5.72	35	0.16	<1	<1	4	8	<1	1		3.61	0.098	
SS4	18/05/2011		Cloudy		10.6	5.72	35	0.16	<1	<1	4	8	<1	1		3.61	0.098	
SS4	16/06/2011		Cloudy		10.4	5.74	56	3.04	<1	<1	3	6	<1	1		8.05	0.221	
SS4	16/06/2011		Cloudy		10.4	5.74	56	3.04	<1	<1	3	6	<1	1		8.05	0.221	
SS4	13/07/2011		Cloudy		12.4	5.76	32	0.27	<1	<1	3	7	<1	<1		5.05	0.116	
SS4	13/07/2011		Cloudy		12.4	5.76	32	0.27	<1	<1	3	7	<1	<1		5.05	0.116	
SS4	24/08/2011		Cloudy		12	5.66	47	0.72	<1	<1	4	7	<1	<1		3.74	0.095	
SS4	24/08/2011		Cloudy		12	5.66	47	0.72	<1	<1	4	7	<1	<1		3.74	0.095	
SS4	29/09/2011		Slightly cloudy		9.5	5.32	43	0.18	<1	<1	4	7	<1	<1		7.98	0.074	
SS4	29/09/2011		Slightly cloudy		9.5	5.32	43	0.18	<1	<1	4	7	<1	<1		7.98	0.074	
SS4	17/10/2011		Cloudy		10.1	5.63	78	3.27	<1	<1	4	8	<1	<1		7.66	0.137	
SS4	17/10/2011		Cloudy		10.1	5.63	78	3.27	<1	<1	4	8	<1	<1		7.66	0.137	
SS4	21/11/2011		Cloudy		13.7	6.15	63	0.45	<1	<1	4	7	<1	<1		11.5	0.144	
SS4	21/11/2011		Cloudy		13.7	6.15	63	0.45	<1	<1	4	7	<1	<1		11.5	0.144	
SS4	14/12/2011		Cloudy		12.7	6.21	64	0.26	<1	<1	4	8	<1	<1		7.91	0.094	
SS4	14/12/2011		Cloudy		12.7	6.21	64	0.26	<1	<1	4	8	<1	<1		7.91	0.094	
SS4	17/01/2012		Cloudy		13.7	5.58	61	11.1	<1	<1	4	6	<1	<1		9.16	0.091	
SS4	28/02/2012		Cloudy		13.3	6.07	65	0.3	<1	<1	4	7	<1	<1		9.37	0.03	
SS4	6/03/2012		Cloudy		13.9	5.23	47	0.2	<1	<1	5	7	<1	<1		7.84	0.06	
SS4	17/04/2012		Brown, cloudy		12.7	5.66	53	0.31	<1	<1	4	7	<1	<1		7.22	0.059	
SS4	15/05/2012		Brown, cloudy		10.6	5.95	50	2.4	<1	<1	4	7	<1	<1		5.86	0.068	
SS4	12/06/2012		Brown, cloudy		8.4	5.64	40	0.34	<1	<1	4	7	<1	<1		3.19	0.105	
SS4	12/07/2012		Slightly cloudy - 70cm			5.82	28	0.11	<1	<1	3	7	<1			1.47	0.047	
SS4	21/08/2012		Cloudy brown 78cm			5.31	27	0.37	<1		4	7	<1			2.64	0.049	
SS4	17/09/2012		Cloudy, 69 cm		12.5	5.92	52	0.2	<1	<1	4	10	<1			6.26	0.072	
SS4	17/10/2012		Slightly cloudy, 0.85 m		11.9	6.04	62	0.21	<1	<1	4	9	<1			5.33	0.056	
SS4	12/11/2012		Cloudy, 0.86 m		13.5	5.97	70	0.75	<1	<1	4	8	<1			10.9	0.079	
SS4	10/12/2012		Cloudy, brown, 0.78 m		12	5.96	75	0.49	<1	<1	4	8	<1			11.2	0.077	
SS4	14/01/2013		Cloudy, 0.89 m		15	6.14	82	0.18	<1	<1	4	8	<1			12.3	0.054	
SS4	12/02/2013		Cloudy, 0.82 m		14.5	6.14	86	1.12	<1	<1	6	8	<1			14.3	0.072	
SS4	11/03/2013		Cloudy, 0.86 m		15.2	6.17	85	0.09	<1	<1	5	7	<1			10.7	0.031	
SS4	15/04/2013		Cloudy, 0.81		13.5	6.04	83	0.16	<1	<1	5	6	<1			11.2	0.031	
SS4	15/05/2013		Cloudy, 0.86 m			5.75	55	0.29	<1	<1	5	7	<1			5.68	0.054	
SS4	12/06/2013		Brown, cloudy, 0.77 m		9.6	4.5	35	0.06	<1	<1	5	7	<1			1.18	0.03	
SS4	9/07/2013		Cloudy, 0.79 m			5.49	34	0.18	<1	<1	9	6	<1			1.99	0.034	
SS4	5/08/2013		Cloudy, 0.78 m		9	5.68	35	0.12	<1	<1	4	6	<1			1.38	0.061	
SS4	10/09/2013		Brown, cloudy, 0.82 m		10.5	5.54	38	0.03	<1	<1	4	7	<1			2.16	0.052	
SS4	10/10/2013		Cloudy, 0.86 m		11.8	5.5	43	0.07	<1	<1	4	6	<1			3.62	0.063	
SS4	11/11/2013		Brown, cloudy, 0.74 m		10.7	5.72	44	0.07	<1	<1	3	7	<1			4.92	0.044	
SS4	10/12/2013		Brown, 0.87m		13.2	5.7	46	0.15	<1	<1	4	7	<1			4	0.051	
SS4	8/01/2014		Brown, cloudy, 0.84 m		12.7	5.9	48	0.11	<1	<1	5	7	<1			4.37	0.034	
SS4	12/02/2014		Cloudy, 1.03m		16.1	5.99	47	0.17	<1	<1	7	6	<1			6.46	0.054	
SS4	13/03/2014		Cloudy, 0.80 m		14.9	5.37	65	0.1	<1	<1	5	5	<1			5.36	0.143	
SS4	3/04/2014		Cloudy, 0.79 m		14.7	5.7	62	0.09	<1	<1	5	5	<1			6.32	0.197	
SS4	22/10/2014			Clear	15.2	4.88	<10	0.08	<1	<1	4	8	<1	<1		0.88	0.232	
SS4	15/04/2015			Cloudy	13.4	5.54	54	0.07	<1	<1	4	6	<1	<1		4.28	0.034	
SS4	11/05/2015			Cloudy	10.7	5.15	34	0.07	<1	<1	4	5	<1	<1		0.67	0.03	
SS4	15/06/2015			Cloudy	9.1	5.68	43	0.1	<1	<1	3	5	<1	<1		0.42	0.02	
SS4	21/07/2015			Clear	9	5.28	33	0.18	<1	<1	3	4	<1	1		0.11	0.021	
SS4	13/08/2015			Cloudy	7	5.17	31	0.1	<1	<1	4	4	<1	<1		0.23	0.025	
SS4	18/09/2015			Slightly Cloudy	8.6	4.98	32	0.07	<1	<1	4	6	<1	<1		0.08	0.014	
SS4	14/10/2015			Cloudy	10.7	5.01	23	0.07	<1	<1	3	6	<1	<1		0.27	0.019	
SS4	16/11/2015			Slightly Cloudy	12	5.06	37	0.06	<1	<1	7	6	<1	<1		0.4	0.028	
SS4	14/12/2015			Clear	13.4	4.62	37	0.1	<1	<1	3	7	<1	<1		0.22	0.022	

location I	Date of Sample	Comments	Comments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
SS4	8/01/2016			Cloudy	15.4	4.69	38	0.04	<1	<1	3	5	<1	2		1.92	0.01	
SS4	8/02/2016			Slightly Cloudy	15.8	5.21	37.8	0.07	<1	<1	5	7	<1	<1		0.43	0.017	
SS4	10/03/2016			Cloudy	14.9	5.18	43	0.06	<1	<1	4	7	<1	<1		1.11	0.018	
SS4	14/04/2016			Cloudy	13	5.28	40	0.2	<1	<1	5	6	<1	<1	0.003	0.16	0.013	<0.05
SS4	12/05/2016			Cloudy	11.1	5.01	35	0.05	<1	<1	4	5	<1	<1		0.3	0.008	
SS4	23/06/2016			Cloudy	8.8	5.08	36	0.13	<1	<1	4	5	<1	<1		0.18	0.01	
SS4	11/07/2016			Cloudy	9	5.21	31	0.11	<1	<1	4	4	<1	4		0.22	0.009	
SS4	11/08/2016			Slightly Cloudy	8.3	4.62	34	0.05	<1	<1	4	4	<1	<1		0.11	0.01	
SS4	14/09/2016			Clear	9.7	5	32	0.08	<1	<1	3	5	<1	<1		0.25	0.023	
SS4	17/10/2016			Slightly Cloudy	9	4.97	29	0.08	<1	<1	4	5	<1	<1		0.18	0.023	
SS4	14/11/2016			Slightly Cloudy	11.8	4.93	33	0.06	<1	<1	4	5	<1	<1		0.27	0.012	
SS4	8/12/2016			cloudy	14.9	4.74	37	0.1	<1	<1	5	6	<1	<1		0.47	0.015	
SS4	5/01/2017			Cloudy	13.3	4.66	39	0.06	<1	<1	4	5	<1	2		1.18	0.019	
SS4	15/02/2017			Cloudy	16.5	5.15	36	0.06	<1	<1	4	6	<1	2		1.04	0.013	
SS4	16/03/2017			Clear	14.4	5.71	177	0.07	<1	<1	4	4	<1	12		0.49	<0.005	
SS4	28/04/2017			Cloudy	11.7	6.08	70	0.08	1	<1	10	11	<1	<1		0.18	0.007	
SS4	17/05/2017			Cloudy	10.8	5.6	36	0.15	<1	<1	3	6	<1	1		1.08	0.012	
SS4	8/06/2017			Cloudy	9	5.64	41	0.08	<1	<1	4	6	<1	<1			0.021	
SS4	19/07/2017			Cloudy	7	7	47	0.1	<1	<1	4	6	<1	<1		2.43	<0.005	
SS4	18/08/2017			Cloudy	7.1	5.3	39	0.09	<1	<1	5	8	<1	<1		0.08	0.03	
SS4	28/09/2017			Slightly Cloudy	6.8	5.1	41	0.07	<1	<1	4	5	<1	<1		0.22	0.016	
SS4	25/10/2017			Clear	10.4	5.8	35	0.12	<1	<1	5	10	<1	<1		0.27	0.008	
SS4	8/11/2017			Slightly Cloudy	10.4	5	33	0.09	<1	<1	3	6	<1	<1		0.48	0.024	
SS4	11/12/2017	ble amount to complete all analysis		Clear	14.1	6.9	60	0.2	<1	<1	4		<1			0.43	<0.005	
SS4	17/01/2018			Cloudy	16.1	5.8	47	0.04	<1	<1	3	5	<1	<1		8.78	0.013	
SS4	15/02/2018			Cloudy	14.9	5.8	50	0.12	<1	<1	4	8	<1	<1		1.2	0.014	
SS4	6/06/2018			Clear	5.4	4.5	33	0.06	<1	<1	5	6	<1	<1		0.13	<0.005	
SS4	19/07/2018			Cloudy	4.5	6.9	40	0.06	<1	<1	5	7	<1	1		<0.05	0.064	
SS4	22/08/2018			Cloudy	4.2	5	32	0.07	<1	<1	3	6	<1	1		0.78	0.012	
SS4	19/09/2018			Cloudy	7.2	6.4	48	0.15	<1	<1	3	6	<1	<1	0.003	0.08	0.014	<0.05
SS4	25/10/2018			Cloudy	13.1	3.1	22	0.03	<1	<1	5	4	<1	<1	0.005	0.25	0.02	<0.05
SS4	22/11/2018			Cloudy	10	4.8	48	0.16	<1	<1	4	6	<1	4	0.01	0.08	0.047	<0.05
SS4	3/01/2019			Cloudy	13.9	5.5	43	0.08	<1	<1	5	7	1	2	0.008	2.23	0.081	<0.05
SS4	5/02/2019			slightly cloudy	14.4	5.5	55	0.28	<1	<1	5	5	<1	2	0.005	4.87	0.035	<0.05
SS4	6/03/2019			Cloudy	12.8	5.3	45	0.06	<1	<1	4	6	<1	<1	0.004	1.98	0.036	<0.05
SS4	10/04/2019			Slightly Cloudy	10.8	5.7	44	0.06	<1	<1	4	6	<1	<1	0.005	4.03	0.042	<0.05
SS4	30/05/2019			Clear	8.6	4.6	39											
SS5	22/02/2011		Cloudy		14.8	5.82	41	0.35	<1	<1	3	4	<1	2		6.05	0.122	
SS5	23/03/2011		Cloudy		16.4	5.57	39	0.24	<1	<1	3	2	<1	2		6.67	0.07	
SS5	23/03/2011		Cloudy		16.4	5.57	39	0.24	<1	<1	3	2	<1	2		6.67	0.07	
SS5	20/04/2011		Cloudy, brown		12.4	5.41	24	0.07	<1	<1	3	5	<1	2		1.04	0.056	
SS5	20/04/2011		Cloudy, brown		12.4	5.41	24	0.07	<1	<1	3	5	<1	2		1.04	0.056	
SS5	18/05/2011		Cloudy		10.6	5.34	23	0.12	<1	<1	4	9	<1	3		0.66	0.086	
SS5	18/05/2011		Cloudy		10.6	5.34	23	0.12	<1	<1	4	9	<1	3		0.66	0.086	
SS5	16/06/2011		Cloudy		9.7	5.13	28	1.03	<1	<1	3	5	<1	2		1.85	0.231	
SS5	16/06/2011		Cloudy		9.7	5.13	28	1.03	<1	<1	3	5	<1	2		1.85	0.231	
SS5	13/07/2011		Cloudy		8.5	5.35	17	0.15	<1	<1	3	4	<1	2		0.72	0.132	
SS5	13/07/2011		Cloudy		8.5	5.35	17	0.15	<1	<1	3	4	<1	2		0.72	0.132	
SS5	24/08/2011		Cloudy		9.8	4.86	26	0.54	<1	<1	3	4	<1	1		0.95	0.057	
SS5	24/08/2011		Cloudy		9.8	4.86	26	0.54	<1	<1	3	4	<1	1		0.95	0.057	
SS5	29/09/2011		Brown, cloudy		9.8	4.81	32	0.31	<1	<1	5	5	<1	5		0.39	0.065	
SS5	29/09/2011		Brown, cloudy		9.8	4.81	32	0.31	<1	<1	5	5	<1	5		0.39	0.065	
SS5	17/10/2011		Cloudy		10.1	5.1	29	1.56	<1	<1	3	5	<1	2		0.98	0.115	
SS5	17/10/2011		Cloudy		10.1	5.1	29	1.56	<1	<1	3	5	<1	2		0.98	0.115	
SS5	21/11/2011		Cloudy		13.2	5.54	30	0.19	<1	<1	4	5	<1	<1		2.98	0.128	
SS5	21/11/2011		Cloudy		13.2	5.54	30	0.19	<1	<1	4	5	<1	<1		2.98	0.128	
SS5	14/12/2011		Cloudy		12.6	5.5	29	0.12	<1	<1	3	5	<1	2		2.16	0.085	
SS5	14/12/2011		Cloudy		12.6	5.5	29	0.12	<1	<1	3	5	<1	2		2.16	0.085	
SS5	17/01/2012		Brown, cloudy		13.6	4.8	34	0.18	<1	<1	3	6	<1	2		3.19	0.063	
SS5	28/02/2012		Brown, cloudy		15.4	5.07	33	0.18	<1	<1	4	4	<1	<1		3.98	0.032	
SS5	6/03/2012		Cloudy		14.1	4.49	29	0.17	<1	<1	3	4	<1	2		4.75	0.041	
SS5	17/04/2012		Brown, cloudy		13	5.18	33	0.21	<1	<1	3	4	<1	2		4.05	0.058	
SS5	15/05/2012		Brown, cloudy		10.3	5.45	22	0.93	<1	<1	2	4	<1	2		1.11	0.073	
SS5	12/06/2012		Brown, cloudy		8.9	5.25	25	0.25	<1	<1	2	4	<1	2		0.59	0.116	
SS5	12/07/2012		Cloudy - 54cm			5.55	20	0.19	<1	<1	2	4	<1			0.39	0.047	
SS5	21/08/2012		Cloudy brown 69cm			5.06	21	0.26	<1		3	3	<1			0.42	0.082	

location I	Date of Sample	Comments	omments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium m	Sodium mg/L	Chloride mg/L	Potassium mg	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
SS5	17/09/2012		Cloudy, 78cm		11.6	5.39	23	0.23	<1	<1	3	5	<1			0.37	0.056	
SS5	17/10/2012		Cloudy, 0.65 m		12.1	5.56	31	0.15	<1	<1	3	5	<1			0.75	0.067	
SS5	12/11/2012		Cloudy brown, 0.75 m		14.2	5.92	60	0.21	<1	<1	2	5	<1			7.53	0.036	
SS5	10/12/2012		Cloudy, brown, 0.87 m		12	5.56	51	0.39	<1	<1	6	5	<1			5.45	0.078	
SS5	14/01/2013		Cloudy, 1.16 m		16.5	6.24	66	0.12	<1	<1	4	4	<1			6	0.054	
SS5	12/02/2013		Cloudy, 0.62 m		15	5.7	45	1.55	<1	<1	4	4	<1			6.06	0.067	
SS5	11/03/2013		Cloudy, 0.62 m		16.2	5.95	43	0.35	<1	<1	4	3	<1			3.93	0.037	
SS5	15/04/2013		Cloudy, 0.75		13.8	5.48	29	0.04	<1	<1	4	4	<1			1.05	0.042	
SS5	15/05/2013		Brown, cloudy, 0.77 m			5.23	29	0.89	<1	<1	3	4	<1			1.34	0.067	
SS5	12/06/2013		Brown, cloudy, 0.74 m		10.3	4.75	24	0.04	<1	<1	3	4	<1			0.08	0.041	
SS5	9/07/2013		Cloudy, 0.75 m			5.51	21	0.13	<1	<1	7	3	<1			0.37	0.034	
SS5	5/08/2013		Cloudy, 0.70 m		9.1	5.71	26	0.07	<1	<1	4	5	<1			0.25	0.07	
SS5	10/09/2013		Brown, cloudy, 0.82 m		10	5.16	24	0.06	<1	<1	3	4	<1			0.13	0.073	
SS5	10/10/2013		Cloudy, 0.89 m		12.8	4.99	32	0.07	<1	<1	3	4	<1			0.43	0.075	
SS5	11/11/2013		Brown, cloudy, 0.67 m		11.1	5.23	25	0.06	<1	<1	2	4	<1			0.72	0.034	
SS5	10/12/2013		Brown, 0.89m		13.5	5.3	33	0.08	<1	<1	3	4	<1			0.13	0.054	
SS5	8/01/2014		Brown, cloudy, 1.12 m		12.9	5.93	34	0.04	<1	<1	4	4	<1			1.38	0.101	
SS5	12/02/2014		Cloudy, 1.30m, insufficient sample		17.8	6.52	66											
SS5	13/03/2014		Cloudy, 0.78 m		15.2	5.26	43	0.05	<1	<1	4	3	<1			0.92	0.167	
SS5	3/04/2014		Cloudy, 0.65 m		15.4	5.25	35	0.04	<1	<1	3	3	<1			0.59	0.154	
SS5	22/10/2014			Clear	14.6	4.73	<10	0.12	<1	<1	2	4	<1	2		0.13	0.129	
SS5	15/04/2015			Cloudy	14	5.01	35	0.08	<1	<1	3	4	<1	2		0.29	0.038	
SS5	11/05/2015			Slightly Cloudy	11.1	4.94	28	0.14	<1	<1	3	2	<1	2		0.12	0.027	
SS5	15/06/2015			Slightly Cloudy	9.9	4.88	31	0.2	<1	<1	2	3	<1	2		0.17	0.02	
SS5	21/07/2015			Cloudy	8.1	8.83	34	0.04	<1	<1	4	6	<1	<1		0.35	0.03	
SS5	13/08/2015			Cloudy	7.8	5.07	32	0.24	<1	<1	3	3	<1	1		0.23	0.03	
SS5	18/09/2015			Clear	8.6	4.8	34	0.23	<1	<1	3	5	<1	1		0.17	0.015	
SS5	14/10/2015			Slightly Cloudy	10.9	4.93	27	0.15	<1	<1	2	5	<1	1		0.56	0.019	
SS5	16/11/2015			Slightly Cloudy	13.1	4.73	38	0.18	<1	<1	5	5	<1	<1		0.34	0.024	
SS5	14/12/2015			Cloudy	28	4.82	37	0.07	<1	<1	3	5	<1	1		1.26	0.022	
SS5	8/01/2016			Cloudy	14.2	4.31	35	0.08	<1	<1	4	6	<1	<1		0.28	0.013	
SS5	8/02/2016			Slightly Cloudy	17.4	4.98	38.8	0.1	<1	<1	3	4	<1	2		1	0.017	
SS5	10/03/2016			Cloudy	15.7	5.27	38	0.05	<1	<1	3	4	<1	<1		1.6	0.01	
SS5	14/04/2016			Cloudy	14.4	5.2	36	0.13	<1	<1	3	4	<1	1	0.008	0.08	0.012	<0.05
SS5	12/05/2016			Cloudy	12.2	5.05	40	0.06	<1	<1	4	4	<1	2		0.22	0.015	
SS5	23/06/2016			Cloudy	9.8	5	35	0.13	<1	<1	3	4	<1	1		0.07	0.008	
SS5	11/07/2016			Cloudy	9.7	4.95	31	0.14	<1	<1	3	4	<1	2		0.08	0.008	
SS5	11/08/2016			Cloudy	8.7	4.39	32	0.11	<1	<1	3	2	<1	1		0.14	0.011	
SS5	14/09/2016			Slightly cloudy	10.2	4.88	28	0.12	<1	<1	2	3	<1	2		0.14	0.017	
SS5	17/10/2016			Clear	9.6	4.88	27	0.1	<1	<1	3	3	<1	3		0.13	0.014	
SS5	14/11/2016			Slightly Cloudy	12.7	4.9	29	0.08	<1	<1	3	3	<1	2		0.28	0.007	
SS5	8/12/2016			cloudy	14.5	4.32	30	0.08	<1	<1	3	3	<1	1		0.55	0.015	
SS5	5/01/2017			Cloudy	14	4.73	39	0.05	<1	<1	2	2	<1	8		0.78	0.023	
SS5	15/02/2017			Cloudy	16.7	5.22	31	0.03	<1	<1	3	3	<1	<1		1.91	0.006	
SS5	16/03/2017			Slightly Cloudy	14.1	5.4	190	0.16	<1	<1	11	6	<1	<1		2.23	0.029	
SS5	28/04/2017			Cloudy	12	6.32	76	0.12	<1	<1	10	11	<1	<1		0.2	0.028	
SS5	17/05/2017			Cloudy	9.9	5.68	32	0.05	<1	<1	4	7	<1	<1		1	0.015	
SS5	8/06/2017			Cloudy	8.8	5.22	30	0.1	<1	<1	4	6	<1	<1			0.016	
SS5	19/07/2017			Clear	7.3	7.7	21	0.03	<1	<1	3	4	<1	2		0.07	<0.005	
SS5	18/08/2017			Cloudy	8	5.3	32	0.09	<1	<1	3	5	<1	1		<0.05	0.015	
SS5	28/09/2017			Slightly Cloudy	7.5	5.1	41	0.09	<1	<1	3	4	<1	<1		0.08	0.016	
SS5	25/10/2017			Clear	13.8	5.5	34	0.11	<1	<1	4	7	<1	<1		0.27	0.007	
SS5	8/11/2017			Cloudy	11.5	4.9	35	<0.01	<1	<1	<1	4	<1	1		<0.05	<0.005	
SS5	11/12/2017			Clear	14	7.5	63	0.12	<1	<1	3	7	<1			0.32	<0.005	
SS5	17/01/2018			Cloudy	12.9	5.8	43	0.11	<1	<1	4	7	<1	<1		6.39	0.02	
SS5	15/02/2018			Cloudy	15.1	5.7	46	0.04	<1	<1	2	5	<1	7		1	0.012	
SS5	14/03/2018			Slightly Cloudy	15.1	5.2	29	0.11	<1	<1	4	2	1	3		0.44	0.011	
SS5	11/04/2018			Slightly Cloudy	12.7	4.8	27	0.08	<1	<1	3	6	<1	<1		0.36	<0.005	
SS5	9/05/2018			Cloudy	18.8	5.7	41	0.03	<1	<1	4	8	<1	3		3.17	0.008	
SS5	6/06/2018			Clear	7	6	27	0.08	<1	<1	5	6	<1	<1		0.14	<0.005	
SS5	19/07/2018			Cloudy	4.4	6.6	38.97	0.1	<1	<1	5	8	<1	1		<0.05	0.064	
SS5	22/08/2018			Cloudy	5.8	4.6	37	0.15	<1	<1	3	6	<1	<1		<0.05	0.012	
SS5	19/09/2018			Slightly Cloudy	8.4	5.6	50	0.14	<1	<1	3	6	<1	3	0.004	0.08	0.013	<0.05
SS5	25/10/2018			Cloudy	10.5	3.6	83	0.23	<1	<1	4	7	<1	<1	0.006	<0.05	0.025	<0.05
SS5	22/11/2018			Cloudy	10.2	4.9	47	0.15	<1	<1	3	7	<1	<1	0.009	0.08	0.054	<0.05
SS5	3/01/2019			Clear	14.5	4.7	40	0.18	<1	<1	4	8	<1	<1	0.009	0.11	0.034	<0.05

location	Date of Sample	Comments	Comments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium m	Sodium mg/L	Chloride mg/L	Potassium mg	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
SS5	5/02/2019			Cloudy	14.7	4.8	41	0.12	<1	<1	4	6	<1	<1	0.01	0.7	0.038	<0.05
SS5	6/03/2019			Cloudy	13.7	4.9	50	0.17	<1	<1	3	7	<1	<1	0.012	0.31	0.06	<0.05
SS5	10/04/2019			Cloudy	12.7	5.2	36	0.08	<1	<1	3	6	<1	<1	0.01	0.24	0.055	<0.05
SS5	30/05/2019			Clear	9.9	4.3	32											
SSE1	11/03/2013	Cloudy, 2.76 m. Not enough water for analysis			15.2	4.81	36											
SSE2	12/06/2012		Brown, cloudy		7.8	5.54	39	0.12	<1	<1	5	8	<1	1		0.35	0.049	
SSE2	12/07/2012		Cloudy - 55cm			5.92	38	0.06	<1	<1	4	9	<1			0.57	0.058	
SSE2	21/08/2012		Cloudy brown 60cm			5.59	36	0.04	<1		5	9	<1			0.81	0.087	
SSE2	17/09/2012		Slightly cloudy, 76cm		11.5	5.55	45	0.05	<1	<1	6	15	4			0.86	0.075	
SSE2	22/10/2012		Cloudy, 0.83 m		11.9	5.44	49	0.13	<1	<1	8	10	1			0.69	0.089	
SSE2	12/11/2012		Black 1.07 m		15.3	5.67	43	0.07	<1	<1	5	9	<1			1.59	0.075	
SSE2	11/12/2012	loudy, brown, 1.47 m. Not enough sample for analysi			14.8	5.35	46											
SSE2	12/02/2013		Cloudy, 1.11 m		17.2	5.4	42	1.72	<1	<1	6	8	<1			3.17	0.143	
SSE2	11/03/2013		Dark brown, cloudy, 0.94 m		16.1	5.18	38	0.07	<1	<1	5	8	<1			0.36	0.032	
SSE2	15/04/2013	n, 1.42. not enough water to be sent away for additi			14	5.28	40											
SSE2	19/06/2013	ack, cloudy, 0.92 m. Not enough water for extra analy			7.5	5.05	33											
SSE2	9/07/2013		Cloudy, 1.33 m			5.24	32	0.06	<1	<1	10	7	<1			0.08	0.03	
SSE2	6/08/2013	Cloudy, not enough to fill bottles, 1.54 m			9.8	5.32	70											
SSE3	22/02/2011		Cloudy		15.4	5.89	42	0.38	<1	<1	5	7	<1	<1		3.62	0.118	
SSE3	23/03/2011		Cloudy		18.3	5.74	43	0.5	<1	<1	6	7	<1	<1		3.8	0.06	
SSE3	23/03/2011		Cloudy		18.3	5.74	43	0.5	<1	<1	6	7	<1	<1		3.8	0.06	
SSE3	20/04/2011		Cloudy, brown		12.3	6.03	38	0.14	<1	<1	6	6	<1	<1		1.54	0.025	
SSE3	20/04/2011		Cloudy, brown		12.3	6.03	38	0.14	<1	<1	6	6	<1	<1		1.54	0.025	
SSE3	18/05/2011		Cloudy		10.4	5.41	23	0.07	<1	<1	5	6	<1	<1		0.24	0.022	
SSE3	18/05/2011		Cloudy		10.4	5.41	23	0.07	<1	<1	5	6	<1	<1		0.24	0.022	
SSE3	16/06/2011		Cloudy		9	5.82	45	0.18	<1	<1	4	6	<1	<1		0.95	0.066	
SSE3	16/06/2011		Cloudy		9	5.82	45	0.18	<1	<1	4	6	<1	<1		0.95	0.066	
SSE3	13/07/2011		Cloudy		5.7	5.4	20	0.1	<1	<1	4	6	<1	<1		0.72	0.101	
SSE3	13/07/2011		Cloudy		5.7	5.4	20	0.1	<1	<1	4	6	<1	<1		0.72	0.101	
SSE3	24/08/2011		Cloudy		12.8	5.18	27	0.23	<1	<1	4	7	<1	<1		0.31	0.036	
SSE3	24/08/2011		Cloudy		12.8	5.18	27	0.23	<1	<1	4	7	<1	<1		0.31	0.036	
SSE3	29/09/2011		Brown, cloudy		9.5	5.27	37	0.1	<1	<1	4	6	<1	<1		1.77	0.053	
SSE3	29/09/2011		Brown, cloudy		9.5	5.27	37	0.1	<1	<1	4	6	<1	<1		1.77	0.053	
SSE3	17/10/2011		Cloudy		10.2	5.33	34	0.7	<1	<1	4	6	<1	<1		1.36	0.087	
SSE3	17/10/2011		Cloudy		10.2	5.33	34	0.7	<1	<1	4	6	<1	<1		1.36	0.087	
SSE3	21/11/2011		Cloudy		13.1	5.87	36	0.22	<1	<1	4	6	<1	<1		5.47	0.102	
SSE3	21/11/2011		Cloudy		13.1	5.87	36	0.22	<1	<1	4	6	<1	<1		5.47	0.102	
SSE3	14/12/2011		Cloudy		11.7	5.89	47	0.19	<1	<1	3	7	<1	<1		5.99	0.049	
SSE3	14/12/2011		Cloudy		11.7	5.89	47	0.19	<1	<1	3	7	<1	<1		5.99	0.049	
SSE3	17/01/2012		Brown, cloudy		13.9	5.38	49	0.19	<1	<1	4	4	<1	<1		7.33	0.05	
SSE3	28/02/2012		Brown, cloudy		15.5	5.91	55	0.18	<1	<1	4	7	<1	<1		8.19	0.038	
SSE3	6/03/2012		Brown, cloudy		13.3	5.74	51	0.21	<1	<1	4	8	<1	<1		7.26	0.033	
SSE3	17/04/2012		Brown, cloudy		12.5	5.51	48	0.23	<1	<1	4	6	<1	3		9	0.04	
SSE3	15/05/2012		Brown, cloudy		10.3	5.48	29	0.15	<1	<1	4	6	<1	<1		1.16	0.055	
SSE3	12/06/2012		Brown, cloudy		9.3	5.58	25	0.23	<1	<1	3	6	<1	<1		0.92	0.034	
SSE3	12/07/2012		Cloudy - 69cm			5.73	31	0.18	<1	<1	3	6	<1			0.54	0.053	
SSE3	21/08/2012		Cloudy brown 74cm			5.46	23	0.16	<1		3	6	<1			0.76	0.064	
SSE3	17/09/2012		Cloudy, 65cm		10.9	5.63	27	0.14	<1	<1	3	7	<1			1.04	0.051	
SSE3	17/10/2012		Cloudy, 0.88 m		12.5	6.02	52	0.21	<1	<1	4	7	<1			4.63	0.029	
SSE3	12/11/2012		Cloudy, 1.06 m		13	6.25	74	0.2	<1	<1	4	6	<1			10.3	0.031	
SSE3	10/12/2012		Cloudy, brown, 1.23 m		11.8	6.21	80	0.19	<1	<1	4	6	<1			11.4	0.046	
SSE3	14/01/2013		Cloudy, brown 1.85 m		13.5	5.4	48	0.86	<1	<1	4	5	<1			6.67	0.054	
SSE3	12/02/2013		Cloudy, 1.01 m		15.6	6.05	70	0.09	<1	<1	6	5	<1			5.96	0.056	
SSE3	11/03/2013		Cloudy, 0.71 m		15.2	6.34	93	0.06	<1	<1	5	5	<1			13	0.032	
SSE3	15/04/2013		Cloudy, 1.26		14.1	6.29	102	0.07	<1	<1	5	4	<1			14.4	0.048	
SSE3	15/05/2013	nge, cloudy, 1.68 m, not enoug bottles for all paraemters				5.59	42	0.17								0.75	0.027	
SSE3	19/06/2013	Cloudy, 1.85 m. Not enough water for extra anlysis			9.8	5.21	26											
SSE3	9/07/2013		Slightly cloudy, 1.40 m			5.33	31	0.16	<1	<1	10	2	<1			0.18	0.038	
SSE3	1/05/2014		Cloudy, 1.81 m		13.1	7.72	35	0.08	<1	<1	6	<1	<1			0.27	0.105	
SSE3	18/05/2015			Cloudy	12.3	5.26	48	0.2	<1	<1	6	2	<1	5		0.23	0.039	
SSE3	27/07/2015			Cloudy	9.4	6.07	41	0.07	<1	<1	7	2	<1	1		0.27	0.026	
SSE3	25/07/2016			Cloudy	11.2	5.48	40	0.84	<1	<1	5	1	<1	6		0.27	<0.005	
SSE3	28/09/2016				12.3	6.88	22											
TG1	15/10/2012		Cloudy brown, 0.48 m		13.8	6.32	43	0.24	3	1	3	6	<1			0.36	0.162	
TG1	12/11/2012		Cloudy, brown, 0.67 m		12.1	5.93	53	0.08	3	1	2	5	<1			0.92	0.07	
TG1	10/12/2012		Brown, cloudy, 0.67 m		12.6	5.21	53	0.17	3	1	3	5	<1			1.98	0.058	

location I	Date of Sample	Comments	Comments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
TG1	14/01/2013	Cloudy, brown, 0.86 m			14	5.87	53	0.65	3	1	3	4	<1			3.82	0.065	
TG1	12/02/2013		Cloudy, 0.43 m		14.8	5.75	51	0.22	3	1	4	6	<1			1.78	0.087	
TG1	11/03/2013	Brown, cloudy, 61.2 m			15.1	5.85	55	0.04	2	<1	4	6	<1			2.07	0.069	
TG1	15/04/2013	Slightly Cloudy, 0.63			14.3	5.68	46	0.04	2	<1	4	4	<1			0.76	0.057	
TG1	15/05/2013	Brown, cloudy, 0.64 m				5.74	40	0.4	2	<1	3	4	<1			1.44	0.064	
TG1	12/06/2013	Brown cloudy, 0.64 m			9.6	4.95	33	0.06	2	<1	3	4	<1			0.16	0.033	
TG1	9/07/2013	Slightly cloudy, 0.62 m				5.74	31	0.18	2	<1	3	4	<1			0.27	0.031	
TG1	5/08/2013	Slightly cloudy, 1.49 m			9.2	5.8	29	0.09	<1	<1	3	4	<1			0.15	0.05	
TG1	10/09/2013	Slightly cloudy, 0.67 m			11.4	5.5	34	0.02	<1	<1	3	5	<1			0.07	0.084	
TG1	10/10/2013		Cloudy, 0.70 m		12.1	5.62	52	0.05	<1	<1	4	7	3			2.59	0.06	
TG1	11/11/2013	Slightly cloudy, 0.78 m			11.2	5.67	39	0.08	<1	<1	3	5	<1			0.9	0.059	
TG1	10/12/2013	Slightly Cloudy, 0.79m			14.6	5.75	42	0.07	<1	<1	4	4	<1			0.2	0.049	
TG1	8/01/2014	Slightly cloudy, 0.92 m			13	5.89	40	0.06	<1	<1	4	5	<1			0.33	0.083	
TG1	12/02/2014	Cloudy, 1.19m, insufficient sample			15.8	5.83	29											
TG1	13/03/2014		Clear, 0.69 m		15.2	5.3	61	0.07	1	<1	5	6	<1			0.06	0.236	
TG1	3/04/2014		Cloudy, 0.58 m		15.4	5.49	55	0.1	<1	<1	5	6	<1			<0.05	0.146	
TG1	15/04/2015			Slightly Cloudy	14.9	5.31	41	0.04	<1	<1	4	5	<1	3		0.09	0.042	
TG1	11/05/2015			Clear	11.2	5.38	35	0.05	<1	<1	3	4	<1	1		0.06	0.033	
TG1	15/06/2015			Clear	10.3	5.31	34	0.04	<1	<1	2	4	<1	1		<0.05	0.027	
TG1	21/07/2015			Slightly Cloudy	9.3	8.56	34	0.03	<1	<1	3	4	<1	1		0.07	0.033	
TG1	13/08/2015			Cloudy	7.7	5.58	41	0.05	<1	<1	3	4	<1	1		0.15	0.033	
TG1	18/09/2015			Clear	10	5.28	36	0.03	<1	<1	3	5	<1	1		0.3	0.024	
TG1	14/10/2015			Clear	11.6	5.42	25	0.03	<1	<1	3	4	<1	1		0.13	0.017	
TG1	16/11/2015			Clear	13	5.1	37	0.03	<1	<1	3	4	<1	<1		0.11	0.019	
TG1	14/12/2015			Clear	15.8	5.43	41	0.02	<1	<1	3	7	<1	1		0.07	0.029	
TG1	8/01/2016			Clear	15	4.95	41	0.03	<1	<1	4	5	<1	3		0.13	0.011	
TG1	8/02/2016			Clear	15.3	4.88	43.5	0.04	<1	<1	4	7	<1	1		0.06	0.015	
TG1	10/03/2016			Clear	16.9	5.26	51	0.04	<1	<1	4	7	<1	1		0.49	0.02	
TG1	14/04/2016			Slightly Cloudy	14.1	5.33	43	0.04	<1	<1	4	5	<1	2	0.036	<0.05	0.033	<0.05
TG1	12/05/2016			Clear	12.6	5.28	38	0.06	<1	<1	3	3	<1	2		<0.05	0.012	
TG1	23/06/2016			Clear	10	5.37	42	0.05	<1	<1	3	6	<1	1		<0.05	0.007	
TG1	11/07/2016			Clear	10.1	5.13	36	0.04	<1	<1	3	5	<1	2		<0.05	0.012	
TG1	11/08/2016			Clear	9	4.75	34	0.05	<1	<1	3	3	<1	1		0.07	0.012	
TG1	14/09/2016			Clear	10.9	5.5	35	0.05	<1	<1	2	5	<1	<1		0.06	0.019	
TG1	17/10/2016			Clear	9.8	5.27	30	0.06	<1	<1	4	5	<1	<1		0.06	0.033	
TG1	14/11/2016			Clear	12.4	5.17	36	0.06	<1	<1	3	4	<1	<1		0.11	0.012	
TG1	8/12/2016			clear	14.6	5.59	40	0.05	<1	<1	4	5	<1	<1		0.1	0.032	
TG1	5/01/2017			Clear	14.9	5.08	44	0.04	<1	<1	3	3	<1	4		0.24	0.02	
TG1	27/02/2017			Clear	18.5	5.4	27	0.06	<1	<1	3	4	<1	2		0.46	<0.005	
TG1	16/03/2017			Cloudy	15.3	5.97	164	0.2	<1	<1	14	24	<1	<1		2.25	0.028	
TG1	17/05/2017			Cloudy	11.8	6.94	25	0.04	<1	<1	3	7	<1	2		1.03	0.013	
TG1	8/06/2017			Cloudy	8.1	7.2	71	0.05	<1	<1	12	9	<1	3			0.022	
TG1	19/07/2017			Cloudy	6.9	6.9	61	0.07	<1	<1	3	6	<1	<1		0.18	0.005	
TG1	18/08/2017			Clear	8.5	5.3	42	0.07	<1	<1	4	7	<1	6		0.1	0.013	
TG1	28/09/2017			Clear	8.1	5.3	35	0.1	<1	<1	4	4	<1	1		0.11	0.026	
TG1	25/10/2017			Slightly Cloudy	12.9	7.8	39	0.06	<1	<1	3	5	<1	9		0.13	<0.005	
TG1	8/11/2017			Slightly Cloudy	11.1	5.7	49	0.13	<1	<1	3	6	<1	2		0.5	0.021	
TG1	11/12/2017			Slightly Cloudy	14.3	7.6	29	0.06	<1	<1	1	4	<1			0.14	<0.005	
TG1	17/01/2018			Slightly Cloudy	16.2	6.2	52	0.32	<1	<1	5	5	<1	<1		1.87	0.009	
TG1	15/02/2018			Slightly Cloudy	15.8	5.6	55	0.46	<1	<1	4	6	<1	<1		0.22	0.019	
TG1	14/03/2018			Clear	13.6	5.1	29	0.12	<1	<1	3	3	<1	<1		0.45	0.006	
TG1	11/04/2018			Slightly Cloudy	12	4.6	41	0.1	<1	<1	3	6	<1	<1		0.3	<0.005	
TG1	9/05/2018			Cloudy	19.2	5.5	40	0.02	<1	<1	4	7	<1	2		0.82	0.011	
TG1	6/06/2018			Slightly cloudy	5.9	5.9	34	0.06	<1	<1	4	6	<1	<1		0.14	<0.005	
TG1	19/07/2018			Cloudy	5.4	6	34	0.06	<1	<1	5	5	<1	2		<0.05	0.05	
TG1	22/08/2018			Cloudy	6	4.2	37	0.07	<1	<1	3	5	<1	6		<0.05	0.013	
TG1	19/09/2018			Cloudy	7.1	6.1	54	0.14	<1	<1	3	5	<1	1	0.003	0.07	0.013	<0.05
TG1	25/10/2018			Slightly Cloudy	10.2	4.5	51	0.07	<1	<1	4	8	<1	<1	0.017	0.21	0.036	<0.05
TG1	22/11/2018			Cloudy	10.6	4.6	105	0.1	<1	<1	4	11	<1	2	0.046	1.85	0.017	<0.05
TG1	3/01/2019			Clear	15.8	5.3	48	0.06	<1	<1	5	9	1	2	0.024	0.42	0.049	<0.05
TG1	6/03/2019			Clear	15.6	5.5	42	0.09	<1	<1	4	7	<1	<1	0.034	0.22	0.092	<0.05
TG1	10/04/2019			Slightly Cloudy	13	5.1	46	0.05	<1	<1	4	7	<1	2	0.028	0.19	0.07	<0.05
TG1	30/05/2019			Clear	10.5	4.7	69											
TG2	19/11/2018			Cloudy	11	4.9	31	0.12	<1	<1	3	6	<1	<1	0.01	<0.05	0.011	<0.05
TG2	20/12/2018	iificent water sample		Cloudy	13.2	5.1	50	0.35	6	<1	6	7	<1	2	0.094	0.28	0.014	<0.05
TG2	14/01/2019			Cloudy	13.9	6	105	0.16	6	1	5	10	<1	2	0.095	0.08	0.007	<0.05

location I	Date of Sample	Comments	Comments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium m	Sodium mg/L	Chloride mg/L	Potassium mg	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
TS1	15/04/2015			Dry			0											
TS1	11/05/2015			Cloudy	11.9	5.43	26	0.03	<1	<1	3	2	<1	<1		<0.05	0.02	
TS1	15/06/2015			Cloudy	11.5	5.34	30	0.03	<1	<1	2	3	<1	1		<0.05	0.018	
TS1	21/07/2015			Cloudy	11.2	7.37	32	0.03	<1	<1	4	4	<1	<1		<0.05	0.023	
TS1	13/08/2015			Cloudy, Black	10.1	5.54	34	0.05	<1	<1	4	3	<1	1		<0.05	0.01	
TS1	18/09/2015			Cloudy	10.2	5.29	32	0.02	<1	<1	3	4	<1	3		<0.05	0.012	
TS1	14/10/2015			Cloudy, Black	10.7	5.35	21	0.01	<1	<1	2	3	<1	<1		<0.05	<0.005	
TS1	16/11/2015			Cloudy Black	11.8	5.31	28.4	<0.01	<1	<1	3	3	<1	<1		<0.05	0.006	
TS1	14/12/2015			Cloudy	12.1	5.86	34	0.03	<1	<1	2	5	<1	<1		0.08	0.034	
TS1	11/07/2016			Cloudy	11.8	2.28	22	0.03	<1	<1	2	3	<1	<1		<0.05	0.007	
TS1	11/08/2016			Cloudy	10.3	4.45	31	0.02	<1	<1	3	2	<1	<1		<0.05	0.005	
TS1	14/09/2016			Cloudy	11	5.18	24	0.03	<1	<1	2	3	<1	<1		<0.05	0.012	
TS1	17/10/2016			Cloudy	9.3	5.62	22	0.03	<1	<1	3	4	<1	<1		<0.05	0.008	
TS1	14/11/2016			Cloudy	11	5.51	32	0.03	<1	<1	3	4	<1	<1		<0.05	0.005	
TS1	8/12/2016			cloudy	11.2	4.91	37	0.04	<1	<1	4	5	<1	2		0.14	0.022	
TS1	5/01/2017			Cloudy	12.1	5.16	29	0.02	<1	<1	2	3	<1	<1		0.75	<0.005	
TS2	16/10/2012		Cloudy brown, 0.95 m		12.1	6.54	88	0.2	20	<1	4	7	<1			0.19	0.017	
TS2	12/11/2012		Cloudy, brown, 1.17 m		12.1	6.6	119	0.57	17	<1	4	6	<1			0.73	0.04	
TS2	10/12/2012		Cloudy, brown, 1.47 m		11.9	6.15	119	0.16	19	<1	4	6	<1			0.68	0.026	
TS2	14/01/2013		Cloudy, 1.80 m		13.6	6.64	134	0.04	23	<1	5	5	<1			0.09	0.02	
TS2	12/02/2013		Cloudy, 1.58 m		14	6.43	122	0.07	18	<1	6	6	<1			0.14	0.078	
TS2	11/03/2013		Cloudy, 1.08		14.4	6.73	107	0.02	15	<1	5	1	<1			0.06	0.031	
TS2	15/04/2013		Slightly Cloudy, 1.38		14	6.38	82	0.02	12	<1	5	5	<1			0.06	0.027	
TS2	15/05/2013		Cloudy, 1.71 m			6.22	58	0.39	6	<1	4	5	<1			0.41	0.038	
TS2	12/06/2013		Brown cloudy, 0.148 m		10.1	6.78	95	0.03	12	<1	5	5	<1			<0.05	0.015	
TS2	10/07/2013		Cloudy, 1.42 m		9.8	6.58	104	0.04	13	<1	5	5	<1			<0.05	0.074	
TS2	5/08/2013		Cloudy, 1.49 m		10.5	6.45	78	0.04	8	<1	4	5	<1			<0.05	0.055	
TS2	10/09/2013		Cloudy, 1.70 m		13	6.45	82	0.02	9	<1	5	6	1			<0.05	0.048	
TS2	10/10/2013		Slightly cloudy, 1.85 m		12.8	6.13	74	0.01	8	<1	5	7	2			<0.05	0.067	
TS2	11/11/2013		Cloudy, 1.98 m		11.8	6.1	46	0.04	2	<1	3	6	<1			0.11	0.042	
TS2	10/12/2013		Cloudy, 1.99m		13.9	6.04	53	0.04	3	<1	4	5	<1			0.25	0.028	
TS2	8/01/2014		Slightly cloudy, 2.19 m		12.5	6.03	39	0.05	1	<1	4	6	<1			<0.05	0.055	
TS2	12/02/2014		Cloudy, 2.43m, insufficient sample		16.2	5.92	31											
TS2	13/03/2014		Cloudy, 2.28 m		16	5.72	48	0.07	1	<1	4	5	<1			<0.05	0.108	
TS2	15/04/2015			Cloudy	15.2	5.76	43	0.05	<1	<1	4	6	1	<1		<0.05	0.047	
TS2	11/05/2015			Clear	12.1	6.01	55	0.08	4	<1	5	4	<1	2		0.05	0.026	
TS2	15/06/2015			Cloudy	11.8	6.06	56	0.05	5	<1	3	4	<1	<1		<0.05	0.027	
TS2	21/07/2015			Cloudy	11	7.88	66	0.04	5	<1	4	4	<1	1		<0.05	0.02	
TS2	13/08/2015			Cloudy	10.6	6.11	50	0.04	4	<1	4	3	<1	<1		<0.05	0.016	
TS2	18/09/2015			Slightly Cloudy	10.6	6.02	50	0.02	3	<1	4	5	<1	<1		<0.05	0.02	
TS2	14/10/2015			Cloudy	11.3	6.21	30	0.03	2	<1	3	4	<1	<1		<0.05	0.011	
TS2	16/11/2015			Slightly Cloudy	12.7	5.94	46	0.05	2	<1	4	4	<1	<1		<0.05	0.014	
TS2	14/12/2015			Clear	14.1	5.86	45	0.03	2	<1	4	6	1	<1		<0.05	0.029	
TS2	8/01/2016			Slightly Cloudy	14.7	5.58	37	0.05	1	<1	4	5	<1	2		<0.05	0.014	
TS2	8/02/2016			Cloudy	14.9	5.96	47.3	0.05	3	<1	4	4	<1	<1		<0.05	0.008	
TS2	10/03/2016			Cloudy	15.7	5.84	44	0.05	1	<1	3	6	<1	<1		<0.05	0.014	
TS2	14/04/2016			Cloudy	14.2	5.73	38	0.25	<1	<1	4	4	<1	<1	0.01	<0.05	0.012	<0.05
TS2	12/05/2016			Cloudy	13.3	5.63	33	0.05	<1	<1	3	4	<1	<1		<0.05	0.014	
TS2	23/06/2016			Cloudy	10	5.25	45	0.48	<1	<1	5	3	<1	6		0.36	0.007	
TS2	11/07/2016			Cloudy	10.8	5.6	45	0.21	2	<1	4	4	<1	10		0.2	0.007	
TS2	11/08/2016			Clear	10.3	5.17	37	0.11	1	<1	4	2	<1	<1		0.07	<0.005	
TS2	14/09/2016			Cloudy	10.7	5.5	38	0.25	<1	<1	5	4	<1	4		0.17	0.006	
TS2	17/10/2016			Slightly Cloudy	8.6	5.54	27	0.11	<1	<1	5	3	<1	<1		0.07	0.011	
TS2	14/11/2016			Slightly Cloudy	12	5.63	34	0.09	1	<1	4	3	<1	<1		0.14	0.006	
TS2	8/12/2016			cloudy	13.7	5.61	45	0.08	2	<1	5	5	<1	1		0.28	0.016	
TS2	5/01/2017			Slightly Cloudy	13.3	5.57	38	0.03	1	<1	4	3	<1	<1		0.17	0.01	
TS2	15/02/2017			Cloudy	15.3	5.66	40	0.06	<1	<1	5	5	<1	2		0.33	0.018	
TS2	16/03/2017			Slightly Cloudy	15.4	5.92	73	0.07	<1	<1	4	4	<1	<1		0.53	<0.005	
TS2	28/04/2017			Cloudy	14.1	5.86	60	0.03	1	<1	8	8	<1	1		0.11	0.028	
TS2	17/05/2017			Cloudy	12.1	5.7	28	0.06	<1	<1	2	4	<1	<1		0.21	0.01	
TS2	8/06/2017			Cloudy	7.9	5.9	115	0.11	<1	<1	4	6	<1	<1			0.022	
TS2	19/07/2017			Clear	6.7	7.8	91	0.03	<1	<1	2	4	<1	<1		0.05	<0.005	
TS2	18/08/2017			Cloudy	9.3	5.7	38	0.07	<1	<1	4	6	<1	5		<0.05	0.018	
TS2	28/09/2017	nt Sample for TOG analysis		Cloudy	8.6	5.7	52	0.05	<1	<1	6	6	1	<1		<0.05	0.026	
TS2	25/10/2017			Clear	9.9	7.1	39	0.12	<1	<1	4	7	<1	<1		0.27	0.008	
TS2	11/12/2017			Slightly Cloudy	14.4	7.3	28	0.09	<1	<1	2	4	<1			0.24	<0.005	

location I	Date of Sample	Comments	omments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
TS2	17/01/2018			Slightly Cloudy	13.9	5.8	45	0.06	<1	<1	4	6	<1	<1		6.26	0.013	
TS2	14/03/2018			Slightly Cloudy	14.9	6.2	20	0.11	<1	<1	4	2	1	<1		0.46	0.01	
TS2	11/04/2018			Clear	12.8	5.7	20	0.09	<1	<1	3	6	<1	<1		0.28	<0.005	
TS2	9/05/2018			Slightly Cloudy	19.2	5.6	73	0.02	<1	<1	7	14	<1	2		0.28	0.013	
TS2	6/06/2018			Clear	6	4.9	37	0.07	<1	<1	5	6	<1	<1		0.15	0.006	
TS2	5/02/2019			Cloudy	15.9	5	45	0.4	<1	<1	6	4	<1	6	0.01	0.22	0.039	<0.05
TS2	6/03/2019			Cloudy	15	5.3	42	0.21	<1	<1	4	6	<1	2	0.009	0.06	0.034	<0.05
TS2	10/04/2019	le amount to conduct TOG analysis		Cloudy	12.8	5.6	52	0.94	<1	<1	6	7	2	2	0.016	0.13	0.088	<0.05
TS3	17/10/2012		Cloudy, 1.32 m		13.8	5.69	80	0.12	<1	<1	3	7	<1			8.42	0.064	
TS3	12/11/2012		Slightly cloudy, 0.92 m		11.8	5.72	62	0.14	1	<1	3	5	<1			8.12	0.078	
TS3	10/12/2012		Slightly cloudy, 1.00 m		11.8	4.83	58	0.12	1	<1	4	6	<1			7.81	0.067	
TS3	14/01/2013		Clear, 0.94 m		14	5.71	56	0.26	1	<1	3	5	<1			8.17	0.08	
TS3	12/02/2013		Slightly cloudy, 0.95 m		14.2	5.75	60	0.13	1	<1	4	7	<1			7.27	0.071	
TS3	11/03/2013		Clear, 0.87 m		14.4	5.94	62	0.12	1	<1	4	6	<1			7.46	0.057	
TS3	15/04/2013		Clear, 0.96		12.9	5.71	50	0.08	1	<1	4	5	<1			4.07	0.043	
TS3	15/05/2013		Slightly cloudy, 0.97 m			5.74	50	0.11	<1	<1	3	5	<1			6.17	0.087	
TS3	12/06/2013		Slightly cloudy, 0.87 m		8.2	5.65	30	0.04	1	<1	3	5	<1			0.88	0.044	
TS3	10/07/2013		Cloudy, 0.97 m		7.4	5.6	29	<0.01	<1	<1	3	6	<1			0.19	0.09	
TS3	5/08/2013		Clear, 0.94 m		7.5	5.75	46	0.08	<1	<1	3	6	<1			4.19	0.054	
TS3	10/09/2013		Clear, 0.97 m		9.8	5.55	44	0.06	<1	<1	3	6	<1			4.07	0.068	
TS3	10/10/2013		Slightly cloudy, 0.99 m		10.6	5.44	50	0.1	<1	<1	3	5	<1			5.39	0.05	
TS3	11/11/2013		Clear, 0.91 m		10.4	5.16	45	0.11	<1	<1	2	5	<1			6.1	0.038	
TS3	10/12/2013		Clear, 0.97m		12.8	5.57	45	0.1	<1	<1	3	6	<1			5.47	0.05	
TS3	8/01/2014		Clear, 1.02 m		12.7	5.5	39	0.08	<1	<1	3	6	<1			3.17	0.074	
TS3	12/02/2014		Slightly Cloudy, 1.07m		15.2	5.4	33	0.06	<1	<1	4	6	<1			2.18	0.125	
TS3	13/03/2014		Clear, 1.0 m		14.7	5.33	49	0.07	<1	<1	4	5	<1			2.77	0.106	
TS3	15/04/2015			Clear	13.4	5.06	43	0.05	<1	<1	4	7	<1	<1		0.47	0.047	
TS3	11/05/2015			Clear	10.4	5.05	37	0.07	<1	<1	4	6	<1	<1		0.34	0.037	
TS3	15/06/2015			Clear	8.7	5.01	35	0.08	<1	<1	2	6	<1	<1		0.31	0.024	
TS3	21/07/2015			Clear	9	6.86	37	0.07	<1	<1	3	6	<1	<1		0.64	0.03	
TS3	13/08/2015			Cloudy	6	5.14	38	0.09	<1	<1	3	5	<1	<1		0.41	0.024	
TS3	18/09/2015			Clear	7.8	5.11	41	0.05	<1	<1	3	7	<1	<1		0.88	0.031	
TS3	14/10/2015			Clear	9.9	5.27	34	0.04	<1	<1	3	6	<1	<1		2.37	0.019	
TS3	16/11/2015			Clear	12	5.96	87	0.08	<1	<1	5	6	<1	<1		12	0.025	
TS3	14/12/2015			Clear	14.4	5.25	56	0.07	<1	<1	3	7	<1	<1		5.2	0.028	
TS3	8/01/2016			Clear	14	5.14	47	0.06	<1	<1	3	6	<1	<1		3.54	0.012	
TS3	8/02/2016			Clear	15.9	5.36	49.7	0.06	<1	<1	4	6	<1	<1		3.76	0.021	
TS3	10/03/2016			Slightly Cloudy	15.2	5.47	53	0.06	<1	<1	3	6	<1	<1		4.62	0.024	
TS3	14/04/2016			Slightly Cloudy	12.6	5.29	43	0.02	<1	<1	3	5	<1	<1	0.035	0.1	0.028	<0.05
TS3	12/05/2016			Clear	10.9	5.02	33	0.04	<1	<1	3	4	<1	<1		0.21	0.013	
TS3	23/06/2016			Clear	8.7	5.01	33	0.05	<1	<1	3	4	<1	<1		0.24	0.013	
TS3	11/07/2016			Clear	10.5	5.04	31	0.06	<1	<1	3	5	<1	<1		0.31	0.016	
TS3	11/08/2016			Clear	7.5	4.4	33	0.06	<1	<1	3	4	<1	<1		0.24	0.012	
TS3	14/09/2016			Clear	8.9	4.81	30	0.06	<1	<1	2	5	<1	<1		0.41	0.016	
TS3	17/10/2016			Slightly Cloudy	9.9	5.82	31	0.04	<1	<1	4	5	<1	<1		0.42	0.03	
TS3	14/11/2016			Clear	12	5.33	37	0.05	<1	<1	3	4	<1	<1		2.37	0.009	
TS3	8/12/2016			clear	14.7	5.39	60	0.07	<1	<1	4	5	<1	<1		6.16	0.028	
TS3	5/01/2017			Clear	14.4	5.15	41	0.06	<1	<1	3	4	<1	<1		2.67	0.019	
TS3	15/02/2017			Clear	18.1	5.3	135	0.05	<1	<1	4	5	<1	<1		3.22	0.037	
TS3	16/03/2017			Clear	15.7	5.34	67	0.07	<1	<1	4	4	<1	8		0.48	<0.005	
TS3	28/04/2017			Cloudy	14.5	5.68	58	0.04	1	<1	8	8	<1	1		0.12	0.041	
TS3	17/05/2017			Cloudy	13	6.29	26	0.03	<1	<1	2	4	<1	<10		0.2	0.012	
TS3	8/06/2017			Cloudy	7.4	6.93	102	0.09	<1	<1	4	7	<1	2			0.021	
TS3	19/07/2017			Clear	7.4	8.2	27	0.03	<1	<1	2	4	<1	2		0.05	<0.005	
TS3	18/08/2017			Cloudy	6.6	5.1	36	0.04	<1	<1	3	6	<1	4		0.31	0.022	
TS3	28/09/2017			Slightly Cloudy	6.5	5.1	42	0.06	<1	<1	3	5	<1	<1		0.3	0.022	
TS3	25/10/2017			Clear	10.2	6.7	40	0.11	<1	<1	4	7	<1	<1		0.27	0.007	
TS3	8/11/2017			Clear	9.6	5.4	41	0.02	<1	<1	3	6	<1	<1		2.87	0.017	
TS3	11/12/2017			Slightly Cloudy	14.2	7.4	30	0.08	<1	<1	2	4	<1			0.2	<0.005	
TS3	17/01/2018			Slightly Cloudy	16	5.9	47	0.05	<1	<1	4	6	<1	<1		6.27	0.014	
TS3	15/02/2018			Clear	15.1	5.6	43	0.02	<1	<1	3	6	<1	<1		1.83	0.017	
TS3	14/03/2018			Slightly Cloudy	15.7	6.1	17	0.11	<1	<1	4	2	1	<1		0.45	0.009	
TS3	11/04/2018			Clear	11.9	5.2	27	0.09	<1	<1	3	6	<1	<1		0.26	<0.005	
TS3	9/05/2018			Slightly Cloudy	18	5.6	98	0.02	<1	<1	7	14	<1	<1		0.3	0.012	
TS3	6/06/2018			Slightly Cloudy	6.1	5.6	41	0.08	<1	<1	5	6	<1	<1		0.14	<0.005	
TS3	19/07/2018			Slightly Cloudty	5.3	7.4	43	0.07	<1	<1	9	4	<1	10		0.05	0.036	

location I	Date of Sample	Comments	omments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/	Sulfate as SO4	Manganese (fi	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg
TS3	22/08/2018			Slightly Cloudy	4.8	4.2	32	0.02	<1	<1	3	5	<1	<1		0.12	0.014	
TS3	19/09/2018			Slightly Cloudy	7.6	5.2	55	0.25	<1	<1	3	5	<1	3	0.004	0.1	0.018	0.36
TS3	25/10/2018			Clear	8.5	4.6	38	0.05	<1	<1	4	6	<1	<1	0.033	0.6	0.034	<0.05
TS3	22/11/2018			Cloudy	11	4.4	51	0.29	<1	<1	6	8	<1	<1	0.036	2.64	0.038	<0.05
TS3	3/01/2019			Clear	14.5	5.3	41	0.04	<1	<1	4	7	<1	<1	0.034	2.05	0.041	<0.05
TS3	5/02/2019			Clear	14.8	5.1	50	0.06	<1	<1	4	6	<1	<1	0.033	4.15	0.035	<0.05
TS3	6/03/2019			Cloudy	13.2	5.6	39	0.05	<1	<1	3	6	<1	<1	0.03	1.81	0.028	<0.05
TS3	10/04/2019			Cloudy	11	5.4	44	0.06	<1	<1	4	6	<1	<1	0.036	3.49	0.076	<0.05
TS3	30/05/2019			Clear	8	4.4	32											
XS1	16/10/2012		Cloudy brown, 1.07 m		14.2	6.07	63	0.12	<1	<1	6	8	<1			1.08	0.013	
XS1	12/11/2012		Cloudy, brown, 1.15 m		12	5.95	85	0.08	<1	<1	4	8	<1			3.36	0.044	
XS1	10/12/2012		Cloudy, 1.13 m		13	5.5	90	0.05	2	<1	5	8	<1			4.28	0.047	
XS1	14/01/2013		Slightly cloudy, 1.16 m		13.8	5.21	65	0.09	1	<1	5	7	<1			6.33	0.083	
XS1	12/02/2013		Slightly cloudy, 1.14 m		14.9	5.83	85	0.27	2	<1	7	8	<1			8.64	0.114	
XS1	11/03/2013		Slightly cloudy, 1.10 m		15.1	6.02	80	0.14	2	<1	6	6	<1			6.8	0.1	
XS1	15/04/2013		Slightly Cloudy, 1.15		13.7	5.35	43	0.01	<1	<1	5	6	<1			<0.05	0.057	
XS1	15/05/2013		Clear, 1.15 m			5.49	35	0.06	<1	<1	5	7	<1			0.2	0.059	
XS1	12/06/2013		Slightly cloudy, 0.111 m		9.3	3.38	307	0.02	<1	<1	5	7	<1			0.05	0.047	
XS1	9/07/2013		Clear, 1.10 m			5.52	34	0.06	<1	<1	5	6	<1			0.06	0.037	
XS1	5/08/2013		Clear, 1.11 m		9.5	5.25	35	0.04	<1	<1	5	6	<1			0.15	0.052	
XS1	10/09/2013		Clear, 1.14 m		11.1	5.18	35	0.02	<1	<1	5	7	<1			<0.05	0.124	
XS1	10/10/2013		Clear, 1.16 m		11	5.16	35	0.02	<1	<1	5	6	<1			<0.05	0.042	
XS1	11/11/2013		Clear, 1.12 m		11	5.12	36	0.03	<1	<1	4	7	<1			0.26	0.062	
XS1	10/12/2013		Clear, 1.09m		13.5	5.21	41	0.02	<1	<1	5	7	<1			0.07	0.069	
XS1	8/01/2014		Clear, 1.20 m		13.6	5.37	38	0.03	<1	<1	5	7	<1			0.08	0.074	
XS1	12/02/2014		Clear, 1.20m		15.5	5.26	34	0.04	<1	<1	5	7	<1			<0.05	0.098	
XS1	13/03/2014		Clear, 1.20 m		15.2	4.76	53	0.07	<1	<1	5	6	<1			<0.05	0.218	
XS1	3/04/2014		Clear, 1.13 m		14.9	5.25	48	0.04	<1	<1	5	6	<1			<0.05	0.09	
XS1	15/04/2015			Clear	14	5.23	48	0.02	<1	<1	5	7	<1	<1		<0.05	0.039	
XS1	11/05/2015			Clear	11.5	5.3	47	0.03	<1	<1	5	6	<1	<1		<0.05	0.03	
XS1	15/06/2015			Clear	10	5.68	45	0.03	<1	<1	4	7	1	<1		<0.05	0.041	
XS1	21/07/2015			Clear	8.8	5.43	40	0.05	<1	<1	5	6	<1	<1		<0.05	0.024	
XS1	13/08/2015			Clear	7.9	5.32	45	0.02	<1	<1	5	5	<1	<1		<0.05	0.028	
XS1	18/09/2015			Clear	9.5	5.06	40	0.02	<1	<1	5	8	<1	<1		<0.05	0.017	
XS1	14/10/2015			Clear	11.1	5.09	31	0.02	<1	<1	4	6	<1	<1		0.07	0.015	
XS1	16/11/2015			Clear	13	5.18	47	<0.01	<1	<1	5	7	<1	<1		<0.05	0.03	
XS1	14/12/2015			Clear	15.5	5.23	23	0.03	<1	<1	4	8	<1	<1		<0.05	0.036	
XS1	8/01/2016			Clear	14	4.77	43	0.02	<1	<1	4	7	1	<1		<0.05	0.014	
XS1	8/02/2016			Yellow, clear	14.4	5.35	40.4	0.01	<1	<1	5	8	<1	<1		<0.05	0.015	
XS1	10/03/2016			Clear	15.8	5.11	49	0.02	<1	<1	4	8	<1	<1		<0.05	0.013	
XS1	14/04/2016			Clear	13.6	5.15	43	0.02	<1	<1	5	8	<1	<1	0.02	<0.05	0.021	<0.05
XS1	12/05/2016			Clear	12	5.28	42	0.02	<1	<1	4	6	<1	<1		<0.05	0.011	
XS1	23/06/2016			Clear	10.2	5.28	40	0.02	<1	<1	3	6	<1	<1		<0.05	0.01	
XS1	11/07/2016			Clear	10	5.09	42	0.03	<1	<1	4	7	<1	<1		<0.05	0.013	
XS1	11/08/2016			Clear	9.2	4.88	46	0.03	<1	<1	4	6	<1	<1		<0.05	0.017	
XS1	14/09/2016			Clear	10.6	5.31	46	0.03	<1	<1	4	6	<1	<1		<0.05	0.02	
XS1	17/10/2016			Clear	9.6	5.75	37	0.02	<1	<1	6	7	<1	<1		<0.05	0.034	
XS1	14/11/2016			Clear	12.2	5.07	40	0.02	<1	<1	5	6	<1	<1		0.07	0.017	
XS1	8/12/2016			clear	14	5.06	45.72	0.03	<1	<1	5	7	<1	1		0.49	0.022	
XS1	5/01/2017			Clear	14.5	4.84	42	0.02	<1	<1	4	6	<1	9		0.32	0.025	
XS1	15/02/2017			Clear	16.5	5.31	54	0.02	<1	<1	6	8	<1	2		0.26	0.026	
XS1	16/03/2017			Cloudy	15.1	6.01	210	0.09	<1	<1	5	6	<1	7		2.21	0.028	
XS1	28/04/2017	gh water for lab parameters			12.5	6.84	78	0.21	<1	<1	16	4	<1	1		0.19	<0.005	
XS1	17/05/2017			Clear	11.4	8.27	75	0.01	<1	<1	15	24	<1	<1		0.07	0.027	
XS1	8/06/2017			Cloudy	7.9	6.97	69	0.18	<1	<1	12	9	<1	<1			<0.005	
XS1	19/07/2017			Cloudy	7	7.1	59	0.07	<1	<1	3	6	<1	<1		0.17	0.008	
XS1	18/08/2017			Clear	8.4	5.1	47	0.02	<1	<1	6	10	<1	2		<0.05	0.014	
XS1	28/09/2017			Clear	8.1	5.1	53	0.03	<1	<1	5	6	<1	<1		0.07	0.024	
XS1	25/10/2017			Clear	12.6	8.3	41	0.06	<1	<1	3	4	<1	<1		0.12	<0.005	
XS1	8/11/2017			Clear	10.8	5.3	57	<0.01	<1	<1	<1	8	<1	4		<0.05	<0.005	
XS1	11/12/2017			Cloudy	14.4	7.7	28	0.08	<1	<1	2	4	<1			0.17	<0.005	
XS1	18/01/2018			Slightly Cloudy	14.9	6.9	33	0.25	<1	<1	2	1	<1	<1		0.97	0.009	
XS1	15/02/2018			Slightly Cloudy	13.9	5	34	0.01	<1	<1	5	8	<1	<1		<0.05	0.024	
XS1	14/03/2018			Clear	13.4	5.2	30	0.12	<1	<1	4	2	1	<1		0.48	0.01	
XS1	11/04/2018			Slightly Cloudy	11.5	5.5	24	0.1	<1	<1	3	7	<1	<1		0.3	<0.005	
XS1	9/05/2018			Cloudy	19.7	5.3	153	0.03	<1	<1	4	44	<1	3		2.94	0.009	

location I	Date of Sample	Comments	:omments/ Obs	Appearance	Temp	pH	EC (µS/cm)	Aluminium (fil	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/	Sulfate as SO4	Manganese (fil	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg/
XS1	6/06/2018			slightly cloudy	5.3	5.5	29	0.06	<1	<1	4	6	<1	<1		0.13	0.007	
XS1	19/07/2018			Cloudy	5.5	5.9	30	0.08	<1	<1	5	5	<1	2		<0.05	0.054	
XS1	22/08/2018			Slightly Cloudy	6.1	4	42	0.02	<1	<1	4	7	<1	<1		0.05	0.027	
XS1	19/09/2018			Clear	7	5.5	52	0.04	<1	<1	6	4	<1	10	0.01	<0.05	0.031	<0.05
XS1	25/10/2018			Slightly Cloudy	9.5	4	62	0.03	<1	<1	6	11	8	<1	0.025	0.12	0.098	<0.05
XS1	22/11/2018			Cloudy	12.7	5.7	49	0.1	<1	<1	4	7	<1	<1	0.038	0.46	0.005	<0.05
XS1	3/01/2019			Clear	14.9	5.4	40	0.02	<1	<1	5	8	<1	1	0.022	0.19	0.053	<0.05
XS1	5/02/2019			Clear	14.9	4.7	43	0.02	<1	<1	5	7	<1	<1	0.016	0.26	0.032	<0.05
XS1	6/03/2019			Clear	14	5.3	40	0.02	<1	<1	4	7	<1	<1	0.021	0.15	0.046	<0.05
XS1	10/04/2019			Cloudy	12.2	5.4	49	0.03	<1	<1	5	8	1	<1	0.013	0.38	0.044	<0.05

location	Date of Sampl	Comments	Appearance	Temp	pH	EC (µS/cm)	Aluminium (filt)	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/	Sulfate as SO4	Manganese (filt	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg/
AP1105	4/12/2018		Clear			26.7	0.02	<1	<1	4	6	<1	<1	0.022	0.18	<0.005	<0.05
AP1204	17/03/2016			18.4	4.33	26	0.02	<1	<1	4	8	<1	2	0.044	<0.05	<0.005	<0.05
AP1204	4/05/2016		Clear	12.4	4.82	90	0.02	<1	<1	5	8	<1	<1	0.039	<0.05	0.013	<0.05
AP1204	1/06/2016		Clear	12.67	6.53	82	0.04	<1	<1	4	8	<1	<1	0.031	<0.05	0.027	<0.05
AP1204	5/07/2016		Clear	11.3	6.57	47	0.08	<1	<1	4	8	<1	<1	0.049	<0.05	0.024	<0.05
AP1204	2/08/2016		Clear with light br	11.5	6.2	60.7	0.03	<1	<1	4	8	<1	<1	0.041	<0.05	0.007	<0.05
AP1204	30/08/2016		Clear	14	5.93	36.5	0.04	<1	<1	6	9	<1	<1	0.042	<0.05	0.01	<0.05
AP1204	30/11/2016		Clear	16.6	5.35	65	0.38	<1	<1	4	8	<1	<1	0.094	0.15	0.013	<0.05
AP1204	4/01/2017		Clear, sand at bas	14.5	5.73	70	0.03	<1	<1	5	7	<1	<1	0.04	<0.05	0.035	<0.05
AP1204	5/02/2017	Hydrasleeve dam	Cloudy brown wi	18.02	6.5	52	0.03	<1	<1	5	7	<1	<1	0.043	<0.05	0.03	<0.05
AP1204	7/03/2017		Clear	11.24	6.22	55	0.02	<1	<1	4	9	<1	<1	0.061	<0.05	0.013	<0.05
AP1204	3/05/2017		Cloudy Brown	10.75	6.38	40	0.12	<1	<1	6	8	<1	<1	0.075	0.21	0.027	<0.05
AP1204	30/05/2017		Clear	11.29	4.21	44	0.23	<1	<1	5	6	<1	<1	0.086	0.14	0.012	<0.05
AP1204	2/08/2017		Clear	9.72	6.22	65	0.03	<1	<1	5	8	<1	<1	0.037	<0.05	0.006	<0.05
AP1204	5/09/2017		Cloudy		4.6	34	0.02	<1	<1	4	8	<1	<1	0.036	<0.05	<0.005	
AP1204	5/12/2017				4.7	33	0.02	<1	<1	4	9	<1	<1	0.043	<0.05	<0.005	
AP1204	7/03/2018				4.98	40.5	0.04	<1	<1	4	11	<1	<1	0.039	<0.05	<0.005	
AP1204	5/06/2018				4.84	41.6	0.02	<1	<1	4	9	<1	<1	0.049	<0.05	<0.005	
AP1204	6/09/2018				4.82	40.2	0.02	<1	<1	4	9	<1	<1	0.033	<0.05	<0.005	<0.05
AP1204	6/03/2019		Clear		5.21	40.1	0.03	<1	<1	4	8	<1	<1	0.039	<0.05	<0.005	<0.05
AP1204	28/05/2019	Field Paramters c	Cloudy		5.84	41.3											
AP4PR	17/03/2016			18.3	4.24	25	<0.01	<1	<1	3	5	<1	2	0.009	<0.05	<0.005	<0.05
AP4PR	4/05/2016		Cloudy	13.7	5	25	0.04	<1	<1	4	5	<1	<1	0.012	<0.05	0.148	<0.05
AP4PR	1/06/2016		Clear	12.58	5.36	29	0.02	<1	<1	4	5	<1	<1	0.008	<0.05	0.015	<0.05
AP4PR	5/07/2016		Slightly Cloudy	11.8	5.24	29	0.02	<1	<1	3	5	<1	<1	0.009	<0.05	0.016	<0.05
AP4PR	2/08/2016		Clear	12.5	6.65	36.2	0.03	<1	<1	4	5	<1	<1	0.012	<0.05	0.008	<0.05
AP4PR	30/08/2016		Cloudy Light Brow	13.9	5.9	24.9	0.02	<1	<1	3	5	<1	<1	0.009	<0.05	0.01	<0.05
AP4PR	30/11/2016		Cloudy Brown	16.7	5.11	32	0.03	<1	<1	4	5	<1	<1	0.011	<0.05	0.035	<0.05
AP4PR	4/01/2017		Cloudy brown	14.9	5.33	30	0.02	<1	<1	4	4	<1	<1	0.009	<0.05	0.01	<0.05
AP4PR	5/02/2017		Very Cloudy Brow	17.84	5.98	36	0.02	<1	<1	4	4	<1	<1	0.01	<0.05	0.027	<0.05
AP4PR	7/03/2017		Cloudy Brown	12.77	6.81	29	0.02	<1	<1	2	6	<1	<1	0.008	<0.05	<0.005	<0.05
AP4PR	3/04/2017		Cloudy	13.16	5.75	28	0.02	<1	<1	4	6	<1	<1	0.01	<0.05	0.019	<0.05
AP4PR	3/05/2017		Cloudy Brown	12.45	5.66	28	0.03	<1	<1	4	6	<1	<1	0.014	<0.05	0.024	<0.05
AP4PR	30/05/2017		Cloudy Brown	11.32	4.84	36	0.02	<1	<1	4	4	<1	<1	0.01	<0.05	0.009	<0.05
AP4PR	2/08/2017		Cloudy Brown	12.45	5.65	60	0.01	<1	<1	4	5	<1	<1	0.01	<0.05	0.007	<0.05
AP4PR	5/09/2017		Cloudy		4.9	27	<0.01	<1	<1	3	5	<1	<1	0.008	<0.05	<0.005	
AP4PR	5/12/2017				4.9	28	0.02	<1	<1	4	6	<1	<1	0.011	<0.05	<0.005	
AP4PR	7/03/2018				5.01	31.7	0.01	<1	<1	3	6	<1	<1	0.01	<0.05	<0.005	
AP4PR	5/06/2018				4.81	30.9	0.01	<1	<1	4	6	<1	<1	0.011	<0.05	<0.005	
AP4PR	6/09/2018				4.86	31.9	0.02	<1	<1	3	6	<1	<1	0.009	<0.05	<0.005	<0.05
AP4PR	4/12/2018		Clear			23.5	0.01	<1	<1	4	6	<1	<1	0.009	<0.05	<0.005	<0.05
AP4PR	6/03/2019		Clear		5.28	28.3	<0.01	<1	<1	4	5	<1	<1	0.009	<0.05	<0.005	<0.05
AP4PR	28/05/2019	Field Paramters c	Slightly Cloudy		6.07	28.9											
AP5PR	17/03/2016			19.3	4.51	18	0.01	<1	<1	2	4	<1	2	0.008	<0.05	0.005	<0.05
AP5PR	4/05/2016		Clear	13.8	5.08	27	0.05	<1	<1	3	4	<1	2	0.013	<0.05	0.113	<0.05
AP5PR	1/06/2016		Clear	13.73	6.36	27	0.03	<1	<1	3	4	<1	<1	0.009	<0.05	0.03	<0.05
AP5PR	5/07/2016		Clear	13.1	5.64	27	0.05	<1	<1	2	3	<1	<1	0.013	<0.05	0.024	<0.05
AP5PR	2/08/2016		Clear to cloudy br	13.4	5.79	35.1	0.11	<1	<1	3	4	<1	13	0.014	0.1	0.022	<0.05
AP5PR	30/08/2016		Clear	15.01	6.18	19.8	0.02	<1	<1	3	4	<1	<1	0.01	<0.05	0.014	<0.05
AP5PR	30/11/2016		Slight Cloudy Brov	17.2	5.78	30	0.03	<1	<1	3	4	<1	<1	0.012	<0.05	0.039	<0.05
AP5PR	4/01/2017		Slightly cloudy bro	14.9	6.19	29	0.03	<1	<1	3	3	<1	<1	0.011	<0.05	0.024	<0.05
AP5PR	5/02/2017		Clear	17.26	6.33	30	0.06	<1	<1	3	3	<1	<1	0.01	<0.05	0.013	<0.05
AP5PR	7/03/2017		Cloudy Brown	12.96	5.87	27	0.02	<1	<1	2	4	<1	<1	0.011	<0.05	0.008	<0.05
AP5PR	3/04/2017		Cloudy	14.93	6.49	33	0.02	<1	<1	3	4	<1	13	0.009	<0.05	0.014	<0.05
AP5PR	3/05/2017		Cloudy Brown	12.78	5.69	25	0.05	<1	<1	3	4	<1	<1	0.017	<0.05	0.03	<0.05
AP5PR	30/05/2017		Clear	12.46	4.11	29	0.03	<1	<1	3	2	<1	<1	0.008	<0.05	0.011	<0.05
AP5PR	2/08/2017		Clear	12.9	5.72	22	0.02	<1	<1	3	3	<1	<1	0.009	<0.05	0.011	<0.05
AP5PR	5/09/2017		Slightly Cloudy		5.1	20	0.01	<1	<1	2	3	<1	<1	0.01	<0.05	0.012	
AP5PR	5/12/2017				5	21	0.02	<1	<1	2	<1	<1	<1	0.008	<0.05	<0.005	
AP5PR	7/03/2018				5.08	24.6	0.02	<1	<1	2	4	<1	<1	0.008	<0.05	<0.005	
AP5PR	5/06/2018				5.07	25.4	0.02	<1	<1	2	4	<1	<1	0.005	<0.05	<0.005	
AP5PR	6/09/2018				4.95	25.3	<0.01	<1	<1	2	4	<1	<1	0.007	<0.05	<0.005	<0.05
AP5PR	4/12/2018		Clear			18.6	<0.01	<1	<1	3	4	<1	<1	0.007	<0.05	0.007	<0.05
AP5PR	6/03/2019		Clear		5.95	37.9	0.01	<1	<1	2	3	<1	<1	0.008	<0.05	<0.005	<0.05
AP5PR	28/05/2019	Field Paramters c	Slightly Cloudy		6.25	21.5											
AP8PR	17/03/2016			19.1	4.62	36	0.02	<1	<1	7	11	<1	5	0.094	<0.05	0.01	<0.05

location	Date of Samp	Comments	Appearance	Temp	pH	EC (µS/cm)	Aluminium (filt)	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/	Sulfate as SO4	Manganese (filt	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg/
AP8PR	4/05/2016		Clear	13.7	5.11	45	<0.01	<1	<1	6	9	<1	<1	0.053	<0.05	0.021	<0.05
AP8PR	1/06/2016		Clear	11.89	5.26	49	0.02	<1	<1	6	10	<1	1	0.043	<0.05	0.015	<0.05
AP8PR	5/07/2016		Clear	11.6	5.28	43	0.12	<1	<1	7	9	<1	1	0.059	0.16	0.016	<0.05
AP8PR	2/08/2016		Clear to cloudy br	12.2	6.29	50.6	0.08	<1	<1	7	9	<1	1	0.056	<0.05	0.016	<0.05
AP8PR	30/08/2016		Clear	14.2	6.18	40.9	0.05	<1	<1	7	9	<1	<1	0.059	<0.05	0.018	<0.05
AP8PR	30/11/2016		Slight Cloudy Brov	18.1	5.72	49	<0.01	<1	<1	7	10	<1	1	0.056	<0.05	0.02	<0.05
AP8PR	4/01/2017		Cloudy brown/gre	14.5	5.47	47	<0.01	<1	<1	7	8	<1	<1	0.053	<0.05	0.032	<0.05
AP8PR	5/02/2017		Slight cloudy brov	15.61	6.27	50	<0.01	<1	<1	7	9	<1	<1	0.054	<0.05	0.012	<0.05
AP8PR	7/03/2017		Cloudy Brown	13.78	5.4	44	0.05	<1	<1	6	10	<1	<1	0.048	<0.05	0.046	<0.05
AP8PR	30/05/2017		Cloudy brown/gre	9.94	5.4	72	0.02	<1	<1	7	7	<1	<1	0.046	<0.05	0.014	<0.05
AP8PR	2/08/2017		Cloudy brown/gre	11.94	5.37	39	0.01	<1	<1	6	9	<1	<1	0.048	<0.05	0.008	<0.05
AP8PR	5/09/2017		Cloudy		5	39	0.01	<1	<1	6	10	<1	<1	0.043	<0.05	0.005	
AP8PR	5/12/2017				4.9	39	<0.01	<1	<1	6	10	<1	<1	0.055	<0.05	<0.005	
AP8PR	7/03/2018				5.44	53	0.01	<1	<1	5	10	<1	<1	0.049	<0.05	<0.005	
AP8PR	5/06/2018				4.75	43.8	0.01	<1	<1	5	10	<1	<1	0.044	<0.05	<0.005	
AP8PR	6/09/2018				4.82	49.7	0.01	<1	<1	6	10	<1	<1	0.054	<0.05	<0.005	<0.05
AP8PR	4/12/2018		Brown, Turbid			34.5	0.01	<1	<1	5	10	<1	<1	0.071	0.08	<0.005	<0.05
AP8PR	6/03/2019		Trubid		4.86	46.7	0.02	<1	<1	6	8	<1	<1	0.049	<0.05	<0.005	<0.05
AP8PR	28/05/2019	Field Paramters c	Cloudy		6.15	43											
AP9PR	17/03/2016			19	4.5	22	<0.01	2	<1	2	3	<1	2	0.013	<0.05	0.005	<0.05
AP9PR	4/05/2016		Clear	14.5	5.4	24	<0.01	1	<1	3	4	<1	<1	0.013	<0.05	0.013	<0.05
AP9PR	2/06/2016		Clear	13.12	5.35	24	<0.01	<1	<1	<1	4	<1	<1	0.01	<0.05	0.006	<0.05
AP9PR	5/07/2016		Clear	12.5	5.66	27	0.29	1	<1	2	2	<1	<1	0.038	0.7	0.019	<0.05
AP9PR	2/08/2016		Clear to cloudy br	12.1	6.62	32.4	0.04	1	<1	3	3	<1	<1	0.015	<0.05	0.031	<0.05
AP9PR	30/08/2016		Cloudy Light Brow	14.2	6.29	20.6	<0.01	1	<1	2	3	<1	<1	0.013	<0.05	0.012	<0.05
AP9PR	30/11/2016		Cloudy Brown	19.5	6.04	34	0.02	1	<1	3	4	<1	<1	0.013	<0.05	0.041	<0.05
AP9PR	4/01/2017		Slightly cloudy bro	15.8	5.75	28	<0.01	<1	<1	3	3	<1	<1	0.014	<0.05	0.016	<0.05
AP9PR	5/02/2017		Slight cloudy brov	16.59	6.24	25	0.01	<1	<1	3	2	<1	<1	0.013	<0.05	0.01	<0.05
AP9PR	7/03/2017		Clear	14.32	5.62	25	0.01	<1	<1	2	3	<1	<1	0.013	<0.05	0.012	<0.05
AP9PR	3/04/2017		Clear	12.76	5.66	25	<0.01	<1	<1	3	3	<1	<1	0.012	<0.05	0.018	<0.05
AP9PR	3/05/2017		Clear- Cloudy bro	12.52	6.75	23	0.05	1	<1	3	4	<1	<1	0.018	0.07	0.088	<0.05
AP9PR	30/05/2017		Clear- Cloudy bro	11.45	4.27	30	0.01	<1	<1	3	2	<1	<1	0.012	<0.05	0.013	<0.05
AP9PR	5/09/2017		Cloudy		5.2	21	<0.01	<1	<1	2	3	<1	<1	0.01	<0.05	<0.005	
AP9PR	5/12/2017				5.3	24	0.01	<1	<1	2	4	<1	<1	0.015	<0.05	0.005	
AP9PR	7/03/2018				5.29	25.4	<0.01	1	<1	2	4	<1	<1	0.013	<0.05	0.006	
AP9PR	5/06/2018				5.26	27.9	<0.01	2	<1	2	4	<1	<1	0.012	<0.05	0.02	
AP9PR	6/09/2018				5.41	30.1	<0.01	2	<1	2	4	<1	<1	0.013	<0.05	<0.005	<0.05
AP9PR	4/12/2018		Brown, Turbid			25.3	<0.01	2	<1	3	4	<1	<1	0.015	<0.05	0.006	<0.05
AP9PR	6/03/2019		Slightly trubid		5.69	30.5	<0.01	2	<1	2	3	<1	<1	0.017	<0.05	<0.005	<0.05
AP9PR	28/05/2019	Field Paramters c	Slightly Cloudy		6.51	28.5											
RSS	17/03/2016			18.3	4.25	26	0.02	<1	<1	4	7	<1	3	0.021	<0.05	0.005	<0.05
RSS	4/05/2016		Clear	14.1	4.81	25	0.05	<1	<1	4	5	<1	<1	0.024	<0.05	0.016	<0.05
RSS	3/06/2016		Clear	11.83	4.67	29	0.05	<1	<1	3	5	<1	<1	0.022	<0.05	0.01	<0.05
RSS	6/07/2016		Clear	10.6	5.24	60	0.19	<1	<1	8	13	<1	<1	0.036	<0.05	0.013	0.05
RSS	2/08/2016		Clear to cloudy br	10.3	5.48	48	0.1	<1	<1	6	11	<1	<1	0.034	<0.05	0.015	<0.05
RSS	30/08/2016		Clear	13.17	5.89	36.7	0.05	<1	<1	6	11	<1	<1	0.028	<0.05	0.009	<0.05
RSS	30/11/2016		Clear	16.2	5.6	31	0.05	<1	<1	5	5	<1	<1	0.021	<0.05	0.03	<0.05
RSS	5/01/2017		Clear	15.4	5.05	31	0.05	<1	<1	4	4	<1	<1	0.028	<0.05	0.013	<0.05
RSS	5/02/2017		Clear	18.19	6.07	32	0.05	<1	<1	4	4	<1	<1	0.023	<0.05	0.009	<0.05
RSS	7/03/2017		Cloudy Brown	13.47	5.14	27	0.04	<1	<1	4	6	<1	<1	0.04	<0.05	0.024	<0.05
RSS	3/04/2017		Slight cloudy	11.81	4.24	59	0.07	<1	<1	8	13	<1	<1	0.021	<0.05	0.031	<0.05
RSS	3/05/2017		Clear	11.89	5.19	24	0.05	<1	<1	5	6	<1	<1	0.025	<0.05	0.027	<0.05
RSS	29/05/2017		Clear	11.57	3.87	37	0.05	<1	<1	4	3	<1	<1	0.022	<0.05	0.014	<0.05
RSS	2/08/2017		Clear	16.9	5.07	29	0.04	<1	<1	4	4	<1	<1	0.022	<0.05	0.008	<0.05
RSS	4/09/2017		Slightly Cloudy		5.3	32	0.05	<1	<1	3	5	<1	<1	0.024	<0.05	0.016	
RSS	5/12/2017				4.7	28	0.04	<1	<1	4	6	<1	<1	0.029	<0.05	0.006	
RSS	7/03/2018				4.83	33.7	0.04	<1	<1	3	6	<1	<1	0.024	<0.05	0.008	
RSS	5/06/2018				4.71	35	0.03	<1	<1	8	6	<1	<1	0.03	<0.05	<0.005	
RSS	6/09/2018				4.96	31.7	0.02	<1	<1	3	5	<1	<1	0.02	<0.05	<0.005	<0.05
RSS	4/12/2018		Clear			25.4	0.03	<1	<1	3	6	<1	<1	0.024	<0.05	<0.005	<0.05
RSS	5/03/2019		Trubid		4.92	41.4	0.04	<1	<1	6	6	<1	<1	0.021	<0.05	<0.005	<0.05
RSS	28/05/2019	Field Paramters c	Slightly Cloudy		6.04	27.4											
SPR1104	17/03/2016			16.2	4.13	20	<0.01	<1	<1	3	4	<1	2	0.011	<0.05	<0.005	<0.05
SPR1104	4/05/2016		Cloudy	14.5	4.99	22	0.02	<1	<1	3	4	<1	<1	0.012	<0.05	0.008	<0.05
SPR1104	2/06/2016		Clear	13.18	4.89	23	0.03	<1	<1	3	4	<1	<1	0.01	<0.05	0.015	<0.05
SPR1104	6/07/2016		Clear	11.4	5.02	22	0.16	<1	<1	3	4	<1	<1	0.02	0.05	0.006	<0.05

location	Date of Samp	Comments	Appearance	Temp	pH	EC (µS/cm)	Aluminium (filt)	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/	Sulfate as SO4	Manganese (filt	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg/
SPR1104	3/08/2016		Clear to cloudy br	12	5.12	22	0.03	<1	<1	3	4	<1	<1	0.022	<0.05	0.015	<0.05
SPR1104	31/08/2016		Cloudy Light Brow	13	5.86	18.5	0.04	<1	<1	3	3	<1	<1	0.013	<0.05	0.012	<0.05
SPR1104	1/12/2016		Slight Cloudy Brov	18.3	6.14	23	0.03	<1	<1	3	3	<1	<1	0.014	<0.05	0.043	<0.05
SPR1104	4/01/2017		Clear	16.5	5.82	19	0.01	<1	<1	4	2	<1	<1	0.013	<0.05	0.011	<0.05
SPR1104	5/02/2017		Clear	17.68	6.19	22	0.02	<1	<1	3	2	<1	<1	0.013	<0.05	<0.005	<0.05
SPR1104	7/03/2017		Clear	15.03	5.5	17	0.02	<1	<1	2	4	<1	<1	0.011	<0.05	0.011	<0.05
SPR1104	4/04/2017		Clear	13.87	5.26	21	0.01	<1	<1	3	4	<1	<1	0.012	<0.05	0.007	<0.05
SPR1104	3/05/2017		Clear	12.22	5.54	19	0.03	<1	<1	3	4	<1	<1	0.011	<0.05	0.024	<0.05
SPR1104	29/05/2017		Clear	11.79	3.4	15	0.02	<1	<1	3	2	<1	<1	0.01	<0.05	0.012	<0.05
SPR1105	6/03/2019		Slightly muddy		5.05	33.5	0.06	<1	<1	4	6	<1	<1	0.033	<0.05	<0.005	<0.05
SPR1105	28/05/2019	Field Paramters co	Clear		5.89	34											
SPR1106	18/03/2016			16.1	4.15	20	0.01	<1	<1	4	4	<1	2	0.021	<0.05	<0.005	<0.05
SPR1106	4/05/2016		Clear	14.7	4.82	22	0.03	<1	<1	3	4	<1	<1	0.02	<0.05	0.01	<0.05
SPR1106	3/06/2016		Clear	12.81	4.75	29	0.03	<1	<1	3	5	<1	<1	0.017	<0.05	0.009	<0.05
SPR1106	6/07/2016		Clear	10.8	4.87	26	0.07	<1	<1	3	4	<1	<1	0.02	<0.05	0.022	<0.05
SPR1106	3/08/2016		Clear to cloudy br	11.6	4.93	25	0.03	<1	<1	3	4	<1	<1	0.02	<0.05	0.018	<0.05
SPR1106	31/08/2016		Cloudy Light Brow	13.1	5.69	22.3	0.06	<1	<1	5	4	<1	<1	0.023	<0.05	0.036	<0.05
SPR1106	30/11/2016		Slight Cloudy Brov	15.2	5.92	26	0.04	<1	<1	4	4	<1	<1	0.023	<0.05	0.063	<0.05
SPR1106	5/01/2017		Slightly cloudy bro	18	5.75	31	0.03	<1	<1	4	4	<1	<1	0.022	<0.05	0.038	<0.05
SPR1106	5/02/2017		Clear	21	5.94	33	0.01	<1	<1	3	3	<1	<1	0.026	<0.05	0.006	<0.05
SPR1106	7/03/2017		Clear	15.71	5.23	25	0.11	<1	<1	3	5	<1	<1	0.021	<0.05	0.014	<0.05
SPR1106	4/04/2017		Clear	14.07	5.49	29	0.02	<1	<1	4	4	<1	<1	0.02	<0.05	0.019	<0.05
SPR1106	3/05/2017		Clear	12.09	4.9	25	0.02	<1	<1	4	4	<1	<1	0.022	<0.05	0.02	<0.05
SPR1106	29/05/2017		Clear	11.43	4.2	31	0.02	<1	<1	3	3	<1	<1	0.018	<0.05	0.009	<0.05
SPR1106	2/08/2017		Clear	11.61	5.03	22	0.03	<1	<1	3	4	<1	<1	0.02	<0.05	0.019	<0.05
SPR1106	4/09/2017		Cloudy		4.9	24	0.03	<1	<1	3	4	<1	<1	0.021	<0.05	0.006	
SPR1106	5/12/2017				4.7	25	0.02	<1	<1	3	5	<1	<1	0.021	<0.05	<0.005	
SPR1106	7/03/2018				4.82	30.4	0.02	<1	<1	3	5	<1	<1	0.022	<0.05	0.005	
SPR1106	5/06/2018				5.22	33.4	0.02	<1	<1	5	5	<1	<1	0.024	<0.05	<0.005	
SPR1106	6/09/2018				4.85	29.1	0.02	<1	<1	3	5	<1	<1	0.025	<0.05	<0.005	<0.05
SPR1106	4/12/2018		Clear			21.9	0.02	<1	<1	3	5	<1	<1	0.029	0.1	<0.005	<0.05
SPR1106	5/03/2019		Med trubidity		4.97	25	0.02	<1	<1	3	4	<1	<1	0.025	<0.05	<0.005	<0.05
SPR1106	28/05/2019	Field Paramters co	Clear		5.86	28.2											
SPR1107	17/03/2016			16.1	3.9	31	0.03	<1	<1	3	6	<1	2	0.021	<0.05	0.008	<0.05
SPR1107	3/05/2016		Clear	13.8	4.73	268	0.03	<1	<1	3	6	<1	<1	0.023	<0.05	0.009	<0.05
SPR1107	3/06/2016		Clear	12.12	5.01	31	0.04	<1	<1	2	4	<1	<1	0.007	<0.05	0.014	<0.05
SPR1107	6/07/2016		Clear	12.2	4.89	30	<0.01	<1	<1	4	6	<1	<1	0.015	<0.05	<0.005	<0.05
SPR1107	2/08/2016		Clear to cloudy br	11.6	5.3	33	0.02	<1	<1	3	6	<1	<1	0.021	<0.05	0.011	<0.05
SPR1107	30/08/2016		Clear	13.9	6.61	25.5	0.02	<1	<1	3	6	<1	<1	0.021	<0.05	0.017	<0.05
SPR1107	1/12/2016		Slight Cloudy Brov	16.7	5.28	28	0.02	<1	<1	3	5	<1	<1	0.02	<0.05	0.054	<0.05
SPR1107	4/01/2017		Slightly cloudy bro	16.6	5.25	31	0.02	<1	<1	4	4	<1	<1	0.019	<0.05	0.014	<0.05
SPR1107	5/02/2017		Clear	16.53	6.48	35	0.02	<1	<1	4	5	<1	<1	0.02	<0.05	0.011	<0.05
SPR1107	7/03/2017		Clear	15.23	5.64	27	0.02	<1	<1	3	6	<1	<1	0.016	<0.05	0.017	<0.05
SPR1107	4/04/2017		Clear	14.04	5.25	28	0.01	<1	<1	4	6	<1	<1	0.019	<0.05	0.014	<0.05
SPR1107	3/05/2017		Clear	12.63	5.22	26	0.02	<1	<1	4	6	<1	<1	0.017	<0.05	0.013	<0.05
SPR1107	29/05/2017		Clear	12.12	3.47	33	0.02	<1	<1	4	4	<1	<1	0.018	<0.05	0.01	<0.05
SPR1107	2/08/2017		Clear	11.68	5.27	22	0.02	<1	<1	4	5	<1	<1	0.021	<0.05	0.023	<0.05
SPR1107	4/09/2017		Slightly Cloudy		4.9	24	0.01	<1	<1	2	4	<1	<1	0.013	<0.05	<0.005	
SPR1107	5/12/2017				4.8	27	0.02	<1	<1	3	6	<1	<1	0.018	<0.05	<0.005	
SPR1107	7/03/2018				4.82	45.3	0.02	<1	<1	2	5	<1	<1	0.013	<0.05	<0.005	
SPR1107	5/06/2018				4.67	26.7	0.02	<1	<1	3	5	<1	<1	0.011	<0.05	<0.005	
SPR1107	6/09/2018				5.19	34.6	0.02	<1	<1	2	4	<1	<1	0.013	<0.05	<0.005	<0.05
SPR1107	4/12/2018		clear			19.3	0.02	<1	<1	3	5	<1	<1	0.02	0.07	0.037	<0.05
SPR1107	5/03/2019		Cloudy		5.69	24.9	0.06	<1	<1	3	4	<1	<1	0.019	<0.05	0.014	<0.05
SPR1107	28/05/2019	Field Paramters co	Clear		6.2	26.1											
SPR1108	17/03/2016			18	3.57	67	0.01	<1	<1	2	4	<1	2	0.005	<0.05	<0.005	<0.05
SPR1108	3/05/2016		Clear	13	4.51	70	0.03	<1	<1	2	5	<1	<1	0.007	<0.05	0.041	<0.05
SPR1108	2/06/2016		Clear	13.17	4.75	29	0.03	<1	<1	3	7	<1	<1	0.018	<0.05	0.021	<0.05
SPR1108	5/07/2016		Clear	12	6.5	30	0.03	<1	<1	2	4	<1	<1	0.008	<0.05	0.006	<0.05
SPR1108	3/08/2016		Clear to cloudy br	10.6	5.11	30.8	0.03	<1	<1	2	4	<1	<1	0.004	<0.05	0.012	<0.05
SPR1108	30/08/2016		Clear	12.8	7.2	22.2	0.04	<1	<1	2	4	<1	<1	0.008	<0.05	0.017	<0.05
SPR1108	1/12/2016		Clear	16.1	5.14	30	0.04	<1	<1	3	4	<1	<1	0.007	<0.05	0.036	<0.05
SPR1108	5/01/2017		Clear	15.6	5.26	30	0.04	<1	<1	3	3	<1	<1	0.006	<0.05	0.011	<0.05
SPR1108	5/02/2017		Clear	21.33	5.49	26	0.03	<1	<1	2	3	<1	<1	0.006	<0.05	0.01	<0.05
SPR1108	8/03/2017		Clear	12.71	5.89	27	0.03	<1	<1	2	4	<1	<1	0.005	<0.05	0.009	<0.05
SPR1108	4/04/2017		Clear	13.95	5.51	24	0.02	<1	<1	3	4	<1	<1	0.005	<0.05	0.012	<0.05

location	Date of Sampl	Comments	Appearance	Temp	pH	EC (µS/cm)	Aluminium (filt)	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/	Sulfate as SO4	Manganese (filt	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg/
SPR1108	3/05/2017		Clear	12.07	4.72	24	0.03	<1	<1	3	4	<1	<1	0.006	<0.05	0.029	<0.05
SPR1108	29/05/2017		Clear	13.37	5.45	28	0.03	<1	<1	3	2	<1	<1	0.006	<0.05	0.03	<0.05
SPR1108	2/08/2017		Clear	10.73	4.72	21	0.03	<1	<1	2	4	<1	<1	0.006	<0.05	0.01	<0.05
SPR1108	4/09/2017		Slightly Cloudy		4.5	26	0.03	<1	<1	2	4	<1	<1	0.006	<0.05	0.009	
SPR1108	5/12/2017				4.4	29	0.03	<1	<1	2	4	<1	<1	0.005	<0.05	<0.005	
SPR1108	7/03/2018				5.19	30.4	0.03	<1	<1	2	5	<1	<1	0.005	<0.05	<0.005	
SPR1108	5/06/2018				4.42	28.4	0.03	<1	<1	2	4	<1	<1	0.004	<0.05	<0.005	
SPR1108	6/09/2018				5.43	44.1	0.03	<1	<1	2	4	<1	<1	0.005	<0.05	<0.005	<0.05
SPR1108	4/12/2018		clear			24.6	0.04	<1	<1	3	4	<1	<1	0.007	<0.05	0.008	<0.05
SPR1108	5/03/2019		Clear		6.35	26.7	0.03	<1	<1	2	4	<1	<1	0.007	<0.05	<0.005	<0.05
SPR1108	28/05/2019	Field Paramters co	Clear		6.32	33.4											
SPR1109	18/03/2016			16.6	4.56	25	<0.01	<1	<1	4	5	<1	2	0.053	<0.05	<0.005	<0.05
SPR1109	4/05/2016		Clear	14.9	4.95	23	0.02	<1	<1	3	6	<1	<1	0.058	<0.05	0.011	<0.05
SPR1109	3/06/2016		Clear	12.81	4.79	26	0.02	<1	<1	3	5	<1	<1	0.044	<0.05	0.013	<0.05
SPR1109	6/07/2016		Clear	10.5	5.03	29	0.02	<1	<1	3	5	<1	<1	0.053	<0.05	0.01	<0.05
SPR1109	2/08/2016		Clear to cloudy br	10.9	5.52	28	0.03	<1	<1	3	5	<1	<1	0.053	<0.05	0.011	<0.05
SPR1109	31/08/2016		Cloudy Light Brow	13.4	5.7	22.4	0.02	<1	<1	3	5	<1	<1	0.041	<0.05	0.015	<0.05
SPR1109	30/11/2016	Insufficient water	Cloudy Brown-	18.7	5.89	32	0.03	<1	<1	4	6	<1	<1	0.039	<0.05	0.057	<0.05
SPR1111	17/03/2016			16.9	4.24	22	<0.01	<1	<1	3	3	<1	2	0.004	<0.05	<0.005	<0.05
SPR1111	4/05/2016		Cloudy	14.4	4.96	20	0.01	<1	<1	3	3	<1	<1	0.004	<0.05	0.012	<0.05
SPR1111	2/06/2016		Clear	13.63	4.89	22	0.02	<1	<1	3	3	<1	<1	0.003	<0.05	0.026	<0.05
SPR1111	6/07/2016		Clear	11.7	5.03	20	0.04	<1	<1	3	3	<1	<1	0.003	<0.05	0.009	<0.05
SPR1111	3/08/2016		Clear to cloudy br	12.3	5.13	21	0.01	<1	<1	3	3	<1	<1	0.004	<0.05	0.016	<0.05
SPR1111	31/08/2016		Clear	13.3	5.98	19.2	0.02	<1	<1	3	3	<1	<1	0.003	<0.05	<0.005	<0.05
SPR1111	1/12/2016		Slight Cloudy Brov	20.8	6.03	26	0.01	<1	<1	3	3	<1	<1	0.004	<0.05	0.022	<0.05
SPR1111	4/01/2017		Slightly cloudy bro	17.4	5.68	21	0.02	<1	<1	4	2	<1	<1	0.003	<0.05	0.013	<0.05
SPR1111	5/02/2017		Cloudy Brown	18.74	5.67	24	0.01	<1	<1	3	2	<1	<1	0.004	<0.05	0.009	<0.05
SPR1111	7/03/2017		Clear	15.55	5.42	21	<0.01	<1	<1	2	3	<1	<1	0.004	<0.05	<0.005	<0.05
SPR1111	4/04/2017		Clear	14.81	5.06	21	<0.01	<1	<1	3	4	<1	<1	0.004	<0.05	0.01	<0.05
SPR1111	3/05/2017		Clear	12.81	5.06	19	0.02	<1	<1	4	3	<1	<1	0.005	<0.05	0.019	<0.05
SPR1111	29/05/2017		Clear	12.75	4.03	26	0.09	<1	<1	3	2	<1	<1	0.004	<0.05	0.011	<0.05
SPR1111	2/08/2017		Clear	12.11	5.14	18	<0.01	<1	<1	3	2	<1	<1	0.005	<0.05	0.01	<0.05
SPR1111	4/09/2017		Slightly Cloudy		5	20	<0.01	<1	<1	2	3	<1	<1	0.002	<0.05	<0.005	
SPR1111	5/12/2017				4.8	21	<0.01	<1	<1	2	4	<1	<1	0.003	<0.05	<0.005	
SPR1111	7/03/2018				4.89	23	0.02	<1	<1	2	3	<1	<1	0.004	<0.05	<0.005	
SPR1111	5/06/2018				5.15	22.9	<0.01	<1	<1	3	3	<1	<1	0.005	<0.05	<0.005	
SPR1111	6/09/2018				5.65	20.5	<0.01	<1	<1	2	3	<1	<1	0.004	<0.05	<0.005	<0.05
SPR1111	4/12/2018		Slightly cloudy			15.4	<0.01	<1	<1	2	3	<1	<1	0.002	0.07	0.005	<0.05
SPR1111	5/03/2019		Slightly cloudy		6.16	22.4	0.02	<1	<1	2	2	<1	<1	0.006	<0.05	<0.005	<0.05
SPR1111	28/05/2019	Field Paramters co	Clear		6.33	18.9											
SPR1112	17/03/2016			17.1	4.05	22	<0.01	<1	<1	2	4	<1	2	0.004	<0.05	<0.005	<0.05
SPR1112	4/05/2016		Clear	14.7	4.85	20	0.02	<1	<1	3	4	<1	<1	0.005	<0.05	0.006	<0.05
SPR1112	2/06/2016		Clear	13.31	4.82	24	0.03	<1	<1	3	4	<1	<1	0.004	<0.05	0.009	<0.05
SPR1112	6/07/2016		Clear	11.7	4.91	22	0.1	<1	<1	3	3	<1	1	0.005	<0.05	0.007	<0.05
SPR1112	3/08/2016		Clear to cloudy br	12.4	5.04	27.1	0.05	<1	<1	3	4	<1	<1	0.004	<0.05	0.015	<0.05
SPR1112	31/08/2016		Clear	13.2	5.8	21.1	0.04	<1	<1	3	4	<1	<1	0.005	<0.05	0.007	<0.05
SPR1112	1/12/2016		Clear	16.8	5.47	28	0.03	<1	<1	3	4	<1	<1	0.004	<0.05	0.019	<0.05
SPR1112	4/01/2017		Slightly cloudy bro	16.1	4.75	24	0.02	<1	<1	3	3	<1	<1	0.005	<0.05	<0.005	<0.05
SPR1112	5/02/2017		Clear	19.36	5.56	26	0.02	<1	<1	2	3	<1	<1	0.005	<0.05	0.009	<0.05
SPR1112	8/03/2017		Clear	13.2	5.06	23	0.04	<1	<1	2	4	<1	<1	0.004	<0.05	0.017	<0.05
SPR1112	4/04/2017		Clear	14.93	5.1	17	0.02	<1	<1	4	4	<1	<1	0.005	<0.05	0.021	<0.05
SPR1112	3/05/2017		Clear	12.71	5.39	21	0.03	<1	<1	4	4	<1	<1	0.005	<0.05	0.029	<0.05
SPR1112	29/05/2017		Clear	13.51	4.75	29	0.03	<1	<1	3	2	<1	<1	0.006	<0.05	0.013	<0.05
SPR1112	2/08/2017		Clear	13.07	5.04	20	0.02	<1	<1	3	4	<1	<1	0.005	<0.05	0.015	<0.05
SPR1112	4/09/2017		Slightly Cloudy		4.9	22	0.02	<1	<1	3	4	<1	<1	0.006	<0.05	0.007	
SPR1112	5/12/2017				4.7	24	0.1	<1	<1	3	4	<1	<1	0.004	<0.05	<0.005	
SPR1112	7/03/2018				4.86	27.3	0.02	<1	<1	2	4	<1	<1	0.004	<0.05	<0.005	
SPR1112	5/06/2018				4.94	28.9	0.02	<1	<1	2	4	<1	<1	0.003	<0.05	<0.005	
SPR1112	6/09/2018				5.08	26.2	0.01	<1	<1	3	4	<1	<1	0.004	<0.05	<0.005	<0.05
SPR1112	4/12/2018		Clear			17.8	0.03	<1	<1	4	4	<1	<1	0.007	<0.05	<0.005	<0.05
SPR1112	5/03/2019		Clear		5.45	23.8	0.02	<1	<1	3	3	<1	<1	0.006	<0.05	0.007	<0.05
SPR1112	28/05/2019	Field Paramters co	Cloudy		6.22	18.5											
SPR1113	17/03/2016			17	4	22	0.02	<1	<1	2	3	<1	4	0.005	<0.05	<0.005	<0.05
SPR1113	4/05/2016		Cloudy	14.2	4.9	18	0.02	<1	<1	2	3	<1	<1	0.005	<0.05	<0.005	<0.05
SPR1113	2/06/2016		Clear	13.31	4.81	23	0.03	<1	<1	2	3	<1	<1	0.005	<0.05	0.006	<0.05
SPR1113	6/07/2016		Clear	11.4	4.87	21	0.03	<1	<1	2	3	<1	<1	0.004	<0.05	<0.005	<0.05

location	Date of Samp	Comments	Appearance	Temp	pH	EC (µS/cm)	Aluminium (filt)	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/	Sulfate as SO4	Manganese (filt	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg/
SPR1113	3/08/2016		Clear to cloudy br	10.8	5.12	21.7	0.03	<1	<1	2	3	<1	<1	0.004	<0.05	0.01	<0.05
SPR1113	31/08/2016		Cloudy Light Brow	13.5	5.77	20.7	0.02	<1	<1	2	3	<1	<1	0.005	<0.05	0.009	<0.05
SPR1113	1/12/2016		Cloudy Brown	15.1	5.5	22	0.02	<1	<1	2	3	<1	<1	0.005	<0.05	0.031	<0.05
SPR1113	4/01/2017		Cloudy Brown	14.7	5.15	24	0.03	<1	<1	3	2	<1	<1	0.004	<0.05	0.008	<0.05
SPR1113	5/02/2017		Cloudy Brown	19.86	5.45	24	0.02	<1	<1	3	2	<1	<1	0.004	<0.05	0.026	<0.05
SPR1113	8/03/2017		Clear	13.27	5.61	22	0.02	<1	<1	1	3	<1	<1	0.004	<0.05	<0.005	<0.05
SPR1113	4/04/2017		Clear	14.99	5.4	23	0.02	<1	<1	3	4	<1	<1	0.004	<0.05	0.005	<0.05
SPR1113	3/05/2017		Clear	12.39	5.05	20	0.42	<1	<1	3	4	<1	<1	0.007	<0.05	0.03	<0.05
SPR1113	29/05/2017		Clear	14.09	4.95	34	0.04	<1	<1	4	2	2	<1	0.006	<0.05	0.071	<0.05
SPR1113	2/08/2017		Clear	12.35	5.05	19	0.06	<1	<1	3	3	<1	<1	0.005	<0.05	0.056	0.39
SPR1113	4/09/2017		Slightly Cloudy		4.8	24	0.02	<1	<1	2	3	<1	<1	0.005	<0.05	0.005	
SPR1113	5/12/2017				4.7	22	0.02	<1	<1	2	4	<1	<1	0.007	<0.05	<0.005	
SPR1113	7/03/2018				4.88	25.4	0.03	<1	<1	2	4	<1	<1	0.004	<0.05	0.026	
SPR1113	5/06/2018				4.93	26.9	<0.01	<1	<1	2	3	<1	<1	0.004	<0.05	<0.005	
SPR1113	6/09/2018				5.55	26.8	0.02	<1	<1	2	3	<1	<1	0.003	<0.05	<0.005	<0.05
SPR1113	4/12/2018		clear			17.6	0.02	<1	<1	2	4	<1	<1	0.002	<0.05	<0.005	<0.05
SPR1113	5/03/2019		Clear		6.15	29.2	0.02	<1	<1	2	3	<1	<1	0.002	<0.05	<0.005	<0.05
SPR1113	28/05/2019	Field Paramters c	Slightly Cloudy		6.4	22.7											
SPR1210	5/03/2019		Very muddy		8.3	31.3	0.02	<1	<1	4	3	<1	<1	0.01	<0.05	0.01	<0.05
SPR1210	28/05/2019	Field Paramters c	Cloudy		6.1	404											
SPR1211	4/12/2018		Clear			39.8	0.08	<1	<1	3	7	<1	<1	0.038	0.16	0.009	<0.05
SPR1211	5/03/2019		Trubid		7.54	58.4	0.07	<1	<1	3	6	<1	<1	0.027	<0.05	<0.005	<0.05
SPR1211	28/05/2019	Field Paramters c	Clear		5.08	41.8											
SPR1301	4/12/2018		Clear			993.7	0.43	81	<1	4	4	<1	4	<0.001	0.1	<0.005	<0.05
SPR1301	5/03/2019		Clear		11.61	811.4	0.42	59	<1	3	4	<1	2	<0.001	<0.05	<0.005	<0.05
SPR1301	28/05/2019	Field Paramters c	Clear		11.59	870.9											
SPR1401	17/03/2016	Purged on the 16/03/2016		18.5	4.44	16	<0.01	<1	<1	4	3	<1	3	0.01	<0.05	0.006	<0.05
SPR1401	4/05/2016		Clear	14	5.11	17	0.02	<1	<1	3	3	<1	<1	0.01	<0.05	0.027	<0.05
SPR1401	3/06/2016		Clear	11.84	4.93	18	0.07	<1	<1	2	2	<1	<1	0.009	<0.05	0.026	<0.05
SPR1401	6/07/2016		Clear	10.6	5.27	20	0.03	<1	<1	3	2	<1	<1	0.011	<0.05	0.008	<0.05
SPR1401	2/08/2016		Clear to cloudy br	11.1	6.12	22	0.05	<1	<1	2	3	<1	<1	0.01	<0.05	0.025	<0.05
SPR1401	30/08/2016		Cloudy Light Brow	13.8	6.19	15.6	0.01	<1	<1	3	3	<1	<1	0.011	<0.05	0.01	<0.05
SPR1401	30/11/2016		Slight Cloudy Brov	17.8	5.73	26	0.02	<1	<1	3	3	<1	<1	0.009	<0.05	0.032	<0.05
SPR1401	5/01/2017		Slightly cloudy bro	14.4	4.84	20	0.02	<1	<1	3	2	<1	<1	0.011	<0.05	0.012	<0.05
SPR1401	5/02/2017		Clear	16.69	6.22	24	0.02	<1	<1	3	2	<1	<1	0.01	<0.05	0.012	<0.05
SPR1401	7/03/2017		Clear	15.3	5.61	22	0.02	<1	<1	3	3	<1	<1	0.009	<0.05	0.024	<0.05
SPR1401	3/04/2017		Slight cloudy	12.96	4.83	21	0.08	<1	<1	3	3	<1	<1	0.013	<0.05	0.053	<0.05
SPR1401	3/05/2017		Clear	12.13	6.07	21	0.02	<1	<1	3	3	<1	<1	0.01	<0.05	0.01	<0.05
SPR1401	29/05/2017		Clear	11.43	4.68	28	<0.01	<1	<1	3	1	<1	<1	0.011	<0.05	0.012	<0.05
SPR1401	2/08/2017		Clear	13.76	5.25	17	0.02	<1	<1	3	2	<1	<1	0.011	<0.05	0.021	<0.05
SPR1401	4/09/2017		Slightly Cloudy		5.2	18	0.02	<1	<1	2	2	<1	<1	0.008	<0.05	<0.005	
SPR1401	5/12/2017				5	19	<0.01	<1	<1	2	3	<1	<1	0.012	<0.05	<0.005	
SPR1401	7/03/2018				5.11	20.4	0.02	<1	<1	2	3	<1	<1	0.024	0.45	<0.005	
SPR1401	5/06/2018				4.87	20.7	0.01	<1	<1	5	3	<1	<1	0.032	<0.05	<0.005	
SPR1401	6/09/2018				5.01	20.6	<0.01	<1	<1	2	3	<1	<1	0.026	<0.05	<0.005	<0.05
SPR1401	4/12/2018		Brown, Turbid			19.4	0.02	<1	<1	2	3	<1	<1	0.031	<0.05	<0.005	<0.05
SPR1401	5/03/2019		Muddy		5.63	34.1	0.02	<1	<1	2	2	<1	<1	0.134	0.51	<0.005	<0.05
SPR1401	28/05/2019	Field Paramters c	Cloudy		6.39	22.3											

location ID	Date of Sample	Flow Observatio	Comments	General Comme	Appearance	Temp	pH	EC (µS/cm)	Aluminium (filt	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/l	Sulfate as SO4 -	Manganese (filt	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg/l
Bore 940	4/02/2008			Sampled at tap, clear			7.2												
Bore 940	15/02/2008			Not pumping, no sample															
Bore 940	19/02/2008			Slightly turbid			7.18												
Bore 940	26/02/2008			Slightly cloudy			7.3												
Bore 940	3/03/2008			Sampled at tap			7.5												
Bore 940	10/03/2008			Clear			7.26												
Bore 940	17/03/2008			Not pumping, not sampled															
Bore 940	26/03/2008			No flow, no sample															
Bore 940	2/04/2008			Clear			7.26												
Bore 940	8/04/2008			Clear			7.07												
Bore 940	17/04/2008			Clear			7.2												
Bore 940	23/04/2008			Sampled at tap, clear			7.17												
Bore 940	28/04/2008			Sampled at tap, clear			7.31												
Bore 940	6/05/2008			Sampled at tap, clear			7.33												
Bore 940	12/05/2008			Sampled at tap, clear			7.9												
Bore 940	20/05/2008			Sampled at tap, clear			7.9												
Bore 940	26/05/2008			Sampled at tap, clear			7.86												
Bore 940	5/06/2008			slightly turbid			7.94												
Bore 940	11/06/2008			Sampled at tap, clear			7.8												
Bore 940	17/06/2008			Sampled at tap, clear			7.94												
Bore 940	25/06/2008			Sampled at tap, clear			7.85												
Bore 940	2/07/2008			Sampled at tap, clear			8.01												
Bore 940	7/07/2008			Sampled at tap, cloudy			7.92												
Bore 940	16/07/2008			Sampled at tap, clear			8.01												
Bore 940	21/07/2008			No sample, no discharge at tap															
Bore 940	29/07/2008			Sampled at tap, clear			7.85												
Bore 940	5/08/2008			Sampled at tap, clear			8.16												
Bore 940	12/08/2008			Sampled at tap, clear			8.12												
Bore 940	20/08/2008			Dry, no flow no sample															
Bore 940	27/08/2008			Sampled at tap, clear			7.99												
Bore 940	5/09/2008			Sampled at tap, clear			7.89												
Bore 940	9/09/2008			Sampled at tap, clear			7.98												
Bore 940	19/09/2008			Sampled at tap, clear			7.83												
Bore 940	22/09/2008			Sampled at tap, cloudy			7.61												
Bore 940	29/09/2008			No discharge, no sample															
Bore 940	8/10/2008			Clear			7.48												
Bore 940	13/10/2008			Dry															
Bore 940	22/10/2008			Dry															
Bore 940	28/10/2008			Clear			7.41												
Bore 940	4/11/2008																		
Bore 940	12/11/2008																		
Bore 940	19/11/2008																		
Bore 940	27/11/2008																		
Bore 940	3/12/2008			No discharge, no sample															
Bore 940	9/12/2008			Clear			7.43												
Bore 940	17/12/2008			No discharge, no sample															
Bore 940	23/12/2008			Clear			7.41												
Bore 940	30/12/2008			Clear			7.32												
Bore 940	9/01/2009																		
Bore 940	15/01/2009						7.31												
Bore 940	22/01/2009						7.29												
Bore 940	30/01/2009						7.4												
Bore 940	5/02/2009						7.26												
Bore 940	10/02/2009						7.3												
Bore 940	16/02/2009						7.17												
Bore 940	26/02/2009						7.19												
Bore 940	5/03/2009						7.09												
Bore 940	12/03/2009						7.08												
Bore 940	18/03/2009						7.13												
Bore 940	25/03/2009						7.15												
Bore 940	30/03/2009						7.11												
Bore 940	6/04/2009						7.43												
Bore 940	17/04/2009						7.4												
Bore 940	21/04/2009						7.17												
Bore 940	30/04/2009						7.19												
Bore 940	5/05/2009						7.21												

location ID	Date of Sample	Flow Observati	Comments	General Comm	Appearance	Temp	pH	EC (µS/cm)	Aluminium (filt	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/l	Sulfate as SO4 -	Manganese (filt	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg/
Bore 940	14/05/2009						7.23												
Bore 940	18/05/2009																		
Bore 940	26/05/2009						7.06												
Bore 940	3/06/2009																		
Bore 940	12/06/2009																		
Bore 940	16/06/2009						7.12												
Bore 940	25/06/2009																		
Bore 940	2/07/2009																		
Bore 940	8/07/2009																		
Bore 940	15/07/2009						7.21												
Bore 940	21/07/2009						7.2												
Bore 940	29/07/2009						7.71												
Bore 940	4/08/2009						7.29												
Bore 940	12/08/2009						7.13												
Bore 940	21/08/2009						7.16												
Bore 940	26/08/2009						7.14												
Bore 940	31/08/2009						7.06												
Bore 940	9/09/2009						7.15												
Bore 940	14/09/2009						7.1												
Bore 940	24/09/2009						7.21												
Bore 940	28/09/2009						7.16												
Bore 940	7/10/2009						7.16												
Bore 940	16/10/2009						7.1												
Bore 940	19/10/2009						7.38												
Bore 940	30/10/2009						7.3												
Bore 940	4/11/2009						7.07												
Bore 940	11/11/2009						7.09												
Bore 940	19/11/2009						7.08												
Bore 940	25/11/2009						7.32												
Bore 940	2/12/2009						7.09												
Bore 940	11/12/2009						7.25												
Bore 940	18/12/2009						7.18												
Bore 940	22/12/2009						7.17												
Bore 940	30/12/2009						7.36												
Bore 940	7/01/2010						7.42												
Bore 940	14/01/2010						7.38												
Bore 940	19/01/2010						7.18												
Bore 940	27/01/2010						7.26												
Bore 940	9/09/2009						7.15						3.25						
Bore 940	22/01/2009						7.17						3.95						
Bore 940	7/01/2010						7.42												
Bore 940	14/01/2010						7.38												
Bore 940	19/01/2010						7.18												
Bore 940	27/01/2010						7.26												
Bore 940	16/02/2011	Sampled at tap		Clear			7.26												
Bore 940	15/03/2011	Sampled at tap		Clear			7.22												
Bore 940	18/04/2011	Sampled at tap		Clear			7.55												
Bore 940	23/05/2011	Sampled at tap		Clear			7.31												
Bore 940	21/06/2011	Sampled at tap		Clear			7.33												
Bore 940	14/07/2011	Sampled at tap		Clear			7.22												
Bore 940	22/08/2011	Sampled at tap		Clear			7.28												
Bore 940	15/09/2011	Sampled at tap		Clear			7.17												
Bore 940	13/10/2011	Sampled at tap		Clear			7.24												
Bore 940	7/11/2011	Sampled at tap		Clear			7.47												
Bore 940	24/11/2011	Sampled at tap		Clear			7.49												
Bore 940	8/12/2011	Sampled at tap		Clear			7.1												
Bore 940	21/12/2011	Sampled at tap		Clear			7.08												
Bore 940	12/01/2012	Sampled at tap					7.35												
Bore 940	24/01/2012	Sampled at tap					7.64												
Bore 940	9/02/2012	Sampled at tap					7.13												
Bore 940	21/02/2012	Sampled at tap					7.15												
Bore 940	8/03/2012	Sampled at tap					7.28												
Bore 940	20/03/2012	Sampled at tap					7.14												
Bore 940	3/04/2012	Sampled at tap					7.25												
Bore 940	17/04/2012	Sampled at tap					7.1												
Bore 940	3/05/2012	Sampled at tap					6.88												

location ID	Date of Sample	Flow Observati	Comments	General Comm	Appearance	Temp	pH	EC (µS/cm)	Aluminium (filt	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/l	Sulfate as SO4 -	Manganese (filt	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg/l
Bore 940	14/05/2012	Sampled at tap					7.19												
Bore 940	5/06/2012	Sampled at tap					7.02												
Bore 940	18/06/2012	Sampled at tap					6.82												
Bore 940	10/07/2012	Sampled at tap					7.28												
Bore 940	25/07/2012	Sampled at tap					7.78												
Bore 940	9/08/2012	Sampled at tap					7.13												
Bore 940	20/08/2012	Sampled at tap					7.29												
Bore 940	5/09/2012	Clear					7.11												
Bore 940	18/09/2012	Clear					7.37												
Bore 940	4/10/2012	Clear					7.17												
Bore 940	18/10/2012	Clear					7.13												
Bore 940	31/10/2012	Clear					7.38												
Bore 940	14/11/2012	Clear					7.07												
Bore 940	27/11/2012	Clear					7.39												
Bore 940	13/12/2012	Clear					7.21												
Bore 940	27/12/2012	Clear					7.2												
Bore 940	23/01/2013	Sampled at tap					7.11												
Bore 940	19/02/2013	Sampled at tap					7.11												
Bore 940	18/03/2013	Sampled at tap					7.17												
Bore 940	17/04/2013	Sampled at tap					7.24												
Bore 940	14/05/2013						7.33												
Bore 940	12/06/2013	Sampled from tap					7.41												
Bore 940	10/07/2013	Sampled at tap					7.23												
Bore 940	7/08/2013	Sampled at tap					7.19												
Bore 940	3/09/2013	Sampled at tap					7.4												
Bore 940	1/10/2013	Sampled at tap					7.41												
Bore 940	29/10/2013	Sampled at tap					7.51												
Bore 940	19/11/2013	Sampled at tap					7.18												
Bore 940	17/12/2013	Sampled at tap					7.62												
Bore 940	6/01/2015					23.6	7.13		0.02								0.13	0.015	0.06
Bore 940	13/01/2015					23.9	7.56		0.01	6	7	267	6	18	49		0.07	0.019	0.05
Bore 940	14/01/2015					24.5	7.48												
Bore 940	15/01/2015					24	7.67												
Bore 940	16/01/2015					22.9	7.22												
Bore 940	20/01/2015					22.5	7.24		<0.01								0.28	0.022	0.06
Bore 940	27/01/2015					21.7	7.45		0.02								0.38	0.019	0.07
Bore 940	3/02/2015					22.4	7.39		<0.01								0.06	<0.005	0.08
Bore 940	10/02/2015					21.9	7.48		0.03	7	7	281	9	20	52		0.14	0.024	<0.05
Bore 940	17/02/2015					23.9	7.3		0.01								0.19	0.013	0.06
Bore 940	25/02/2015					22	7.43		0.04								<0.05	0.021	0.05
Bore 940	3/03/2015	Clear				23.9	7.5										0.06		0.01
Bore 940	10/03/2015		Not Discharging																
Bore 940	17/03/2015		Broken Pipe																
Bore 940	24/03/2015		Not Discharging																
Bore 940	31/03/2015					23.2	7.44			23			48		3.84		0.06	0.002	3.14
Bore 940	7/04/2015	Clear				23.7	7.7		<0.01	7	8	307	14	21	44		2.83	0.014	0.06
Bore 940	14/04/2015	Clear				23.4	7.86		<0.01	2	3	292	6	20	46		0.12	0.017	0.06
Bore 940	21/04/2015					22.3	7.78		<0.01								0.63	0.01	0.06
Bore 940	28/04/2015					23	7.86		0.01								0.58		0.08
Bore 940	5/05/2015					22.7	7.9		0.02								0.63	0.007	0.06
Bore 940	12/05/2015					23.1	7.78		0.01								0.39	0.013	0.06
Bore 940	13/05/2015					21.8	7.53		<0.01	7	8	272	12	18	48		0.54	0.009	0.06
Bore 940	19/05/2015					23.3	7.83		0.01								0.61	0.009	0.07
Bore 940	2/06/2015						7.96		<0.01								0.6	0.01	0.07
Bore 940	9/06/2015					23.1	7.86		0.01								0.66	0.027	0.06
Bore 940	9/06/2015					21.2	7.37		0.01	6	8	294	12	22	45		0.21	0.011	0.06
Bore 940	10/06/2015					23	7.83		0.02	6	7	255	13	19	47		0.43	0.011	0.06
Bore 940	16/06/2015					22.9	7.75		0.01								0.47	0.012	0.06
Bore 940	23/06/2015					22.8	7.79		<0.01								0.46	0.01	0.06
Bore 940	30/06/2015					21.7	7.56		<0.01								0.48	0.01	0.06
Bore 940	7/07/2015					22.2	7.73		0.02								0.33	0.009	0.08
Bore 940	8/07/2015					22	7.78		<0.01	7	7	262	11	20	45		0.25	0.021	0.06
Bore 940	14/07/2015					22.7	7.72		0.05								0.38	0.008	0.06
Bore 940	20/07/2015					23.2	7.78												
Bore 940	21/07/2015					23.2	7.78		<0.01								0.28	0.01	0.21
Bore 940	28/07/2015					22.2	7.76		<0.01								0.28	0.005	0.07

location ID	Date of Sample	Flow Observatio	Comments	General Comme	Appearance	Temp	pH	EC (µS/cm)	Aluminium (filt	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/L	Sulfate as SO4 -	Manganese (filt	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg/
Bore 940	4/08/2015					22.8	7.75		0.14								0.23	0.012	0.06
Bore 940	6/08/2015					22.5	7.68		0.01	7	7	278	8	19	46		0.42	0.015	0.06
Bore 940	11/08/2015					23.2	7.73		<0.01								0.14	<0.005	0.06
Bore 940	18/08/2015					22.7	7.72		<0.01								0.22	<0.005	0.06
Bore 940	1/09/2015					22.6	7.65		<0.01								0.39	<0.005	0.12
Bore 940	8/09/2015					22.3	7.77		<0.01								0.58	<0.005	0.06
Bore 940	9/09/2015					22.4	7.7		<0.01	7	7	251	10	18	40		0.36	<0.005	0.05
Bore 940	15/09/2015					23.1	7.74		<0.01								0.21	<0.005	0.06
Bore 940	22/09/2015					23	7.61		<0.01								0.23	<0.005	0.06
Bore 940	29/09/2015					23.3	7.63		<0.01								0.39	0.007	0.06
Bore 940	6/10/2015					23.6	7.66		<0.01								0.54	0.008	0.06
Bore 940	8/10/2015					21.8	7.78		<0.01	7	7	270	6	19	44		0.11	<0.005	0.06
Bore 940	13/10/2015					22.9	7.5		<0.01								0.29	<0.005	0.06
Bore 940	20/10/2015					23.5	7.63		<0.01								0.25	<0.005	0.06
Bore 940	27/10/2015					22.9	7.78		<0.01								0.39	0.014	0.06
Bore 940	3/11/2015					22.7	7.58		<0.01								0.49	0.016	0.08
Bore 940	10/11/2015					23.8	7.66		<0.01	7	8	282	10	20	48		<0.05	0.015	0.07
Bore 940	10/11/2015					23.6	7.82		0.11								0.4	0.012	0.07
Bore 940	17/11/2015					23.3	7.64		<0.01								0.28	0.011	0.06
Bore 940	24/11/2015					23.9	7.4		<0.01								0.26	<0.005	0.07
Bore 940	1/12/2015					24.6	7.55		<0.01								0.18	<0.005	0.05
Bore 940	8/12/2015					23.6	7.73		<0.01								0.4	0.023	0.06
Bore 940	9/12/2015		NPI			23.5	7.4		<0.01	7	8	278	7	20	48		0.06	<0.005	0.06
Bore 940	10/12/2015					24.6	7.66		<0.01	7	7	251	11	18	49		0.3	0.013	0.08
Bore 940	15/12/2015					25.8	7.49		0.02								0.2	<0.005	0.08
Bore 940	23/12/2015					23	7.76		<0.01								0.25	<0.005	0.05
Bore 940	29/12/2015					22.7	7.56		<0.01								0.46	<0.005	0.06
Bore 940	5/01/2016				Clear	22.1	7.54		<0.01								0.5	0.01	0.06
Bore 940	7/01/2016				Clear	22.3	7.69		<0.01	7	8	274	13	19	44		<0.05	<0.005	<0.05
Bore 940	12/01/2016				Clear	23.5	7.56		<0.01								0.28	<0.005	0.06
Bore 940	19/01/2016				Clear	23.3	7.6		<0.01								0.06	<0.005	0.06
Bore 940	25/01/2016				Clear	22.9	7.42		<0.01								0.12	<0.005	0.06
Bore 940	2/02/2016				Clear	23.7	7.4		<0.01								0.27	<0.005	0.05
Bore 940	4/02/2016				Clear	17.9	6.83		<0.01	8	9	277	32	21	45		0.13	0.008	0.07
Bore 940	9/02/2016				Clear	23	7.23		<0.01								0.37	<0.005	0.06
Bore 940	16/02/2016				Clear	23.2	7.54		<0.1								0.1	<0.005	0.06
Bore 940	16/02/2016				Clear	24.5	7.76												
Bore 940	1/03/2016				Clear	23	7.19		<0.01								<0.05		<0.005
Bore 940	2/03/2016				Clear	24.3	7.64		<0.01	7	8	266	12	19	44		0.06	0.002	<0.005
Bore 940	8/03/2016				Clear	23.1	7.36		<0.01								0.06		<0.005
Bore 940	15/03/2016				Clear	23.4	7.85		0.01								0.06		<0.005
Bore 940	22/03/2016				Clear	22.9	7.76		<0.01								0.06		<0.005
Bore 940	29/03/2016		Unable to access due to chemical spill																
Bore 940	30/03/2016		Weekly Parameters		Clear	23.6	7.71		<0.01								<0.05		0.08
Bore 940	30/03/2016		NPI		Clear	23.6	7.71		<0.01	8	8	250	<1	20	35		0.06	0.002	0.065
Bore 940	5/04/2016		No Sample																
Bore 940	12/04/2016				Clear	23.5	7.63		<0.01	8	8	298	5	22	34		0.22	<0.005	0.06
Bore 940	12/04/2016				Clear	23.2	7.8		<0.01								0.4	<0.005	0.06
Bore 940	19/04/2016				Clear	23.6	7.68		0.03								0.16	<0.005	0.06
Bore 940	26/04/2016				Clear	22.5	7.79		0.12								0.39	0.014	0.07
Bore 940	3/05/2016				Clear	22.8	7.62		0.12								0.11	0.015	0.06
Bore 940	10/05/2016				Clear	22.7	7.79		<0.01	8	7	257	6	19	33		0.09	<0.005	0.05
Bore 940	17/05/2016				Clear	22.9	7.74		<0.01								0.11	<0.005	0.06
Bore 940	24/05/2016				Clear	22.5	7.74												
Bore 940	31/05/2016				Clear	22.7	7.71		<0.01								0.16	0.008	0.06
Bore 940	6/06/2016				Clear	22.4	7.8		<0.01	7	6	259	7	16	29		<0.05	<0.005	<0.05
Bore 940	7/06/2016				Clear	21.7	7.91		<0.01								0.15	<0.005	0.05
Bore 940	14/06/2016				Clear	21.7	7.84		<0.01								0.15	<0.005	<0.05
Bore 940	21/06/2016				Clear	22.4	7.78		<0.01								0.14		0.06
Bore 940	28/06/2016				Clear	22.4	7.92		<0.01								0.13	0.01	0.06
Bore 940	5/07/2016				Clear	22	7.85		<0.01								0.17	<0.005	0.06
Bore 940	5/07/2016				Clear	22	7.85		<0.01	7	6	246	6	18	31		0.28	<0.005	0.06
Bore 940	12/07/2016				Clear	22.9	7.68		<0.01								0.24	0.009	0.09
Bore 940	19/07/2016				Clear	22.7	7.68		<0.01								0.19	0.005	0.06
Bore 940	26/07/2016				Clear	22.5	7.63		<0.01								0.33	0.006	0.07
Bore 940	2/08/2016				Clear	23.1	7.76		<0.01								0.28	0.007	0.07

location ID	Date of Sample	Flow Observatio	Comments	General Comme	Appearance	Temp	pH	EC (µS/cm)	Aluminium (filt	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/l	Sulfate as SO4 -	Manganese (filt	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg/
Bore 940	2/08/2016				Clear	23.1	7.76		<0.01	8	8	267	6	20	24		0.22	<0.005	0.07
Bore 940	9/08/2016				Clear	22.7	7.82		<0.01								0.27	<0.005	0.07
Bore 940	16/08/2016				Clear	23.4	7.67		<0.01								0.34	<0.005	0.06
Bore 940	23/08/2016				Clear	23.4	7.69		<0.01								0.29	<0.005	0.06
Bore 940	30/08/2016				Clear	23.9	7.59		<0.01								0.29	<0.005	0.07
Bore 940	5/09/2016				Clear	19.2	7.39												
Bore 940	6/09/2016				Clear	23.6	7.72		<0.01								0.06		0.009
Bore 940	13/09/2016				Clear	23.9	7.74		<0.01								0.06		<0.005
Bore 940	19/09/2016		NPI		Clear	22	7.75		<0.01	8	8	267	6	20	26		<0.05	0.001	<0.005
Bore 940	20/09/2016				Clear	23.3	7.73		<0.01								0.07		<0.005
Bore 940	27/09/2016				Clear	23.2	7.83		<0.01								0.08		0.016
Bore 940	4/10/2016				Clear	22.6	7.76		<0.01								0.07		0.014
Bore 940	11/10/2016				Clear	23.2	7.69		<0.01								0.06		0.007
Bore 940	12/10/2016				Clear	18.4	6.74		<0.01	8	8	278	6	20	22		0.06	0.001	0.008
Bore 940	18/10/2016				Clear	23.8	7.69		0.01								0.06		<0.005
Bore 940	25/10/2016				Clear	23.8	7.71		<0.01								0.06		0.006
Bore 940	1/11/2016				Clear	23.8	7.68		<0.01								0.08		<0.005
Bore 940	8/11/2016				Clear	24.4	7.67		<0.01								0.06		<0.005
Bore 940	15/11/2016				Clear	24.1	7.71		<0.01								0.06		<0.005
Bore 940	22/11/2016				Clear	23.6	7.65		<0.01								0.07		<0.005
Bore 940	24/11/2016				Clear	23.8	7.67		<0.01	7	8	295	12	21	20		0.07	0.001	<0.005
Bore 940	29/11/2016				Clear	24.1	7.69		<0.01								0.08		<0.005
Bore 940	6/12/2016				clear	24.5	7.64		<0.01								0.06		<0.005
Bore 940	7/12/2016				Clear	24.5	7.47		<0.01								0.06		<0.005
Bore 940	13/12/2016				Clear	24.4	7.64		<0.01								0.08		<0.005
Bore 940	15/12/2016				Clear	22	7.39		<0.01	8	8	254	13	21	22		0.06	0.001	<0.005
Bore 940	20/12/2016				Clear	24.4	7.74		<0.01								0.11		<0.005
Bore 940	28/12/2016				Clear	24.5	7.68		<0.01								0.07		<0.005
Bore 940	3/01/2017					23.9	7.67		<0.01								0.23	<0.005	0.06
Bore 940	4/01/2017					22.7	7.38		<0.01	8	8	264	12	19	19		0.18	<0.005	0.09
Bore 940	10/01/2017					23.9	7.54		<0.01								0.53	<0.005	0.06
Bore 940	17/01/2017					24.7	7.71		<0.01								0.29	<0.005	0.06
Bore 940	24/01/2017					24.4	7.61		<0.01								0.27	<0.005	0.05
Bore 940	31/01/2017					24.5	7.67		<0.01								0.16	<0.005	0.06
Bore 940	7/02/2017					24.1	7.6		<0.01								0.32	<0.005	0.05
Bore 940	14/02/2017					22.1	7.63		<0.01								0.3	<0.005	0.07
Bore 940	16/02/2017					24.5	7.58		<0.01	8	7	262	11	18	20		0.09	<0.005	0.06
Bore 940	21/02/2017					23.9	7.72		<0.01								0.24	<0.005	0.07
Bore 940	28/02/2017					23.8	8.24		<0.01								0.31	0.006	0.06
Bore 940	7/03/2017					23.6	7.64		<0.01								0.18	<0.005	0.06
Bore 940	14/03/2017					22.9	7.81		<0.01								0.27	<0.005	0.05
Bore 940	21/03/2017					23.6	7.6		<0.01								0.28	0.008	0.06
Bore 940	23/03/2017		NPI			22.6	7.68		<0.01	7	7	255	6	19	13		0.19	<0.005	0.06
Bore 940	23/03/2017					22.6	7.68		<0.01	7	7	253	6	19	13		0.28	0.005	0.06
Bore 940	28/03/2017					23.3	7.54		<0.01								0.27	0.008	0.06
Bore 940	4/04/2017					24	7.42		<0.01								0.18	<0.005	0.06
Bore 940	11/04/2017					22.5	7.55		<0.01								0.24	0.011	0.06
Bore 940	12/04/2017					22.4	7.57		<0.01	7	7	246	6	20	15		0.22	0.006	0.06
Bore 940	18/04/2017					22.8	7.65		<0.01								0.21	<0.005	0.07
Bore 940	24/04/2017					23.2	7.82		<0.01								0.26	<0.005	0.05
Bore 940	2/05/2017					24	7.63		<0.01								0.16	<0.005	0.07
Bore 940	9/05/2017					22.7	7.63		<0.01								0.22	<0.005	0.06
Bore 940	16/05/2017					22.9	7.65		<0.01								0.17	0.011	<0.05
Bore 940	18/05/2017					22.2	7.48		<0.01	7	7	248	14	20	10		0.57	<0.005	0.06
Bore 940	23/05/2017					23	7.52		<0.01								0.37	<0.005	0.4
Bore 940	30/05/2017					23.4	7.57		<0.01								0.18	0.008	0.07
Bore 940	6/06/2017					22.1	7.88		<0.01								0.12	0.007	<0.05
Bore 940	7/06/2017		NPI			21.5	7.69		<0.01	8	7	263	20	19	10		0.21	<0.005	0.05
Bore 940	13/06/2017					19.2	7.15		<0.01								0.47	0.01	<0.05
Bore 940	20/06/2017					22.9	7.56		<0.01								0.56	<0.005	0.07
Bore 940	27/06/2017					22.6	7.56		<0.01								0.2	<0.005	0.07
Bore 940	28/06/2017					21.4	7.52		0.04	7	7	261	14	20	9		0.2	<0.005	0.07
Bore 940	4/07/2017					22.6	7.5		<0.01								0.4	<0.005	0.07
Bore 940	11/07/2017					21.6	7.7		<0.01								0.32	<0.005	0.06
Bore 940	18/07/2017					22.6	7.4		<0.01								0.16	<0.005	0.06
Bore 940	25/07/2017					22.7	7.8		<0.01								0.24	<0.005	0.06

location ID	Date of Sample	Flow Observati	Comments	General Comm	Appearance	Temp	pH	EC (µS/cm)	Aluminium (filt	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/l	Sulfate as SO4 -	Manganese (filt	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg/
Bore 940	26/07/2017					20.6	8.1		<0.01	7	7	250	5	19	7		0.22	<0.005	0.06
Bore 940	1/08/2017					22.9	7.8		<0.01								0.22	<0.005	0.06
Bore 940	8/08/2017					22.3	7.8		<0.01								0.21	0.007	<0.05
Bore 940	15/08/2017		Not Operational																
Bore 940	16/08/2017		Not Operational																
Bore 940	22/08/2017					23.1	7.7		<0.01								0.38	<0.005	0.06
Bore 940	29/08/2017					22.5	7.6		<0.01								0.23	<0.005	0.06
Bore 940	5/09/2017					19.8	7.9		<0.01								0.26	<0.005	0.05
Bore 940	6/09/2017		NPI			19.7	7.6		<0.01	7	7	256	12	18	5		0.11	<0.005	0.07
Bore 940	12/09/2017					22.8	7.3		<0.01								0.12	<0.005	0.05
Bore 940	14/09/2017					19.2	7.7		<0.01	7	7	257	9	17	9		0.28	<0.005	0.05
Bore 940	19/09/2017					20.7	7.7		<0.01								0.25	0.005	0.06
Bore 940	26/09/2017					21.1	7.6		<0.01								0.36	<0.005	0.07
Bore 940	3/10/2017					20	7.6		<0.01								0.24	<0.005	0.1
Bore 940	10/10/2017					20.7	7.6		<0.01								0.33	<0.005	0.15
Bore 940	11/10/2017					21.2	7.7		<0.01	7	7	265	8	19	11		0.26	<0.005	0.06
Bore 940	17/10/2017					21.9	7.2		<0.01								0.32	<0.005	0.06
Bore 940	24/10/2017					22.2	7.5		<0.01								0.35	<0.005	<0.05
Bore 940	31/10/2017					22.1	7.9		0.01								0.57	0.013	0.06
Bore 940	7/11/2017								<0.01								0.31	<0.005	<0.05
Bore 940	8/11/2017					19.2	7.5		0.03	8	7	280	10	19	13		1.76	0.027	0.06
Bore 940	14/11/2017					21.9	7.8		<0.01								0.28	<0.005	0.05
Bore 940	21/11/2017					21.7	7.7		<0.01								0.36	<0.005	0.07
Bore 940	28/11/2017					21.5	7.8		<0.01								0.37	0.006	0.06
Bore 940	4/12/2017		No Sample																
Bore 940	5/12/2017		Not Operational																
Bore 940	7/12/2017					22.1	7.7		<0.01								0.1	<0.005	0.08
Bore 940	7/12/2017		NPI			22.1	7.7		<0.01	8	6	247	8	18	11		0.23	<0.005	0.07
Bore 940	12/12/2017		Exploration			21.9	7.5		<0.01	8	7	279	10	18	11		0.3	<0.005	0.08
Bore 940	12/12/2017					21.9	7.5		<0.01								0.39	0.007	<0.05
Bore 940	19/12/2017		Not Operational																
Bore 940	20/12/2017					22.1	7.7		<0.01								0.17	<0.005	0.08
Bore 940	27/12/2017					20.9	7.6		<0.01								0.24	<0.005	0.06
Bore 940	2/01/2018					21.7	7.7		<0.01								0.15	<0.005	0.15
Bore 940	9/01/2018					21	7.7		<0.01								0.3	<0.005	<0.05
Bore 940	11/01/2018					21	7.3		0.06	7	7	248	9	19	11		1.92	0.006	0.06
Bore 940	16/01/2018					20.8	7.7		<0.01								0.4	<0.005	0.12
Bore 940	23/01/2018					21.5	7.6		<0.01								0.22	<0.005	0.06
Bore 940	30/01/2018					23.7	7		<0.01								0.34	0.006	0.07
Bore 940	6/02/2018					21.9	7.6		0.02								0.35	0.008	0.06
Bore 940	13/02/2018					22.5	7.1		<0.01	8	7	252	8	18	10		0.34	<0.005	0.07
Bore 940	13/02/2018					22.1	7.4		<0.01								0.26	<0.005	0.07
Bore 940	20/02/2018					21.2	7.7		<0.01								0.18	0.007	0.06
Bore 940	27/02/2018					20.8	7.4		<0.01								0.26	<0.005	0.07
Bore 940	6/03/2018					21.3	7.3		0.01								0.28	0.007	0.07
Bore 940	13/03/2018					22	7.3		<0.01								0.2	<0.005	0.06
Bore 940	15/03/2018					22.5	7.3		<0.01	7	6	249	13	17	10		0.24	<0.005	0.08
Bore 940	20/03/2018					22.1	7.6		0.01	7	6	243	13	18	9		0.09	<0.005	0.06
Bore 940	27/03/2018					21.4	7.4		<0.01								0.17	<0.005	<0.05
Bore 940	3/04/2018					20.9	7.6		<0.01								0.24	<0.005	0.06
Bore 940	9/04/2018					22.7	7.3		<0.01	8	7	252	12	19	7		0.18	<0.005	<0.05
Bore 940	10/04/2018					21.1	7.3		<0.01								0.17	0.006	0.07
Bore 940	17/04/2018					21.4	7.6		<0.01								0.22	<0.005	0.07
Bore 940	24/04/2018					21.1	7.5		<0.01								0.15	<0.005	0.05
Bore 940	1/05/2018					21.2	7.5		<0.01								0.11	<0.005	0.06
Bore 940	8/05/2018					20.9	7.6		<0.01								0.12	<0.005	0.06
Bore 940	9/05/2018					21.1	7.4		<0.01	8	7	244	11	18	6		0.07	<0.005	0.06
Bore 940	15/05/2018					20.9	7.6		<0.01								0.2	<0.005	0.07
Bore 940	22/05/2018					21.5	7.7		<0.01								0.12	<0.005	0.07
Bore 940	29/05/2018					8.2	7.7		<0.01								0.47	0.012	0.06
Bore 940	5/06/2018					6.8	6.9		<0.01								1.38	0.026	0.06
Bore 940	5/06/2018		NPI Quarterly			6.8	6.9		<0.01	8	7	249	7	18	6		1.42	0.027	0.06
Bore 940	6/06/2018		Not Operational																
Bore 940	12/06/2018		Not Operational																
Bore 940	19/06/2018		Not Operational																
Bore 940	20/06/2018		Not Operational																

location ID	Date of Sample	Flow Observati	Comments	General Comm	Appearance	Temp	pH	EC (µS/cm)	Aluminium (filt	Calcium mg/L	Magnesium mg	Sodium mg/L	Chloride mg/L	Potassium mg/l	Sulfate as SO4 -	Manganese (filt	Iron (filt) mg/L	Zinc (filt) mg/L	Boron (filt) mg/l
Bore 940	26/06/2018		Not Operational																
Bore 940	3/07/2018					21.3	7.6		0.04								0.19	0.006	0.08
Bore 940	9/07/2018					19.7	7.7		<0.01	6	6	249	6	17	5		0.16	<0.005	0.07
Bore 940	10/07/2018					19.7	7.5		<0.01								0.15	<0.005	0.05
Bore 940	17/07/2018					17.9	7.7		<0.01								0.25	0.01	0.08
Bore 940	24/07/2018					19.7	7.3		<0.01								0.12	<0.005	0.07
Bore 940	31/07/2018					21.3	7.6		<0.01								0.33	<0.005	0.06
Bore 940	7/08/2018					22.9	7.3		<0.01								0.15	<0.005	0.06
Bore 940	13/08/2018					20.6	7.1		<0.01	8	7	245	11	21	8		0.26	<0.005	0.07
Bore 940	14/08/2018					22.4	7.2		0.01								0.32	0.019	0.08
Bore 940	21/08/2018					19.8	7.5		<0.01								0.36	<0.005	0.07
Bore 940	28/08/2018					20.7	7.5		0.01								0.3	<0.005	0.08
Bore 940	4/09/2018					20.9	7.5		<0.01	7	6	224	5	16	8		0.25	0.006	0.06
Bore 940	11/09/2018					21.1	7.6		<0.01	8	7	250	6	19	8		0.23	<0.005	0.06
Bore 940	18/09/2018					20.7	7.8		<0.01	8	6	245	6	19	8		0.31	<0.005	0.08
Bore 940	24/09/2018					18	7.5		<0.01	7	7	251	6	18	8		0.16	<0.005	0.06
Bore 940	2/10/2018					15.4	7.5		<0.01	8	7	248	6	19	9		0.11	0.054	0.13
Bore 940	9/10/2018					21.6	7.7		<0.01	8	7	265	6	19	6		0.28	0.012	0.07
Bore 940	16/10/2018					21.5	7.3		0.01	7	7	250	14	19	5		0.31	<0.005	0.07
Bore 940	23/10/2018					22	7.5		<0.01	7	6	237	5	18	6		0.29	<0.005	0.07
Bore 940	30/10/2018					21.8	7.7		0.05	7	7	240	6	18	7		0.2	0.006	0.06
Bore 940	6/11/2018		Sample taken from a tap			22.1	7.5		<0.01	7	6	225	7	17	8		0.25	0.006	0.07
Bore 940	13/11/2018		Sample taken from a tap			21.8	7.8		<0.01	7	6	230	6	18	6		0.25	<0.005	0.07
Bore 940	20/11/2018		Sample taken from a tap			24.1	7.5		<0.01	8	7	256	4	19	5		<0.05	<0.005	0.07
Bore 940	27/11/2018					21.9	7.6		<0.01	7	7	235	5	18	5		0.25	0.006	0.07
Bore 940	4/12/2018					21	7.6		<0.01	7	6	244	4	19	4		0.24	<0.005	<0.05
Bore 940	11/12/2018		Sample from a tap			21	7.7		<0.01	8	7	254	6	20	5		0.25	<0.005	0.09
Bore 940	17/12/2018		Sample disposed as per client request - Client Equipment Failure																
Bore 940	24/12/2018					14.7	7.8		<0.01	8	7	245	6	18	4		0.09	0.006	0.05
Bore 940	2/01/2019		Pump not working no sample taken																
Bore 940	8/01/2019		Pump out of services																
Bore 940	15/01/2019		Pump out of services																
Bore 940	22/01/2019		Pump out of services																
Bore 940	29/01/2019		Pump out of services																
Bore 940	5/02/2019		Not operational																
Bore 940	12/02/2019		Not operational																
Bore 940	19/02/2019					20.6	7.5		<0.01	6	6	278	5	17	<1		0.06	<0.005	0.06
Bore 940	26/02/2019		From tap			13.2	7.4		<0.01	6	6	244	4	16	2		<0.05	<0.005	0.06
Bore 940	5/03/2019					20.1	7.3		<0.01	6	6	263	5	18	<1		<0.05	0.011	0.05
Bore 940	12/03/2019					26.2	7.3		<0.01	8	6	266	6	20	3		<0.05	0.015	0.06
Bore 940	19/03/2019					26.5	7.4		<0.01	8	6	260	5	18	1		<0.05	0.024	0.06
Bore 940	26/03/2019					22.7	7.6		<0.01	6	6	270	5	18	<1		0.16	<0.005	0.06
Bore 940	2/04/2019		From Tap			16.8	7.7		<0.01	6	6	269	3	18	<1		0.15	0.049	<0.05
Bore 940	9/04/2019					16.2	7.5		<0.01	8	7	276	4	19	<1		<0.05	0.006	0.12
Bore 940	16/04/2019					13.2	7.5		<0.01	6	6	267	4	16	2		0.87	0.013	0.07
Bore 940	23/04/2019		Not sampled as Raw Bore 940 not discharging																
Bore 940	30/04/2019		From Tap			13.5	7.4		<0.01	6	5	244	4	17	<1		<0.05	0.005	0.06
Bore 940	7/05/2019					21	6.8		<0.01	8	8	277	7	20	15		0.35	<0.005	0.06
Bore 940	14/05/2019					9.1	6.7		<0.01	8	8	271	6	21	30		<0.05	0.013	0.07
Bore 940	21/05/2019		Not operational																
Bore 940	28/05/2019		Not operational																

Centennial Angus Place Pty Ltd

Angus Place Mine Extension Project (SSD 06_0021): Amendment Report Hydrogeological Model Report

18 October 2019

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Angus Place Mine Extension Project (SSD 06_0021):
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EXECUTIVE SUMMARY

A revised groundwater model has been developed for the Angus Place Mine Extension Project: Amended Project. The involves extension of mining in the 1000 Panel Area.

The model, together with the Swamp Water Balance Model that was developed concurrently with the groundwater model, addresses issues raised during submissions on the Angus Place Mine Extension Project Environmental Impact Assessment by the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mine Development of the Department of Environment and Energy of the Australian Government. As well, the model responds to the new requirements of the Independent Expert Scientific Committee with respect to predictive uncertainty analysis.

Groundwater model calibration indicates that, now observed, changes to groundwater level in Temperate Highland Peat Swamps on Sandstone (THPSS) (which comprise the Newnes Plateau Shrub Swamp and Newnes Plateau Hanging Swamp listed under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth)) at the adjacent mine, Springvale Mine, are matched. Whilst changes to groundwater level in THPSS were predicted at the time of Angus Place Mine Extension Project Environmental Impact Statement, the magnitude observed at the adjacent mine, Springvale Mine, are significantly higher than was presented.

Model simulations incorporating predictive uncertainty analysis have also been undertaken. Modelling indicates that significant decreases in water table levels within THPSS are expected, with the exception of Wolgan River Swamp Upper Swamp and Wolgan River Swamp, as those swamps have a significant contributing catchment from a groundwater and surface water perspective.

Analysis also indicates that the significant decreases in water table levels within THPSS would not recover within the 50 year post mining prediction period.

Consideration of climate change on model predictions is also presented in this report. Analysis indicates that model predictions are not particularly sensitive to assumed climatic conditions.

Groundwater license requirements and combined mine dewatering volumes are presented within the report. Modelling indicates that peak groundwater licence requirement is 6761ML from the Sydney Basin Richmond Groundwater Source in water year 2037/38. Modelling indicates that peak groundwater licence requirement is 1045ML from the Sydney Basin Coxs River Groundwater Source in water year 2039/40.

Surface water licensing requirements are also presented in this report. Modelling indicates that peak surface water licence requirement is 84ML from the Colo River Management Zone of the Hawkesbury and Lower Nepean Rivers Water Source in water year 2041/42. Modelling indicates that peak surface water licence requirement is 13ML from the Wywandy Management Zone of the Upper Nepean and Upstream Warragamba Water Source in water year 2030/31.

Glossary

DRN – an abbreviation for Drain Module boundary condition; is a MOFLOW module that is used for mining cells, seepage faces and ephemeral surface watercourses. Originally developed in MODFLOW for agricultural drains, where flow is one-way/out of the groundwater model.

Equivalent porous media – an assumption of MODFLOW that hydraulic properties within a cell are constant and representative of all detail within that cell through a bulk/single value.

FAO56 – an abbreviation for a standard method of calculating evapotranspiration based on the Penman-Monteith equation. The method is described in the United Nations Food and Agriculture Organisation Irrigation and Drainage Paper No. 56.

FIXED – a term used in the PEST control file to hold a parameter at its current value and not change it.

GHB – an abbreviation for General Head Boundary Module boundary condition; is a MODFLOW module that is generally used on edge of a model domain to represent a constant head value at a significant distance from the edge of the model domain.

IDENTPAR.exe – a PEST utility that calculates the identifiability of a parameter using the methodology of Doherty and Hunt (2009). It is highlighted, however, that because a parameter is not identifiable does not mean that the parameter is not important to the model simulation, just that the calibration dataset does not inform the value of that parameter.

IESC – Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development within the Department of Environment and Energy, Commonwealth of Australia

JCO2JCO.exe – a PEST utility to translate the Jacobian matrix (sensitivity matrix) from one version of a PEST control file to another.

Latin Hypercube Sampling – a mathematical technique, supported through a PEST utility, to deliberately sample the highest and lower probability values of a parameter set informed through its parameter uncertainty file.

MODFLOW-USG – Groundwater modelling code of the United States Geological Survey; the Unstructured Grid variant.

NARCliM – New South Wales and Australian Capital Territory Regional Climate Modelling Project.

Null Case – mining does not proceed into the 1000 Panel Area.

NULL_u90 dataset – output from groundwater model uncertainty analysis associated with the Null Case, consistent with the 90th percentile difference in seepage flows and groundwater/surface water interaction between the Proposed and Null Case simulations.

NULL_u10 dataset – output from groundwater model uncertainty analysis associated with the Null Case, consistent with the 10th percentile difference in seepage flows and groundwater/surface water interaction between the Proposed and Null Case simulations.

Parameter Uncertainty File – a text file that sets the 5th and 95th expected values of parameters to be included in model simulations incorporating predictive uncertainty.

PEST – a parameter estimation and uncertainty analysis software platform; BEOPEST is an alternative version of PEST configured for distributed computing; PEST_HP is a commercial version of PEST.

PEST2LHS.exe – a PEST utility that creates an input file for Latin Hypercube Sampling from a PEST control file and parameter uncertainty file.

PNULPAR.EXE – a PEST utility that facilitates calibration-constrained Monte Carlo uncertainty analysis. The utility superimposes 'calibration knowledge' on the random parameter fields generated by Latin Hypercube Sampling.

Proposed Case – extension of mining at Angus Place Colliery into the 1000 Panel Area.

PROP_u90 dataset – output from groundwater model uncertainty analysis associated with the Proposed Case, consistent with the 90th percentile difference in seepage flows and groundwater/surface water interaction between the Proposed and Null Case simulations.

PROP_u10 dataset – output from groundwater model uncertainty analysis associated with the Proposed Case, consistent with the 10th percentile difference in seepage flows and groundwater/surface water interaction between the Proposed and Null Case simulations.

RIV – an abbreviation for River Module boundary condition; is a MODFLOW module used for perennial watercourses such as lakes and rivers. Flow can be into or out of the groundwater model through a RIV boundary condition.

SAPSWBM – Springvale Angus Place Swamp Water Balance Model; a surface water model that is presented concurrently with this report (refer JBS&G, 2019).

SILO Climatic Dataset - it is maintained by the Science and Technology Division of the Queensland Department of Environment and Science. The rainfall and evapotranspiration data of the SILO climatic dataset is used in this report.

SVADPREP.exe – a PEST utility that groups parameters together based on singular value decomposition (SVD) analysis and rewrites a PEST control file using singular values, thereby significantly reducing the number of simulations needed for each iteration of the calibration process.

SP – an abbreviation for Stress Period; a Stress Period is set in MODFLOW, usually months or quarters, where boundary conditions are constant for that period.

SVD – Singular Value Decomposition; a mathematical technique to identify significant features from a calibration dataset based on the observation sensitivities to the intended parameter set.

SUPCALC.exe – a PEST utility used to identify the number of singular values from a Jacobian matrix/PEST control file.

THPSS – Temperate Highland Peat Swamps on Sandstone

TS – an abbreviation for Time Step; the number of time steps per Stress Period is set in MODFLOW, usually 4 or 5, applied exponentially. Model output is calculated at each time step, however, is only saved if requested.

TVM – an abbreviation for the Time-Varying Material Module; is a MODFLOW module that facilitates changes to hydraulic properties at specified Stress Period. Used in this report to model the subsidence-induced impact of mining.

1. Introduction

This chapter presents the context, objective and layout of the report.

1.1 Overview of Angus Place Colliery

Angus Place Colliery is an existing underground coal mine located northwest of Lithgow, NSW with approval to produce up to 4 million tonnes per annum (Mtpa) of run-of-mine (ROM) high quality thermal coal for domestic marks, including the Mount Piper Power Station which produces about 15% of the total electricity generated in New South Wales (NSW).

Angus Place Colliery is currently on Care and Maintenance and has been since March 2015. Development consent for Angus Place Colliery (SSD 06_0021) will expire in August 2024.

The mine is located 15 kilometres (km) to the northwest of the regional city of Lithgow and is 120 km west northwest of Sydney in NSW.

The Angus Place Colliery Pit Top is situated at the foot of the Newnes Plateau and mining occurs beneath the plateau in the Lithgow Seam, which outcrops in the vicinity. The generalised dip of the Lithgow Seam is to the northeast under a gradient of about 2 to 3 degrees.

Angus Place Colliery is owned by Centennial Springvale Pty Limited (50%) and Springvale SK Kores Pty Limited (50%) as participants in the Springvale unincorporated joint venture. Angus Place Colliery is operated by Centennial Angus Place Pty Limited (Centennial Angus Place).

1.2 Angus Place Mine Extension Project: Amended Project

The MODFLOW groundwater model has been developed to support the Angus Place Mine Extension Project (SSD 5581) Amendment Report. The elements of the Amended Project of relevance to the groundwater model report are as follows:

- An updated mine plan comprising 15 longwalls (LW1001 – LW1015) of varying lengths but all with void widths of 360 m and 55 m chain pillar widths
- Extraction heights of:
    - 2.8 m to 3.4 m for LW1001 – LW1008
    - 1.9 m to 2.5 m for LW1009 – LW1015
- Development of roadways between the Angus Place LW900W area to Springvale Mine mains headings
- Coal production rate of 4.5 Mtpa.

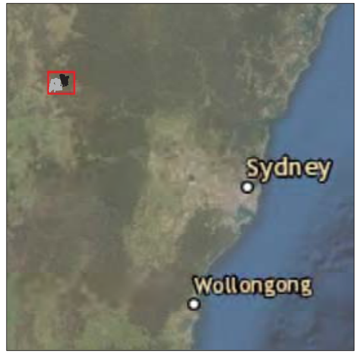
Figure 1.1 presents the layout of mining at Angus Place Colliery, including the panel widths and mine heights. The Mine Schedule, as implemented in the groundwater model, is presented in **Appendix C**.

1.3 IESC Comments on the Angus Place Mine Extension Project

The Angus Place Mine Extension Project received a series of comments from the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mine Development (IESC) on the groundwater model prepared at that time (IESC, 2014). That model was the COSFLOW model developed by the CSIRO (2013) and the Groundwater Impact Assessment was prepared by RPS (2014a).

Longwall Name	Panel Width (m)	Mining Height (m)
LONGWALL 1015	350.38	2.5
LONGWALL 1014	350.38	2.5
LONGWALL 1013	350.38	2.5
LONGWALL 1012	350.38	2.5
LONGWALL 1011	350.38	2.5
LONGWALL 1010	350.38	2.5
LONGWALL 1009	350.38	2.5
LONGWALL 1008	350.38	3.4
LONGWALL 1007	350.38	3.4
LONGWALL 1006	350.38	3.4
LONGWALL 1005	350.38	3.4
LONGWALL 1004	350.38	3.4
LONGWALL 1003	350.38	3.4
LONGWALL 1001	350.38	3.4
LONGWALL 1002	350.38	3.4

Legend:
- Angus Place Proposed Extension
- Angus Place Existing Mine



JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1 | Date: 17-Oct-2019

Drawn By: JZ | Checked By: JB

Scale 1:60,000

0 1 2
km

Coor. Sys. GDA 1994 MGA Zone 56

Site Location and Longwall Layout

FIGURE: 1.X

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D000_LWLayout.mxd
Reference: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Comments received from the IESC were as follows:

- Relevant data and information:
  - Requirement to characterise existing surface water, groundwater and ecological conditions for the majority of Temperate Highland Peat Swamps on Sandstone (THPSS) (*IESC01*).
  - Seasonal surface water flow and an assessment, or estimation, of the baseflow component of the Coxs River (*IESC02*).
- Application of appropriate methods:
  - Inclusion of all swamps in the groundwater model (*IESC03*).
  - Finer scaled, site specific models, informed by a conceptualisation of the hydrology and hydrogeology, would be needed to have confidence in the predictions of groundwater impacts to individual swamps (*IESC04*).
  - Water quality impact estimations for the Coxs River need to consider the increased discharge volumes to Coxs River resulting from reduced demand from the Wallerawang Power Station (*IESC05*).
- Reasonable values and parameters in calculation:
  - Confidence in groundwater model predictions is limited by a lack of site-specific hydrogeological data and lineament groundwater flow behaviour (*IESC06*).

A response to the comments received from the IESC was provided in RPS (2014b). As well, the issues raised were taken into consideration during the development of the new groundwater and swamp water balance models.

An updated response to matters raised by the IESC is provided in **Section 6.2**.

1.4 Water Management Strategy

1.4.1 Current Approach

Angus Place Colliery is currently operating under Care and Maintenance.

A significant volume of water is currently stored underground at Angus Place Colliery in the 800 and the 900 Panel Areas. Water stored in the 900 Panel Area is currently being dissipated through the temporary Angus Place Water Treatment Project (Modification 5 to Angus Place Colliery's project approval (PA 06_0021), now development consent (SSD 06_0021)) with discharge of treated groundwater (treated to 350µS/cm) at a rate up to 10ML/d through Angus Place Licensed Discharge Point 001 (LDP001) to the Coxs River catchment until 31 December 2019. Residuals from the temporary Angus Place Water Treatment Project (as approved) are being diverted to the 800 Panel Area until 31 December 2019. The current stored volume in the 800 Panel Area is being maintained until 31 December 2019.

As presented in JBS&G (2018), from 1 January 2020, discharge from LDP001 will cease and groundwater will be transferred to the Springvale Water Treatment Project for treatment and beneficial re-use within the Mount Piper Power Station cooling water system. From 1 January 2020, dewatering of the 800 Panel Area will commence with transfer to the Springvale Water Treatment Project. That transfer from the 800 Panel Area will include transfer of residuals.

1.4.2 Future Changes

With the extension of Angus Place Colliery into the 1000 Panel Area (this Project), groundwater will continue to be transferred to the Springvale Water Treatment Project for subsequent beneficial re-use at the Mount Piper Power Station.

1.5 Purpose and Objective of the Report

This report presents outcomes of a numerical groundwater model that has been prepared to support the Groundwater Impact Assessment being prepared for the Angus Place Mine Extension Project: Amended Project. Accordingly, this report comprises a technical report on the outcomes of groundwater modelling and reference is made to the Impact Assessment for details in that regard.

It is noted that a surface water model to predict the water cycle of swamps as a result of the Project was also developed concurrently with the groundwater model.

1.6 Layout of the Report

In the context of the project purpose and objectives, the layout of the report (this document) is as follows:

- Chapter 1 – presents the objective of this report and the layout of the report
- Chapter 2 – notes the limitations of the analysis and the report
- Chapter 3 – presents a brief summary of the hydrogeological and environmental setting
- Chapter 4 – presents detailed discussion of the numerical groundwater model including results
- Chapter 5 – presents an analysis of licensing requirements
- Chapter 6 – provides conclusions from the analysis
- Chapter 7 – presents relevant references
- Appendices – present further detail of model-related assumptions and outcomes.

2. Limitations

This report has been prepared for use by the client who has commissioned the works in accordance with the project brief only, and has been based in part on information obtained from the client and other parties.

The advice herein relates only to this project and all results conclusions and recommendations made should be reviewed by a competent person with experience in environmental impact assessment, before being used for any other purpose.

JBS&G accepts no liability for use or interpretation by any person or body other than the client who commissioned the works. This report should not be reproduced without prior approval by the client, or amended in any way without prior approval by JBS&G, and should not be relied upon by other parties, who should make their own enquires.

This report does not provide a complete assessment of the environmental status of the site, and it is limited to the scope defined herein. Should information become available regarding conditions at the site including previously unknown issues, JBS&G reserves the right to review the report in the context of the additional information.

3. Hydrogeological Setting

This chapter provides a brief overview of the hydrogeological and environmental setting of the project at Angus Place Mine Extension Project.

3.1 Overview

Angus Place Colliery is located in the Western Coalfields of NSW, to the northwest of Lithgow.

Mining occurs at Angus Place Colliery in the Lithgow Seam, which is accessed from the Wolgan Road at Lidsdale at the foot of the Newnes Plateau. The dip of the Lithgow Seam is to the northeast at about 2%. The range of elevation of the Lithgow Seam at Angus Place Colliery, including the 1000 Panel Area (the Project) is between 840 metres Australian Height Datum (mAHD) and 670mAHD.

Angus Place Colliery is overlain by the Newnes Plateau. The Newnes Plateau is a surface topographical feature that divides the surface water catchments into the Coxs River (west, southwest), Wolgan River (north) and Bungleboori Creek (east).

Figure 3.1 presents the Digital Elevation Model for the region.

It is noted that the dashed black outline in **Figure 3.1** is the active extent of the groundwater model.

3.2 Rainfall and Evapotranspiration

Rainfall and evapotranspiration (FAO56) data for the region was obtained from the SILO climatic dataset from the Queensland Department of Environment and Science (DES). The gridded dataset (0.05 degrees, equivalent to 5km x 5km cells) was also used in the Springvale Angus Place Swamp Water Balance Model (SAPSWBM) (JBS&G, 2019).

Figure 3.2 presents the distribution of the gridded dataset for rainfall including average annual isohyets for rainfall (mm). **Figure 3.3** presents the equivalent gridded dataset for evapotranspiration (FAO56).

A summary of average rainfall and evapotranspiration (FAO56) from grid cell H7, located above the proposed 1000 Panel Area, is presented in **Table 3.1**.

FAO56 is a standard method of calculating evapotranspiration based on the Penman-Monteith equation. The method is described in the United Nations Food and Agriculture Organisation Irrigation and Drainage Paper No. 56.

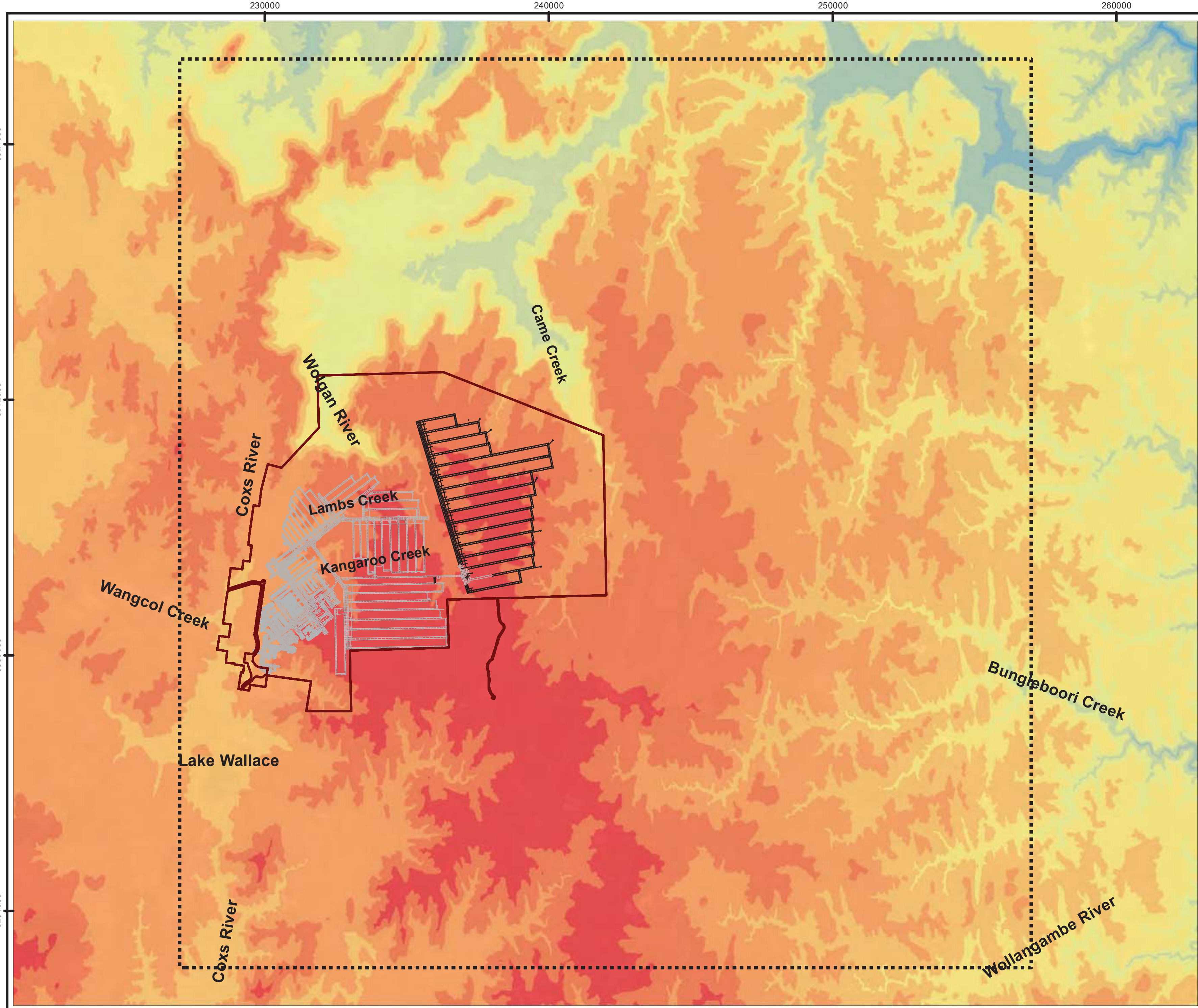
Table 3.1: Rainfall and FAO56 Monthly Average for Cell H7 (mm)

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Rainfall Mean	89.3	86.9	79.1	57.9	54.7	60.9	55.3	55.6	52.0	65.4	73.0	76.8	807.0
FAO Mean	147.1	116.3	101.7	68.9	47.0	32.8	37.5	52.3	75.2	106.0	124.9	146.6	1056.4

For future predictions using the numerical groundwater model, data from the New South Wales and Australian Capital Territory Regional Climate Modelling Project (NARCliM) was accessed.

Of the models available, after adaptation to the SILO grid presented above:

- 'Average' Climate conditions were represented by the ECHAM5_R3 model
- 'Lowest Cumulative Rainfall, Higher Cumulative Evapotranspiration' conditions were represented by the CSIRO-MK3.0_R1 model
- 'Highest Cumulative Rainfall, Lower Cumulative Evapotranspiration' conditions were represented by the MIROC3.2_R2 model.



Legend:
Angus Place Project Application Area
Proposed Extension (1000 Panel)
Existing Mine
Groundwater Model Domain

Elevation
60 - 200
200 - 300
300 - 500
500 - 600
600 - 700
700 - 800
800 - 900
900 - 1,000
1,000 - 1,100
1,100- 1,300

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Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02RevB | Date: 06-Aug-2019

Drawn By: JZ | Checked By: JB

Scale 1:180,000

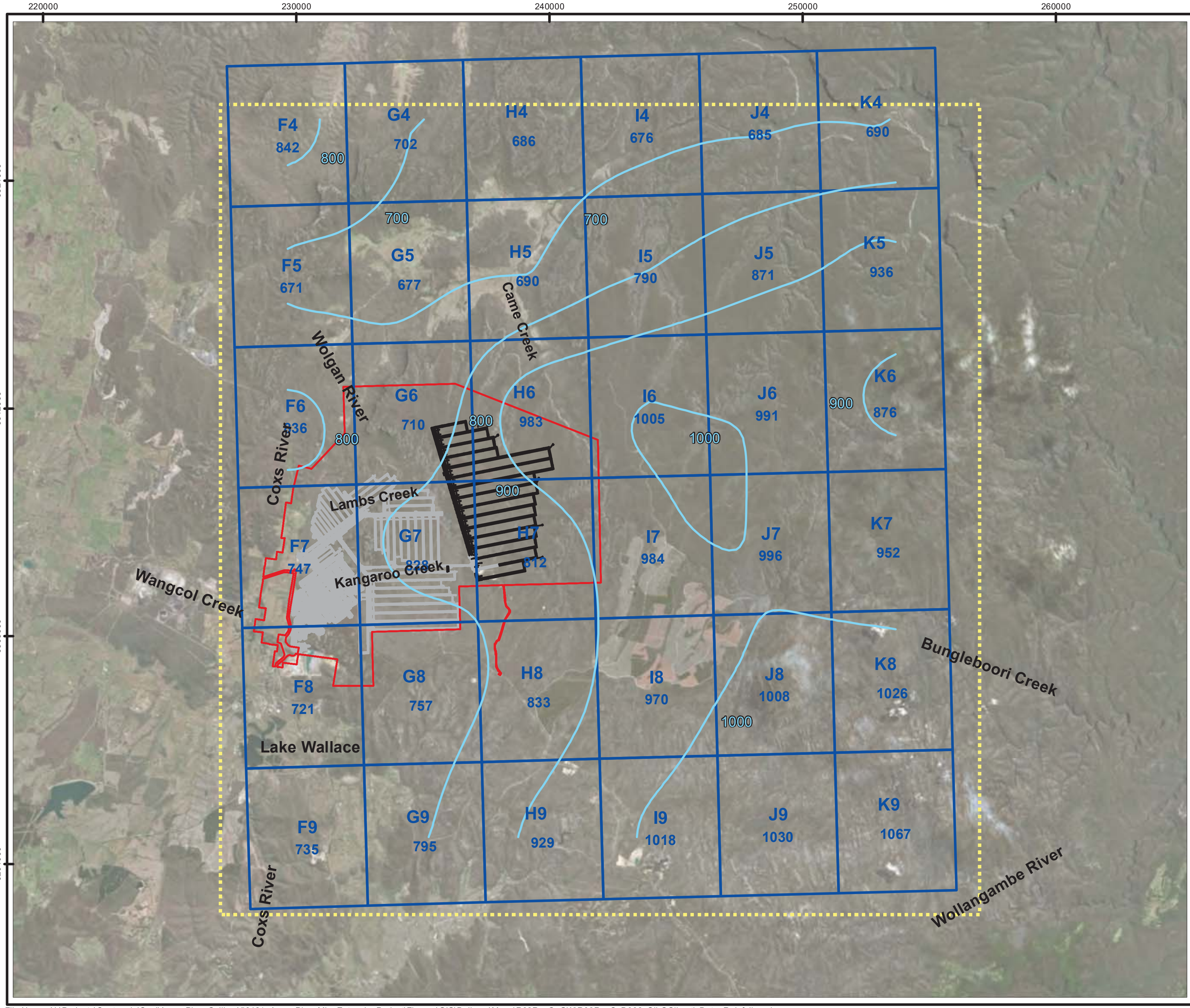
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Digital Elevation Model - Region

FIGURE: 3.1

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02RevC_GW\R02RevB_D001_DEM.mxd
Reference: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Legend:

- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- Groundwater Model Domain
- SILO Gridded Climatic Dataset: Average Annual Rainfall Value (mm)
- Isohyets of Annual Average Rainfall (mm)

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Version: R02RevC	Date: 26-Aug-2019
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Scale 1:200,000	

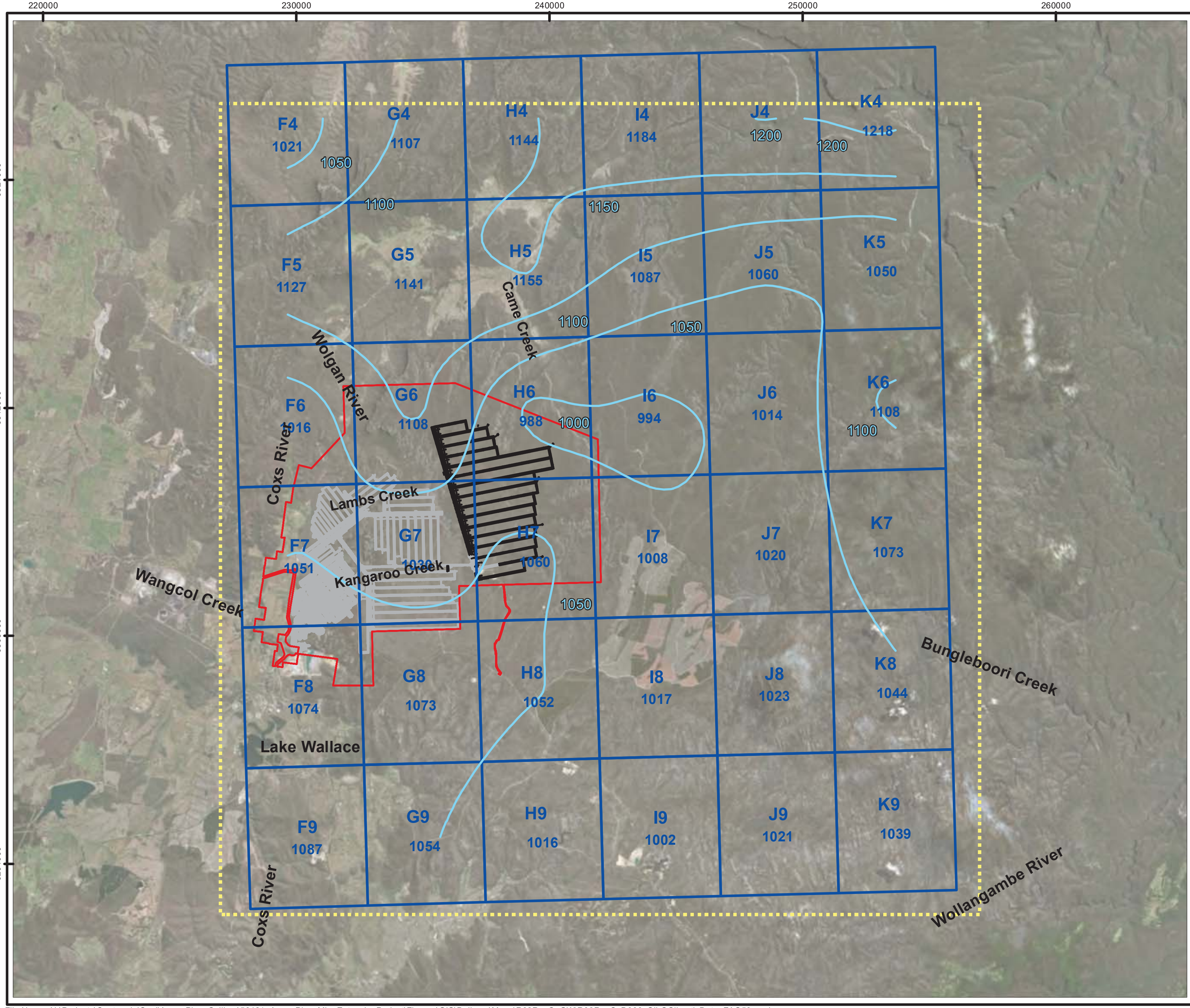
0 3 6
km

Coor. Sys. GDA 1994 MGA Zone 56

SILO Gridded Rainfall Dataset

FIGURE: 3.2

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02RevC_GW\R02RevC_D002_SILOClimaticData_Rainfall.mxd
Reference: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Legend:

- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- Groundwater Model Domain
- SILO Gridded Climatic Dataset: Average Annual FAO56 Value (mm)
- Isohyets of Annual Average FAO56 (mm)

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Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02RevC | Date: 26-Aug-2019

Drawn By: JZ | Checked By: JB

Scale 1:200,000

0 3 6
km

Coor. Sys. GDA 1994 MGA Zone 56

SILO Gridded FAO56 Dataset

FIGURE: 3.3

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02RevC_GW\R02RevC_D003_SILOClimaticData_FAO56.mxd
Reference: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

It is noted that the evapotranspiration outcomes were derived based on mean near-surface temperature derived from NARCliM and all models were found to be quite similar. The largest divergence between climate models was with respect to cumulative rainfall, hence the highest and lowest cumulative rainfall was used to select the adopted model.

It is highlighted that the abovementioned approach is consistent with the advice from the NARCLiM project, which was to select the climate model based on the expected risk of climate change to the project. For a groundwater study, the highest risk is a decline in cumulative rainfall. This is because a decline in cumulative rainfall leads to less groundwater recharge, which in turn leads to lower water table levels in THPSS as well as greater reliance of THPSS on groundwater contribution to surface water flow.

3.3 Hydrology

Angus Place Colliery encompasses two adjacent sub-catchments. The divide between the two catchments runs in a northwest-southeast direction.

To the southwest lies the Upper Nepean and Upstream Warragamba Water Source (Wywandy Management Zone). Locally, this comprises Lambs Creek, Kangaroo Creek and the Upper Coxs River.

To the northeast lies the Hawkesbury and Lower Nepean Rivers Water Source (Colo River Management Zone). Locally, this comprises Carne Creek and the Wolgan River.

3.4 Geology

Angus Place Colliery is located in the southwest corner of the NSW Western Coalfields.

The geological sequence at Angus Place Colliery is Palaeozoic (Carboniferous) through to Mesozoic (Triassic).

The Illawarra Coal Measures are of Late Permian age, and in the vicinity of Angus Place Colliery are relatively thin, with an average thickness of 110m from the Katoomba to the Lithgow Seam.

Underlying the Illawarra Coal Measures is the Shoalhaven Group (Early Permian) and below that is Carboniferous bedrock. Overlying the Illawarra Coal Measures is the Narrabeen Group (Triassic).

Within the geological sequence, from ground to seam, the following units are of hydrogeological significance:

- Burralow Formation
- Banks Wall Sandstone
- Mt York Claystone
- Burra-Moko Head Sandstone
- Caley Formation.

These formations, except for the Mt York Claystone, comprise interbedded siltstone, sandstone and conglomeratic sandstone, with occasional claystone bands, as observed in the characteristic cliffs that occur throughout the area.

It is noted that the Burralow Formation has a sequence of lower permeability shale layers (YS1, YS2, YS3, YS4, YS5, YS5a and YS6) that are important hydrogeologically.

Figure 3.4 presents the generalised stratigraphic sequence at Angus Place Colliery after McHugh (2016). As explained in RPS (2014a), the stratigraphic sequence presented in **Figure 3.4**, was discretised in the COSFLOW groundwater model (CSIRO, 2013) into Aquifer (AQ) and Semi-Permeable (SP) layers. As will be presented below, due to the requirements of Richards Equation, a finer vertical discretisation was adopted in the new groundwater model and therefore the AP and SP terminology was not used. **Figure 3.5** presents the updated discretisation.

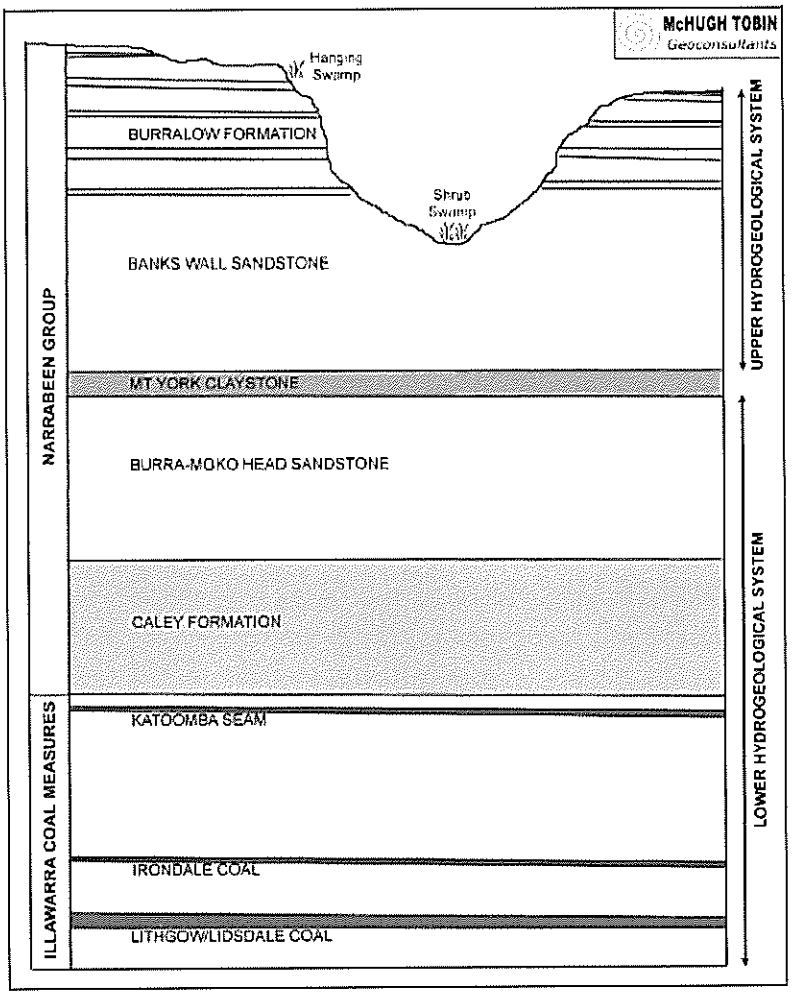


Figure 3.4: Stratigraphic Sequence at Angus Place Colliery (after Figure 16 of McHugh (2016))

3.5 Groundwater Dependent Ecosystems

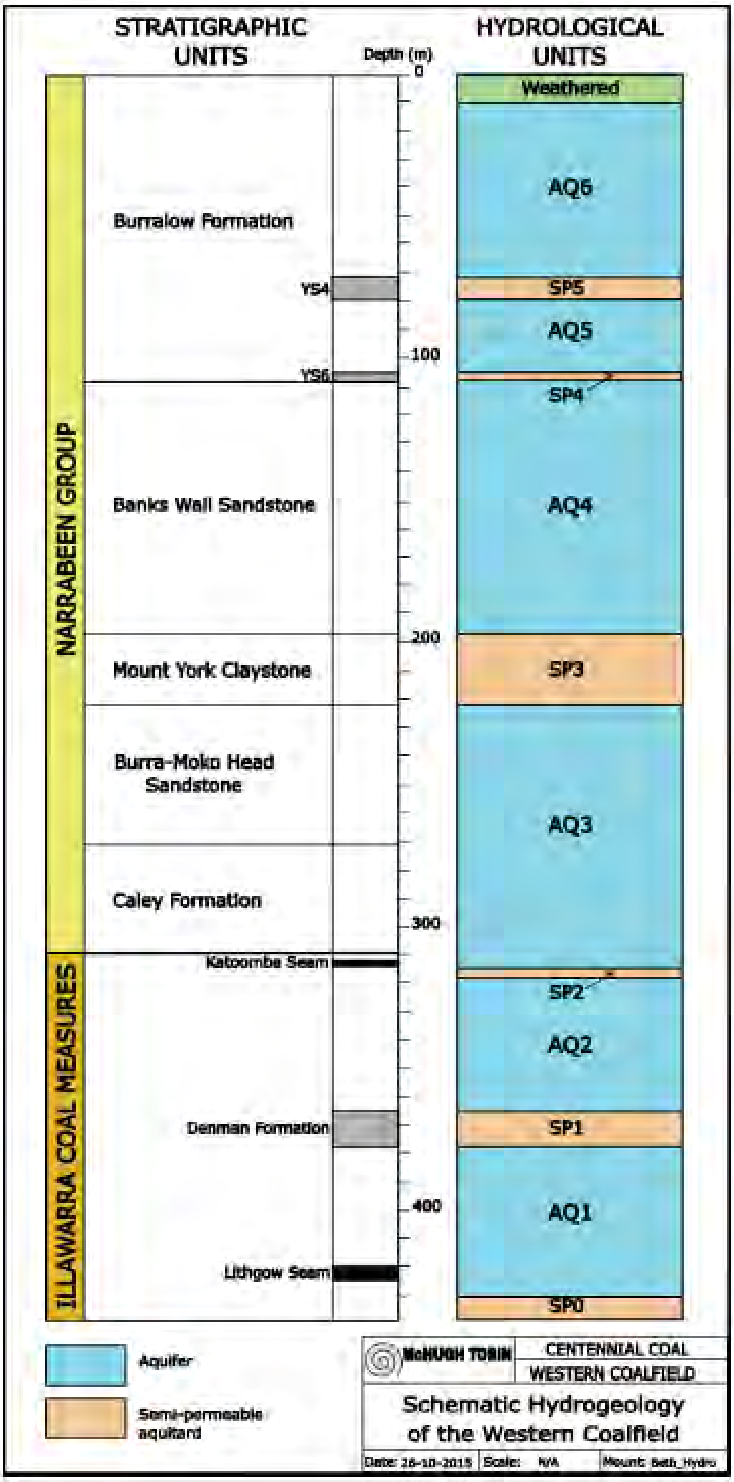
The focus of the numerical groundwater model is the THPSS that reside on the Newnes Plateau.

The SAPSWBM is the surface water balance model of THPSS at Springvale and Angus Place and was constructed, based on outcomes of previous work, to receive input from the groundwater model, namely seepage faces and groundwater/surface water interaction through the valley watercourses and swamps. It is noted that the SAPSWBM is not dynamically linked to the groundwater model.

A detailed investigation of the geology of the THPSS at Springvale Mine and Angus Place Colliery was undertaken by McHugh (2016).

The location of THPSS in the vicinity of the 1000 Panel Area at Angus Place Colliery is presented in **Figure 3.6**. It is noted that the mapped extent of THPSS presented in this report is based on the revised extents presented in RPS (2019) and not the original extents presented in DEC (2006).

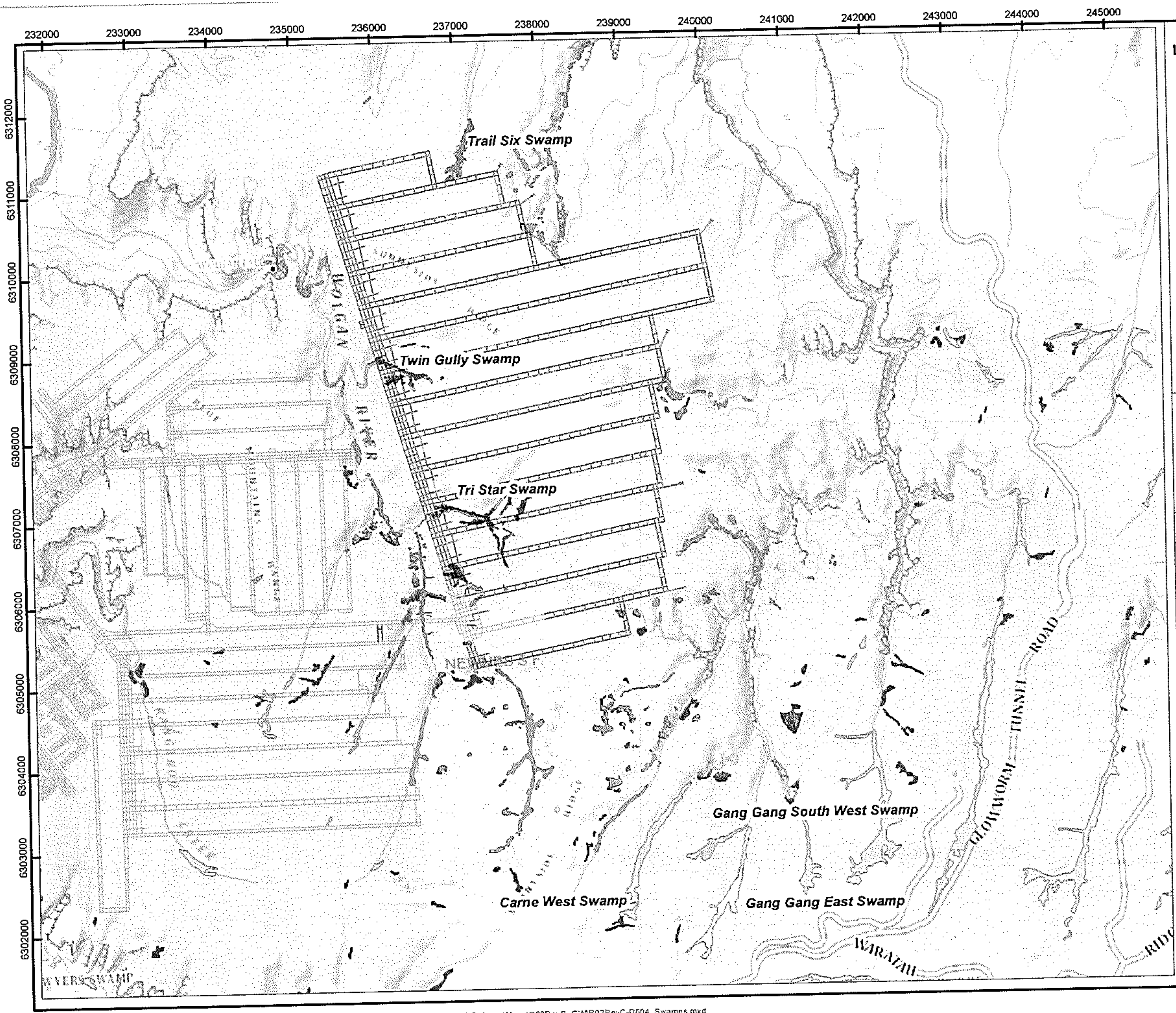
COSFLOW (CSIRO, 2013):



Updated Model:

#	Hydrogeological Unit:
1	Sandstone
2	Shale (YS1)
3	Sandstone
4	Shale (YS2)
5	Sandstone
6	Shale (YS3)
7	Sandstone
8	Shale (YS4)
9	Sandstone
10	Shale (YS5)
11	Sandstone
12	Shale (YS6)
13	Quartzose Sandstone (Banks Wall Sandstone)
14	Quartzose Sandstone (Banks Wall Sandstone)
15	Claystone (Mount York Claystone)
16	Quartzose to quartz-lithic sandstone (Burra-Moko Head Sandstone)
17	Claystone/shalestone/sandstone (Caley Formation)
18	Coal Seam (Katoomba)
19	Claystone/Shale (Farmers C'k Form'n)
20	Lithic sandstone/claystone (Gap Sandstone)
21	Mudstone/silt-claystone (Denman)
22	Sandstone/Mudstone (Glen Davis /Long Swamp Formation)
23	Conglomerate (fluvial) (Blackmans Flat Conglomerate)
24	Coal Seam (Lithgow)
25	Conglomerate (fluvial) (Marrangaroo Conglomerate)
26	Sandstone (shoreline complex - delta front (Nile Subgroup)
27	Siltstone/Sandstone (Shoalhaven Group)
28	Tuff/Granite (Carboniferous)

Figure 3.5: Hydrogeological Units considered in the Groundwater Model (modified from Figure 13 of McHugh (2016))



Legend:

- Proposed Extension
- Existing Mine
- Trail Six/Japan Swamp
- Tri Star Swamp
- Twin Gully Swamp
- Gang Gang South West Swamp
- Gang Gang East Swamp
- Carne West Swamp
- Other Swamps (RPS 2019)
- Shrub Swamp (DEC 2006)
- Hanging Swamp (DEC 2006)

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02RevC	Date: 26-Aug-2019
Drawn By: JZ	Checked By: JB

Scale 1:60,000

0 1 2
km

Coor. Sys. GDA 1994 MGA Zone 56

Location of THPSS in the vicinity of the 1000 Panel Area

FIGURE: 3.6

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02RevC_GW\R02RevC-D004_Swamps.mxd
Reference © Department of Finance Services & Innovation 2018

The THPSS that are located within 600m of the boundary of the 1000 Panel Area include:

- Wolgan River Swamp Upper Swamp
- Tri-Star Swamp
- Wolgan River Swamp
- Twin Gully Swamp
- Crocodile Swamp
- Birds Rock Swamp
- Trail Six Swamp

It is noted that only Twin Gully and Tri-Star Swamp will be undermined in the Amended Project. It is also noted that the location of lineaments with respect to each of the THPSS described in this section are presented in the Groundwater Impact Assessment.

3.5.1 Wolgan River Swamp Upper Swamp

In the recently updated mapping of THPSS on the Newnes Plateau, RPS (2019) the extent of the shrub swamp along the Wolgan River has increased compared to that presented in DEC (2006). That swamp is located below Narrow Swamp, East Wolgan Swamp and Sunnyside Swamp is described in two parts. The upper part of the shrub swamp is referred to in this report as the Wolgan River Swamp Upper Swamp and the lower part is referred to in this report as the Wolgan River Swamp.

The Wolgan River Swamp is noted in McHugh (2016), however, detailed discussion is not presented.

Figure 3.7 presents the location of the Wolgan River Swamp Upper Swamp together with the contours of the Burralow Formation aquitard plies from McHugh (2016).

Figure 3.7: Location of Wolgan River Swamp Upper Swamp and Burralow Formation aquitards (contours from McHugh (2016), background image after Google Earth (2019))

From **Figure 3.7**, the Wolgan River Swamp Upper Swamp resides below the Burralow Formation, within the Banks Wall Sandstone.

3.5.2 Tri-Star Swamp

Figure 3.8 presents the location of Tri-Star Swamp with respect to the Burralow Formation aquitard plies.

From **Figure 3.8**, Tri-Star Swamp consists a north-east and south-east arm, as well as a downstream western arm. The north-east and south-east arms are underlain by aquitard plies YS5 to YS6. The western arm resides wholly within the Banks Wall Sandstone.

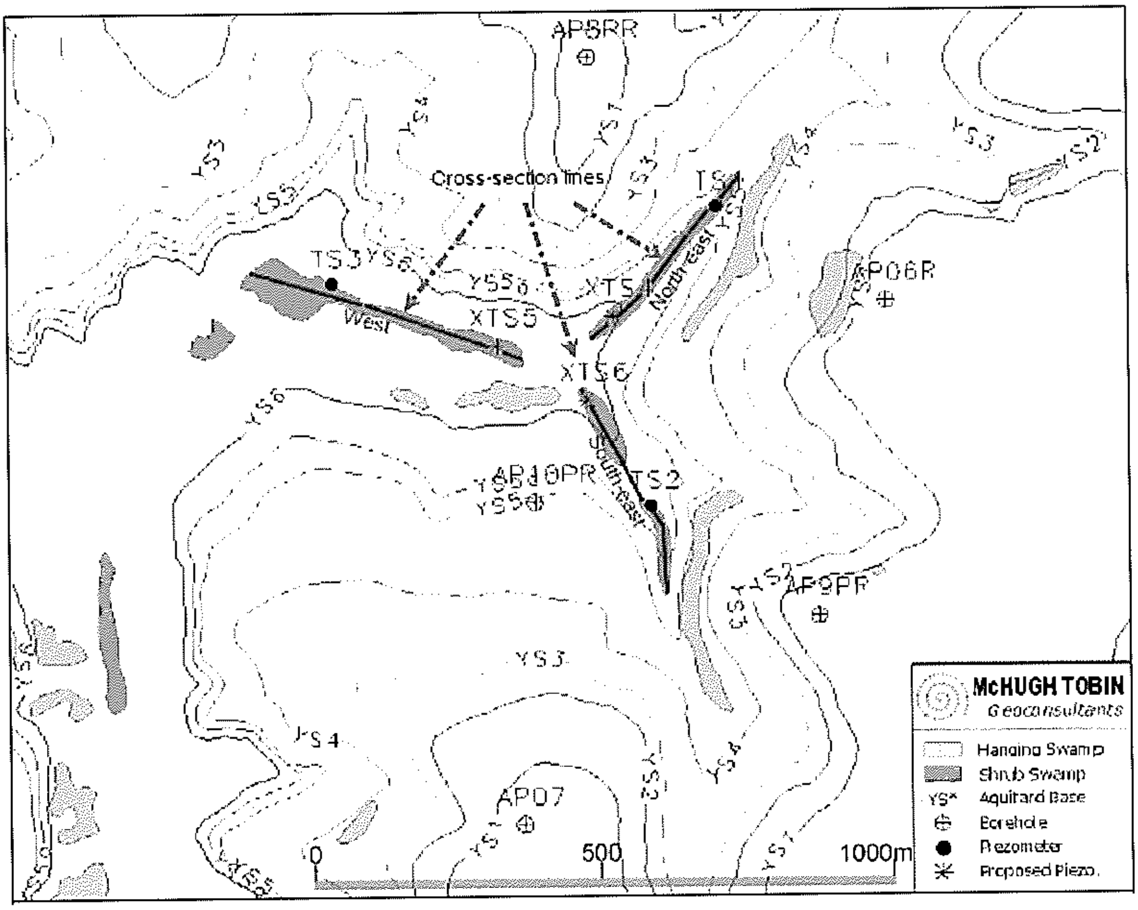


Figure 3.8: Location of Tri-Star Swamp and Burralow Formation aquitards (after Figure 40 of McHugh (2016))

3.5.3 Wolgan River Swamp

The Wolgan River Swamp is described as being the lower portion of the shrub swamp along the Wolgan River. The Wolgan River Swamp is identified in McHugh (2016) as Wolgan Swamp, but is referred to in this report as the Wolgan River Swamp, rather than Wolgan Swamp, so as to distinguish it from East Wolgan Swamp and West Wolgan Swamp respectively.

Wolgan River Swamp is located on the Wolgan River, downstream of the confluence of the tributary containing Tri-Star Swamp.

Figure 3.9 presents the location of Wolgan River Swamp together with the Burralow Formation aquitard plies from McHugh (2016).

Figure 3.9: Location of Wolgan River Swamp and Burralow Formation aquitards (contours from McHugh (2016), background image after Google Earth (2019))

From **Figure 3.9**, Wolgan River Swamp is located wholly within the Banks Wall Sandstone.

3.5.4 Twin Gully Swamp

Figure 3.10 presents the location of Twin Gully Swamp in regard to the Burralow Formation aquitard plies.

From **Figure 3.10**, only the uppermost portion of the eastern arms of Twin Gully Swamp are underlain by YSSa and YS6, else Twin Gully Swamp resides entirely within the Banks Wall Sandstone.

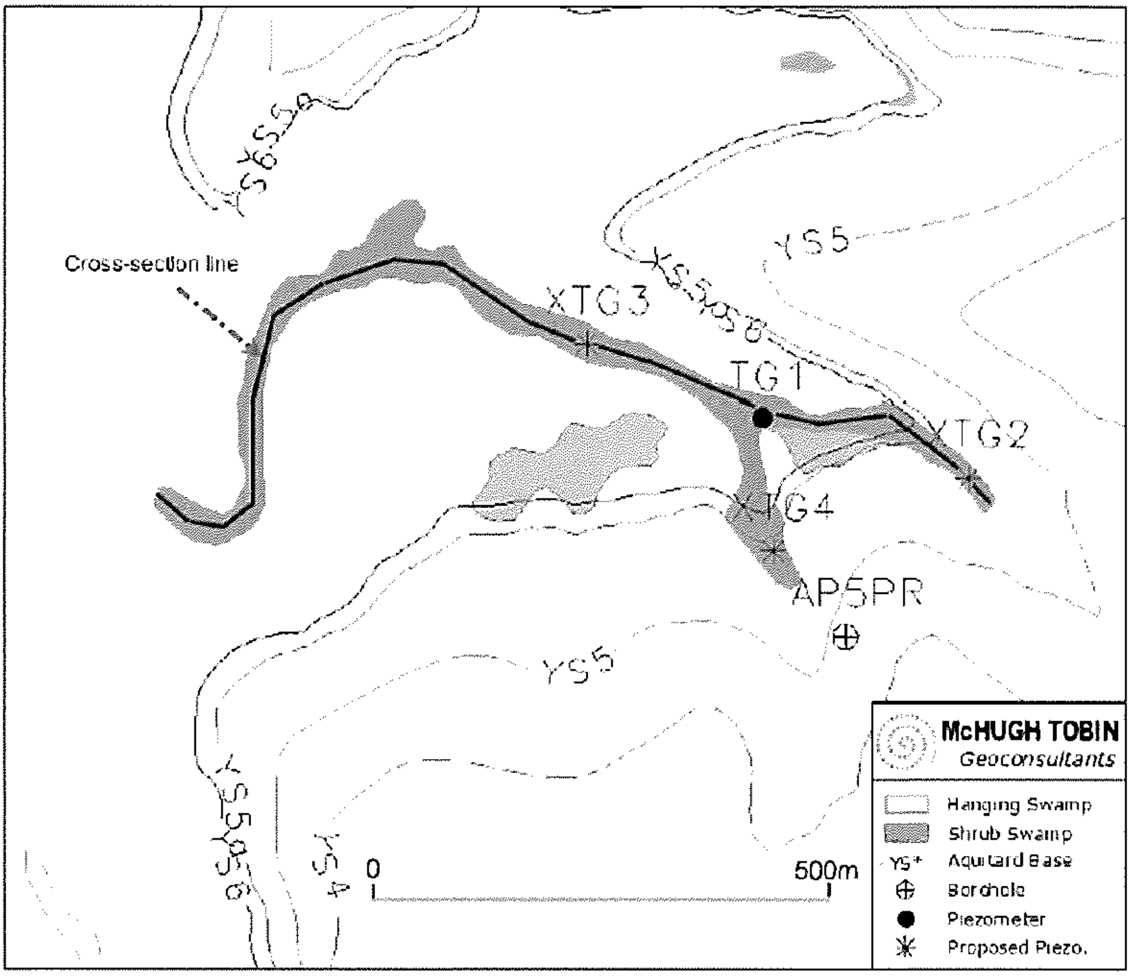


Figure 3.10: Location of Twin Gully Swamp and Burralow Formation aquitards (after Figure 40 of McHugh (2016))

3.5.5 Crocodile Swamp

Crocodile Swamp is located on the eastern side of the 1000 Panel Area.

Figure 3.11 presents the location Crocodile Swamp in regard to Burralow Formation aquitard plies

From **Figure 3.11**, Crocodile Swamp is located within the Banks Wall Sandstone. It is noted that the mapped extent of Crocodile Swamp in McHugh (2016) has been updated in RPS (2019).

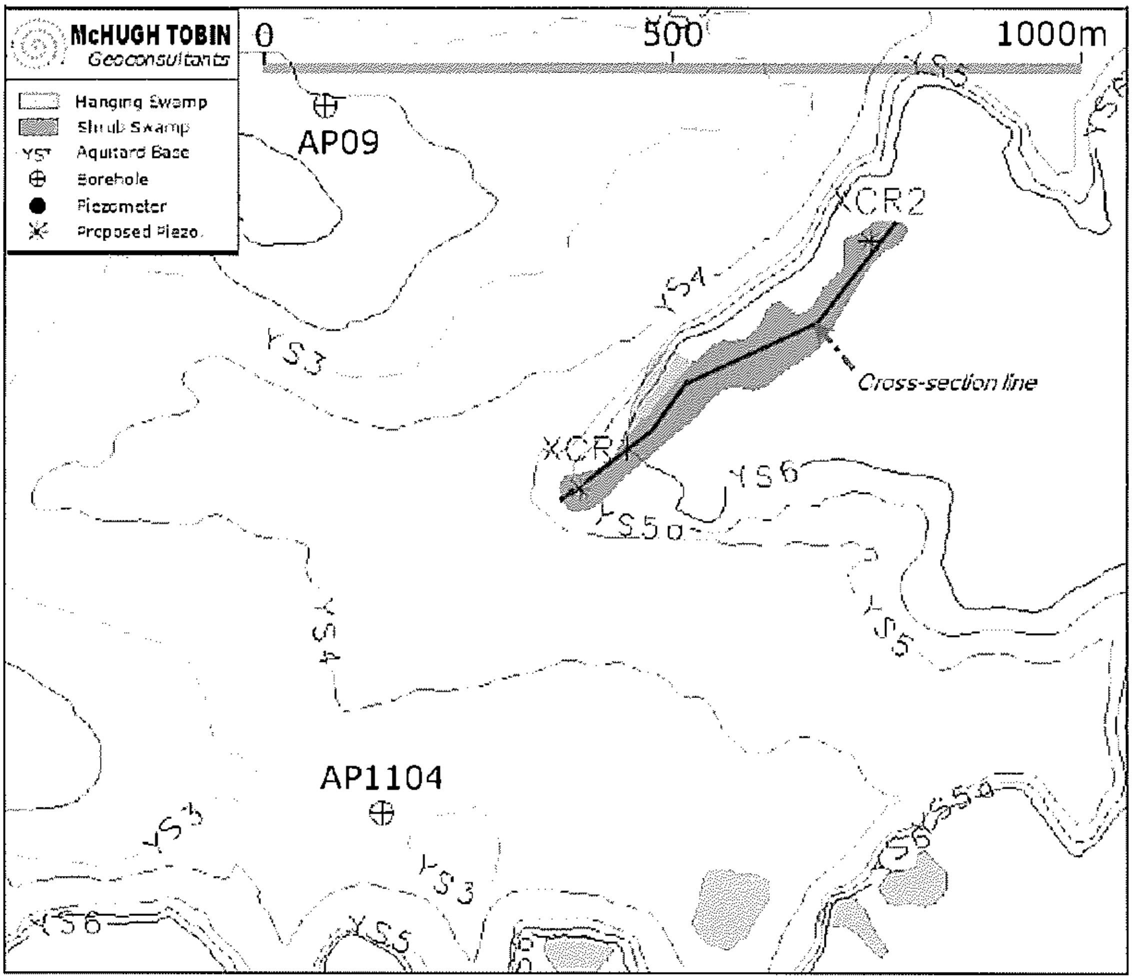


Figure 3.11: Location of Crocodile Swamp and Burralow Formation aquitards (after Figure 40 of McHugh (2016))

3.5.6 Birds Rock Swamp

Birds Rock Swamp is located to the east of the 1000 Panel Area, adjacent to LW1007 and is presented in **Figure 3.12**.

At the time of the investigation by McHugh (2016), Birds Rock Swamp was classified as a hanging swamp.

From **Figure 3.12**, Birds Rock Swamp is located below the Burralow Formation, within the Banks Wall Sandstone and consists of several small portions.

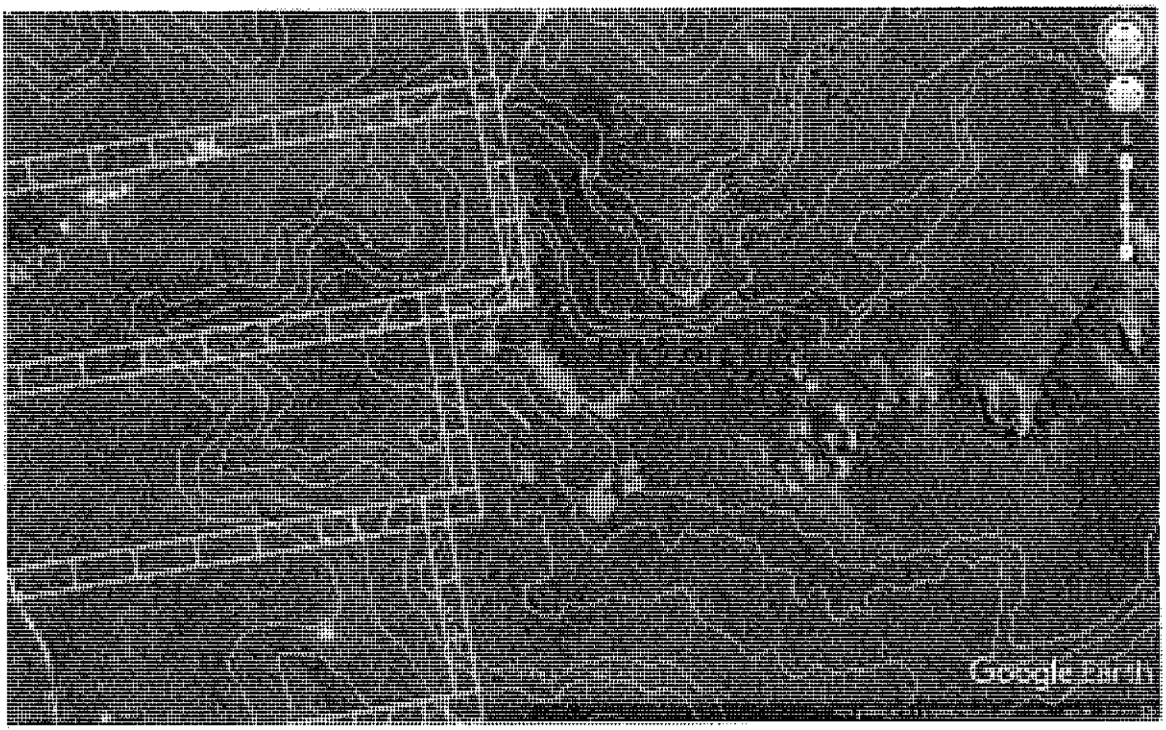


Figure 3.12: Location of Birds Rock Swamp and Burralow Formation aquitards (contours from McHugh (2016), background image after Google Earth (2019))

3.5.7 Trail Six Swamp

Figure 3.13 presents the location of Burralow Formation aquitard plies with respect to Trail Six Swamp. It is noted that Trail Six Swamp is referred to in McHugh (2016) as Japan Swamp.

From **Figure 3.13**, Trail Six Swamp resides entirely within the Banks Wall Sandstone, below the Burralow Formation.

The location of lineaments with respect to Trail Six Swamp is presented in the Groundwater Impact Assessment.

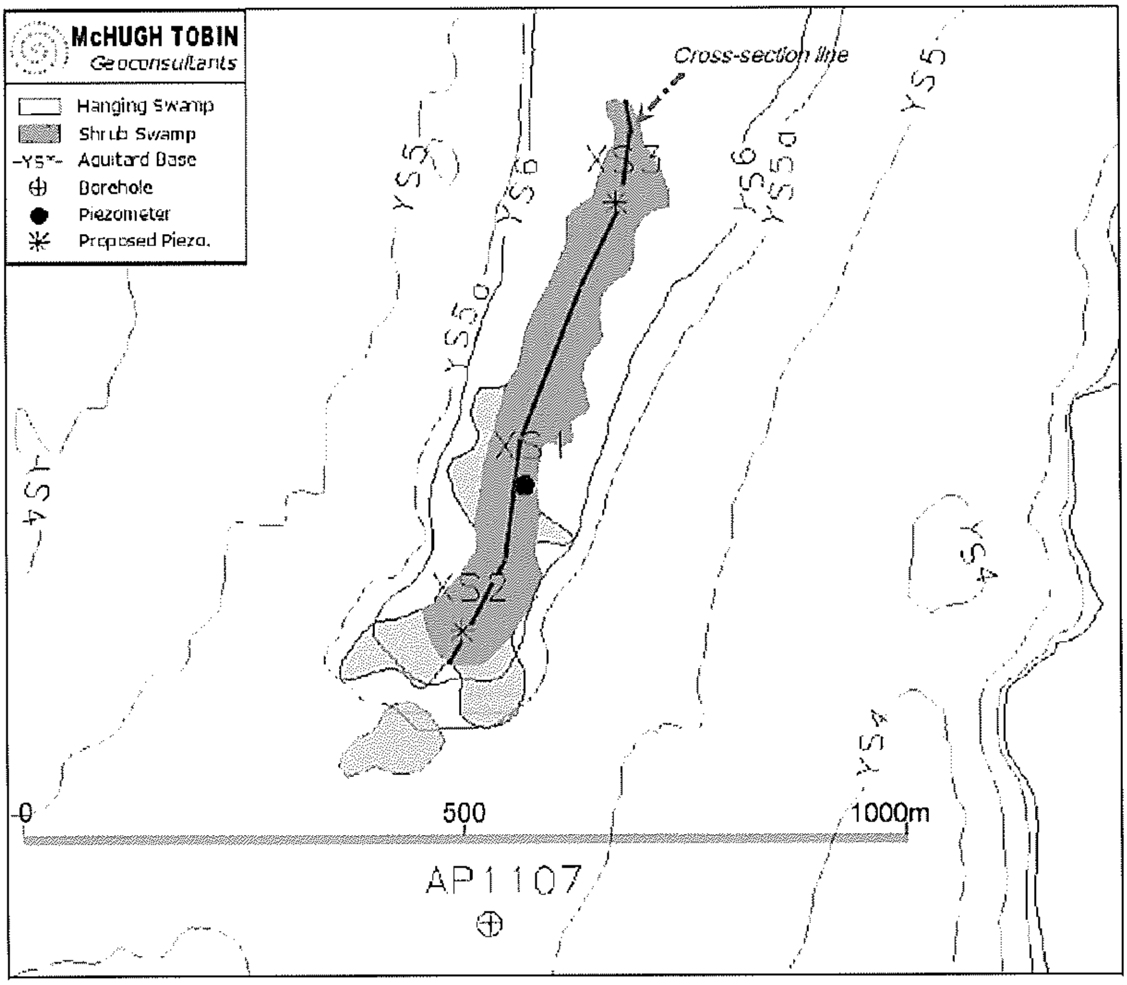


Figure 3.13: Location of Trail Six Swamp and Burralow Formation aquitards (after Figure 31 of McHugh (2016))

3.5.8 Recent Observations

Since the time of the Angus Place Mine Extension Project Groundwater Impact Assessment (RPS, 2014), changes (declines in standing water level and surface water flow) to the hydrologic regime at THPSS at the adjacent operation at Springvale Mine have been observed. For example, at Carne West Swamp, Gang Gang South West Swamp and Gang Gang East Swamp (refer **Figure 3.6**).

The Groundwater Impact Assessment presented for the Angus Place Mine Extension Project (RPS, 2014) was based on the CSIRO COSFLOW groundwater model (CSIRO, 2007 and CSIRO 2013). The CSIRO COSFLOW model was subsequently updated in CSIRO (2015) and CSIRO (2016).

Whilst some changes to the hydrologic regime in the THPSS were predicted by the CSIRO COSFLOW model, as presented in CSIRO (2013, 2015), the magnitude of the decline in water table level in the abovementioned swamps was not predicted and the current numerical groundwater model was developed as part of the engagement with the Independent Monitoring Panel during review of recent Extraction Plans at Springvale Mine.

It is noted that the Independent Monitoring Panel was established at Springvale Mine in accordance with the Project Consent requirements at Springvale Mine.

3.6 Surrounding Operations

There are several mining operations in the vicinity of Angus Place Colliery, including the 1000 Panel Area. These include:

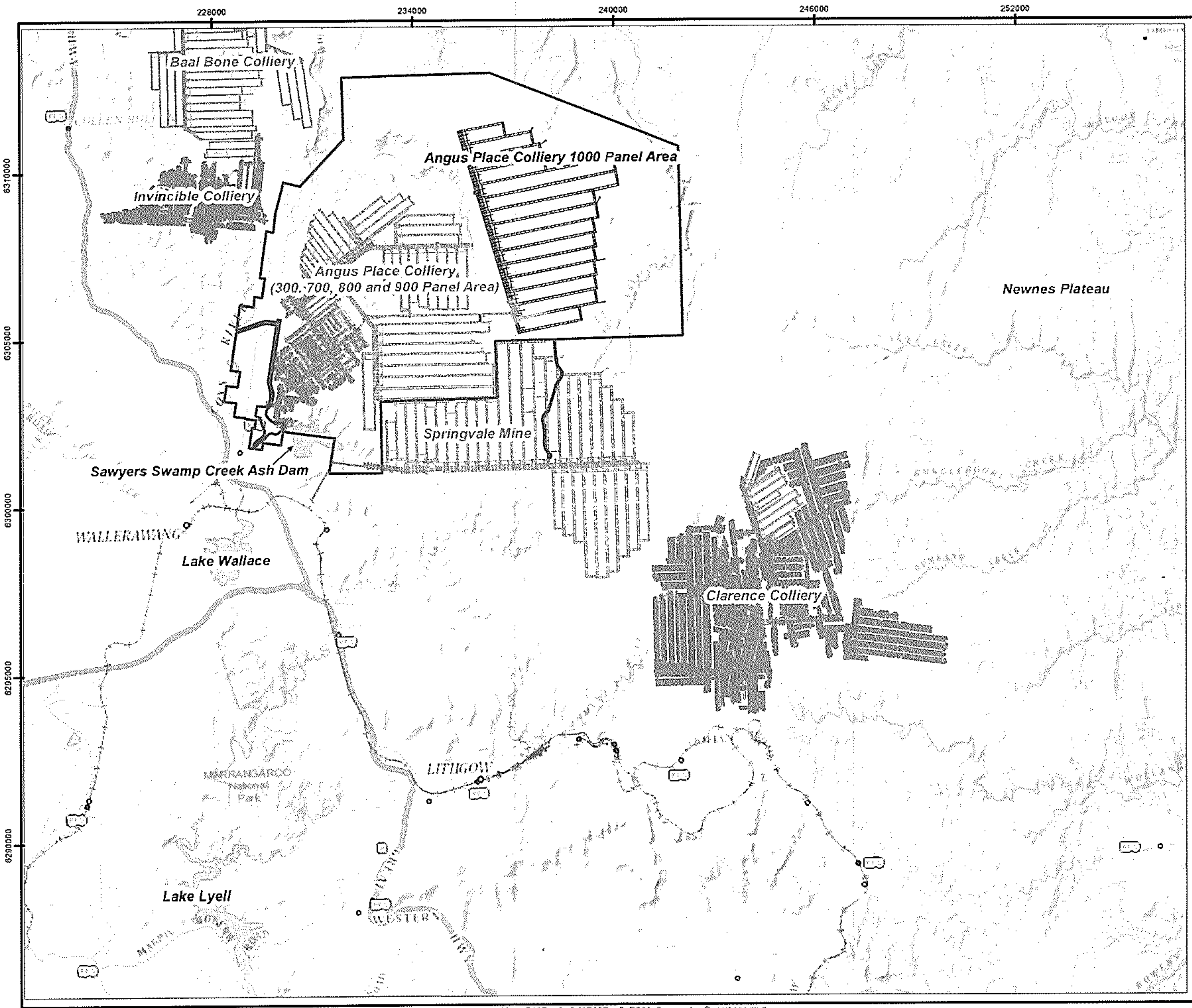
- Springvale Mine, located to the immediate south of Angus Place Colliery:
  - Springvale Mine is operated by Centennial Coal, however, is a separate entity.
- Clarence Colliery, located to the far southeast of Angus Place Colliery and to the east of Springvale Mine:
  - Clarence Colliery is operated by Centennial Coal, however, is, again, a separate entity.
- Baal Bone Colliery, located to the west of Angus Place Colliery, on the other side of the Upper Coxs River:
  - Baal Bone was assumed in the model to be maintained in a dewatered state until October 2018, however, is understood to have been decommissioned earlier
  - Baal Bone is, essentially, a 'dry' mine.
- Invincible Colliery, located to the west of Angus Place Colliery, on the other side of the Upper Coxs River:
  - Invincible was assumed in the model to be maintained in a dewatered state until 2025
  - Invincible is, essentially, a 'dry' mine.

Figure 3.14 presents the location of mining operations adjacent Angus Place Colliery.

3.7 Groundwater Monitoring Network and Summary of Groundwater Investigations

Detailed description of the groundwater monitoring network at Angus Place Colliery is presented in the Groundwater Assessment.

Similarly, a detailed summary of groundwater investigations undertaken at Angus Place Colliery is also presented in the Groundwater Assessment.



Legend:

Angus Place Project Application Area

Angus Place Colliery 1000 Panel

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02RevC	Date: 26-Aug-2019
Drawn By: JZ/JB	Checked By: JB
Scale 1:150,000	

0 2.5 5
km

Coor. Sys. GDA 1994 MGA Zone 56

Location of Mining Operations Immediately Adjacent Augus Place Colliery

FIGURE: 3.14

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02RevC_GW\R02RevC_D001_SurroundingOperations.mxd
Reference: © Department of Finance, Services & Innovation 2018

4. Conceptual Model and Numerical Analysis

This chapter presents the model objectives, model setup including conceptual model (general), model calibration, sensitivity analysis/parameter identifiability and model results incorporating predictive uncertainty.

4.1 Risk Assessment Framework

As identified in the Information Guidelines and the Explanatory Note on Uncertainty Analysis prepared by the IESC (IESC, 2018ab), environmental assessment should be conducted within a risk assessment framework.

A risk assessment was conducted as part of the development of the numerical groundwater model for Springvale Mine and Angus Place Colliery. As identified, a risk assessment was required in response to the draft Explanatory Note on Uncertainty Analysis being issued by the IESC.

The risk assessment was undertaken using Centennial's formal Risk Management Tools, referred to as Workplace Risk Assessment and Control (WRAC). Risk assessment is a typical undertaking in mining operations and there is a well-developed methodology.

The Risk Rating (RR) is based on Likelihood multiplied by Consequence and includes:

- Financial Impact to Annual Business Plan
- Personal Injury
- Business Interruption
- Legal
- Reputation
- Environment

Figure 4.1 presents Centennial's risk matrix, with accompanying ratings based upon adopted likelihood and consequence scales.

CENTENNIAL RISK MATRIX							Likelihood					
	Consequence Note: Consequence may result from a single event or may represent a cumulative impact over a period of 12 months. Use the worst case reasonable consequence if there is more than one.						A Certain	B Probable	C Possible	D Remote	E Improbable	Description (D)
Rating	Financial Impact to Annual Business Plan (F)	Personal Injury (PI)	Business Interruption (BI)	Legal (L)	Reputation (R)	Environment (E)	Common	Has Happened within Centennial	Could Happen & has happened in non-CEY operations	Not Likely	Practically impossible	Probability (Pb)
							Frequent incidents	Regular incidents	Infrequent incidents	Unlikely to occur. Very few recorded or known incidents	May occur in exceptional circumstances Almost no recorded incidents	Incident Frequency (IF)
							Operations – within 3 months	Operations – within 2 years	Operations – within 5 years	Operations – within 10 years	Operations – within 30 years	Operations (Op)
							Project – Every project	Project – Every 2 projects	Project – Every 5 projects	Project – Every 10 projects	Project – Every 30 projects	Project (Pr)
5. Catastrophic	>$50m	Multiple Fatalities	> 1month	Prolonged litigation heavy fines potential jail term	Prolonged international media attention	Long term impairment habitats/ ecosystem	25 (E)	24 (E)	21 (H)	19 (H)	15 (S)	
4. Major	$10m - $50m	Single Fatality	1 week to 1 month	Major breach/ major litigation	International media attention	Long term effects of ecosystem	23 (E)	22 (E)	18 (H)	14 (S)	10 (M)	
3. Moderate	$1m - $10m	Serious/ Disabling Injury	1 day to 1 week	Serious breach of regulation prosecution/ fine	National media attention	Serious medium term environmental effects	20 (H)	17 (H)	13 (S)	9 (M)	6 (L)	
2. Minor	$100k - $1m	Lost Time Injury	12 hrs to 1 day	Non-compliance breaches in regulation	Adverse local public attention	Minor effects to physical environment	16 (S)	12 (S)	8 (M)	5 (L)	3 (L)	
1. Insignificant	<$100k	First Aid Treatment Only	< 12 hrs	Low level compliance issue	Local complaints	Limited physical damage	11 (S)	7 (M)	4 (L)	2 (L)	1 (L)	

Figure 4.1: Centennial's Risk Assessment Matrix

In **Figure 4.1**, (L) is considered Low Risk, (M) is considered Moderate Risk, (S) is considered Significant Risk, (H) is considered High Risk and (E) is considered Extreme Risk.

The risk assessment process was instigated as part of the work at Springvale Mine and Angus Place Mine Extension Project: Amended Project, however, was entered into the Springvale Mine system as one system had to be selected and the report for the next Springvale Mine Extraction Management Plan occurred first.

The risk assessment comprised the following steps:

- Review of Uncertainty Analysis Methods
  - Undertaken by JBS&G (July/August 2018).
- Risk Assessment Workshop
  - Scoping Workshop (held on 16 August 2018)
  - Risk Assessment Workshop (held on 24 August 2018).
- Engagement and Consultation
  - Presentation of proposed approach to the groundwater model to address the outcomes of the risk assessment (7 September 2018).

Table 4.1 presents the risk ratings from the risk assessment and the approach adopted in the numerical groundwater model to manage the risk. **Appendix A** presents the actual risk assessment documentation. As noted, the risk assessment was entered into the Springvale Mine system but was a combined risk assessment for both Springvale Mine and Angus Place Mine Extension Project: Amended Project.

It is noted that model detail described in **Table 4.1** is expanded upon in this chapter, further below.

Table 4.1: Approach to Groundwater Model in response to Risk Assessment Outcomes

Step	Risk Rating	How incorporated into the Groundwater Model?
1. Perched Groundwater	12 (S)	Variably saturated flow approach in MODFLOW-USG. Similar approach in COSFLOW. 28 layers implemented to facilitate. Consideration of the role of lineaments via Pilot Point methodology (heterogeneity), subsidence-induced change to hydraulic properties via Stacked Drains methodology followed by Time-Varying Material property change following cessation of dewatering. Improved temporal and spatial resolution. Model simulations incorporating predictive uncertainty (NSMC) was also undertaken. *(S) because current observations at Springvale Mine imply that predictions for Angus Place Mine Extension Project will be different from that presented in RPS (2014a).*
2. Shallow Groundwater	7 (M)	As above. *(M) because current observations at Springvale Mine imply that predictions for Angus Place Mine Extension Project will be different from that presented in RPS (2014a).*
3. Deep Groundwater	4 (L)	Included in the model but no specific action required.
4. Newnes Plateau Hanging Swamps	13 (S)	Hanging swamps not specifically reported on in RPS (2014a). All hanging swamps included in the groundwater model and predicted change to flow quantified through the swamp water balance. *(S) because current observations at Springvale Mine imply that predictions for Angus Place Mine Extension Project will be different to that presented in RPS (2014a).*
5. Newnes Plateau Shrub Swamps	22 (E)	Consideration of lineaments via Pilot Point methodology (heterogeneity), subsidence-induced change to hydraulic properties via Stacked Drains methodology followed by Time-Varying Material property change following cessation of

Step	Risk Rating	How incorporated into the Groundwater Model?
		dewatering. Increased temporal and spatial resolution. Improved quantification of predicted change to flow. *(E) because current observations at Springvale Mine imply that predictions for Angus Place Mine Extension Project will be different to that presented in RPS (2014a).*
6. Surface and groundwater connectivity	12 (S)	All relevant surface watercourses incorporated into the model (1:25,000 scale hydrology layer in the vicinity of the 1000 Panel Area and major watercourses further afield). *(S) because there have been, locally, changes to surface water flow on the Newnes Plateau at Springvale Mine, which were outside of that presented in the EIS for Springvale Mine. Response to the IMP at Springvale Mine indicate re-emergence of diverted flow further downstream, rather than total loss.*
7. Groundwater bores	S (L)	There are no significant non-mining groundwater users in the vicinity of the 1000 Panel Area. Predicted drawdown at groundwater users will be determined from model output. *(L), given the discussion immediately above.*
8. Groundwater dependent ecosystems	22 (E)	As above for Newnes Plateau Hanging and Shrub Swamps. Long Swamp was raised during Angus Place MOD5. Investigation and instrumentation completed. *(E) because significance of long-term change. NB. Other GDEs (facultative and stygofauna) were (L).*
9. Groundwater licensing	8 (M) 12 (S)	A limitation in COSFLOW was, post-construction, the ability to track the take from different, adjacent water sources. The revised model allowed calculation of take from adjacent sources but was found to be small/minor. *(M) for groundwater because strategic planning of water take is currently underway; (S) for groundwater-induced surface water take as this is a significant constraint.*
10. Groundwater quality	2 (L)	Negligible change to groundwater due to operations therefore not required to be considered.
11. Validation of model parameters with site data	12 (S)	Requirement for updated model to explain (calibrate) observed change in perched and shallow groundwater levels at Springvale Mine. Incorporate outcome of SPR1101 investigation at Springvale Mine via consideration of Height of Fracturing studies by Tammetta (2013) and Ditton and Merrick (2014). Incorporate consideration of lineaments via Pilot Point methodology (heterogeneity). *(S) current observations at Springvale Mine imply that predictions for Angus Place Mine Extension Project will be different to that presented in RPS (2014a).*
12. Site water and salt balance	12 (S)	Mine inflow estimates provided by COSFLOW and will be provided in the updated model, however, at a higher temporal resolution. *(S) because of mine water management considerations. Note however that Angus Place Mine Extension Project: Amended Project will be a nil discharge site.*
13. Surface water users	2 (L)	Modelled change to groundwater contribution to surface water considered in detail, however, is expected to have negligible impact. No specific action required.
14. Cumulative impacts	S (L)	Regional model was developed incorporating adjacent operations (Springvale Mine, Clarence Colliery and Baal Bone and Invincible Colliery). Some limitations based on incomplete knowledge of non-Centennial operations, but not significant.

4.2 Model Objectives and Model Class

The objective of the numerical groundwater model was as follows:

- quantify the spatially and temporally varying change to the groundwater system due to the Angus Place Mine Extension Project: Amended Project

Tasks undertaken to achieve the objective was as follows:

- construct and calibrate a groundwater model in MODFLOW-USG that also matched the observed changes in THPSS at Springvale Mine
- incorporate seepage face and groundwater/surface water interaction through surface watercourses contribution to THPSS
- incorporate and explore the influence of geological lineaments (achieved through Pilot Point heterogeneity in hydraulic properties; the location of lineaments are presented in the Groundwater Impact Assessment report)
- incorporate subsidence-induced change to hydraulic properties based on the Ditton (DgS, 2014, 2015) and Tammetta (2013) geotechnical models
- update predicted mine dewatering and predicted change to surface watercourses and THPSS as a result of mining of the 1000 Panel Area.

In accordance with the Australian Groundwater Modelling Guidelines (Barnett et. al., 2012), the intended model confidence level classification for the numerical groundwater model is Class 2. **Table 4.2** presents the characteristics and indicators of a Class 2 model, together with a summary of the responses to each of those characteristics and indicators, with detail presented further below.

4.3 Conceptual Model

The conceptual model for Angus Place Colliery/Springvale Mine is as follows:

- There are three groundwater systems
  - a perched system upon which THPSS in the 300, 700, 800 and 900 Panel Area reside but in the 1000 Panel Area only partially reside.
    - Burralow Formation comprising a laterally extensive sequence of aquitard plies, interspersed by sandstone
    - drilling has confirmed that THPSS are not directly underlain by a low permeability/clay unit due to swamp formation processes, therefore THPSS are susceptible to change due to mining-related subsidence
    - clear association between presence of geological structures and location of THPSS, likely to be due to structural weakness at inception of watercourse formation.
  - shallow system consisting sandstones and siltstones above the locally thick Mt York Claystone.
    - Tri-Star, Twin Gully and Trail Six Swamps in the 1000 Panel Area mostly exist in the Banks Wall Sandstone, which occurs stratigraphically lower than the Burralow Formation.
  - a deep system comprises sandstones and coal layers, within which depressurisation in advance of coal mining occurs, underlain by Carboniferous basement.
- groundwater flow direction in the near-surface and shallow system is a subdued reflection of surface topography, with extensive interaction with local watercourses and seepage faces albeit of low flow magnitude.
- groundwater flow direction in the regional system is to the north northeast under a gradient of about 1 to 2%, with discharge to the cliff sides of the Wolgan Valley and the Colo River.

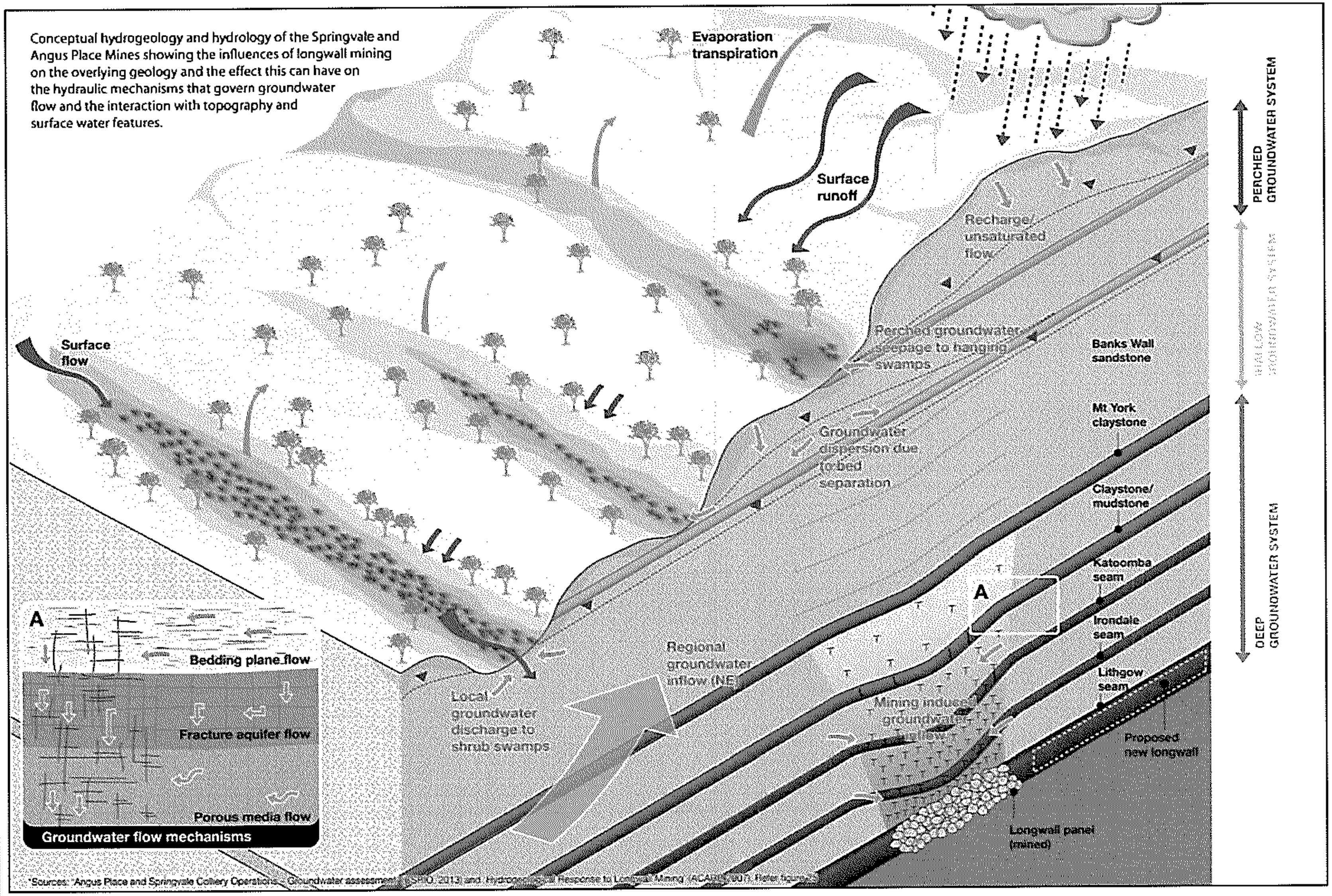
Figure 4.2 presents the conceptual model for the Angus Place Mine Extension Project: Amended Project (after Figure 9 of RPS, 2014). As noted in **Figure 3.5**, a finer vertical discretisation was adopted for the updated groundwater model and hence the AQ and SP terms were not continued.

Table 4.2: Model Confidence Level Classification – characteristics and indicators (Class 2) (after Barnett et. al., 2012)

Data	Calibration	Prediction	Key Indicator
• Groundwater head observations and bore logs are available but may not provide adequate coverage throughout the model domain. *Consistent: There is a significant groundwater monitoring network available encompassing Angus Place Colliery, Springvale Mine and Clarence Colliery. Far-field monitoring not included but outside of area of interest.* • Metered groundwater- extraction data may be available but spatial and temporal coverage may not be extensive. *Consistent: Detailed mine dewatering data is available at Angus Place Colliery, Springvale Mine and at Clarence Colliery (through back calculation using a Site Water Balance).* • Streamflow data and baseflow estimates available at a few points. *Consistent: On-the-ground monitoring (THPSS and within the Coxs River) was calibrated against using the Swamp Water Balance Model. The Swamp Water Balance model received groundwater model output.* • Reliable irrigation-application data available in part of the area or for part of the model duration. *N/A: No comment needed*	• Validation* is either not undertaken or is not demonstrated for the full model domain. *Consistent: Validation not attempted.* • Calibration statistics are generally reasonable but may suggest significant errors in parts of the model domain(s). *Consistent: Reasonable calibration achieved with respect to heads and mine dewatering rates.* • Long-term trends not replicated in all parts of the model domain. *Consistent: Reasonable calibration to long-term trends. Some differences to the commencement of mining-induced depressurisation in some vibrating wire piezometers.* • Transient calibration to historic data but not extending to the present day. • Seasonal fluctuations not adequately replicated in all parts of the model domain. *N/A: Whilst model included seasonal variation, through quarterly stress periods, the model domain is dominated by mining, rather than irrigation, therefore this characteristic is not relevant.* • Observations of the key modelling outcome data set are not used in calibration. *Exceeded: All key modelling outcome data set were used in calibration. These included mine dewatering rates, swamp piezometers, standpipe piezometers and vibrating wire piezometers*	• Transient calibration over a short time frame compared to that of prediction. *Consistent: Calibration period was 1979 through to 2018. Prediction period was 2018 through to 2091 (valid model output).* • Temporal discretisation used in the predictive model is different from that used in transient calibration. *Consistent: Some discretisation used in calibration and prediction models, except for recovery period.* • Level and type of stresses included in the predictive model are outside the range of those used in the transient calibration. *Exceeded: Mining has been on-going within the model domain since before 1979. Magnitude of stresses in calibration model are the same as those in the prediction model.* • Validation* suggests relatively poor match to observations when calibration data is extended in time and/or space. *N/A: Validation not undertaken.*	• Key calibration statistics suggest poor calibration in parts of the model domain. *Exceeded: Calibration statistics (sRMS) was 6.6%.* • Model predictive time frame is between 3 and 10 times the duration of transient calibration. *Consistent: Calibration period was 1979 through to 2018. Prediction period was 2018 through to 2091 (valid model output).* • Stresses are between 2 and 5 times greater than those included in calibration. *Exceeded: Mining has been on-going within the model domain since before 1979. Magnitude of stresses in calibration model are the same as those in the prediction model.* • Temporal discretisation in predictive model is not the same as that used in calibration. *Consistent: Some discretisation used in calibration and prediction models, except for recovery period.* • Mass balance closure error is less than 1% of total. *Consistent: Mass balance closure error was less than 0.1% for the calibration model and for the prediction simulation incorporating uncertainty analysis. A minor exception was SP198 and SP199 of the prediction simulations incorporating uncertainty analysis. Accordingly, these SPs were omitted from the processed model results.* • Not all model parameters consistent with conceptualisation. *Consistent: As noted in detail further below, during calibration with PEST, some parameters do adopt compensatory/surrogate roles; however,*

Data	Calibration	Prediction	Key Indicator
			remained consistent with conceptual model. Any residual issue with parameterisation overcome through stochastic-based model prediction incorporating uncertainty analysis comporing a Proposed and Null Case. • Spatial refinement too coarse in key parts of the model domain. *Exceeded: Quad-tree refinement used to optimise grid resolution in area of interest. This was supplemented by construction of the Swamp Water Balance Model to assess sub-catchment detail in a separate hydrological model.* • The model has been reviewed and deemed fit for purpose by an independent hydrogeologist. *Consistent: Model has been reviewed by a 3rd party hydrogeologist and deemed fit for purpose.*

*Validation: Validation is where a portion of the calibration dataset is excluded from the calibration process and is instead used, subsequently, to confirm the performance of the model.



Legend:

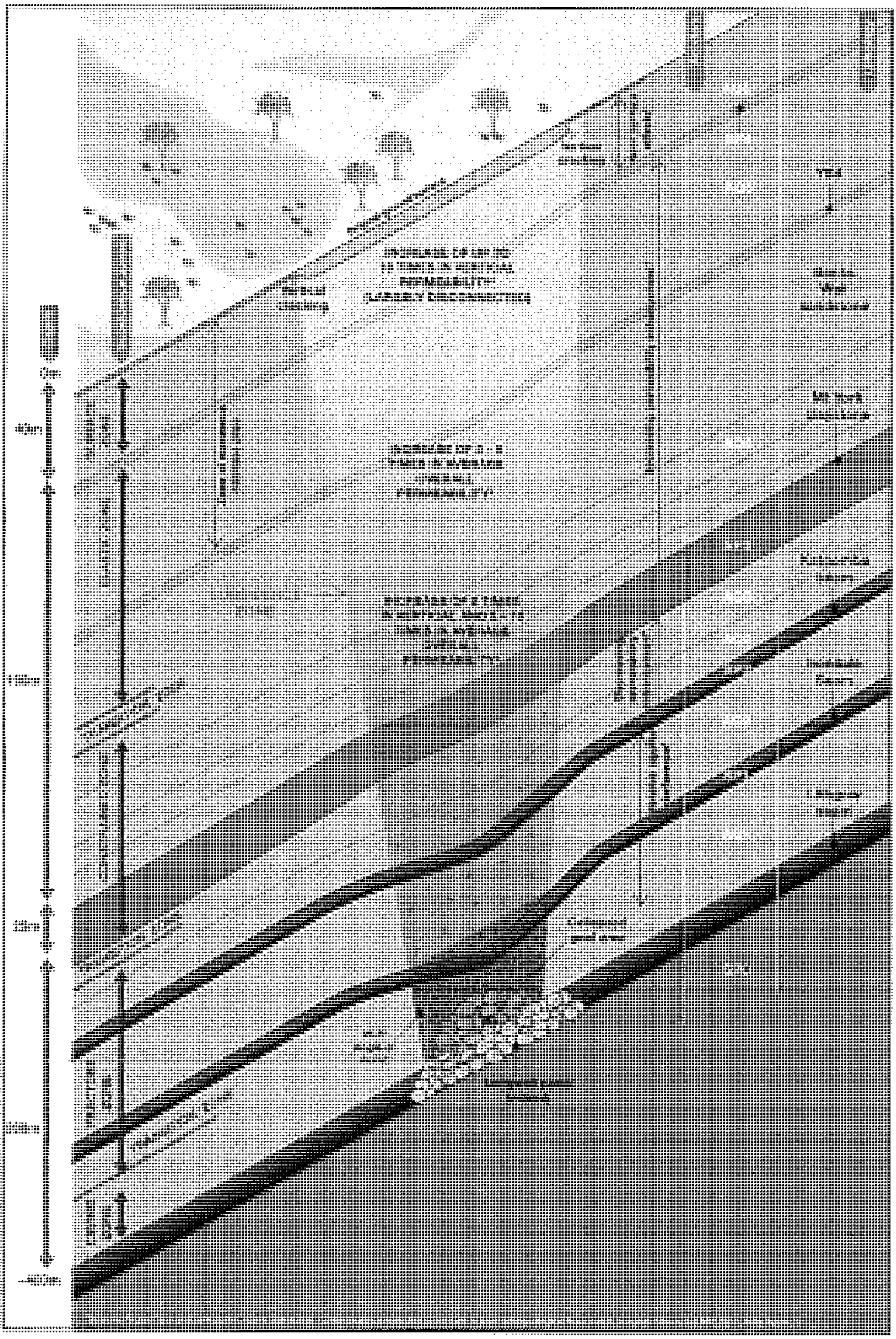
JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02RevC	Date: 27-Aug-2019
Drawn By: JZ	Checked By: JB
Scale N/A	
Coord. Sys. N/A	

Springvale Angus Place Conceptual Hydrogeology (after RPS 2014a)

FIGURE: 4.2a

Document Path: n:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\DeliveryMaps\R02RevC_GW\R02RevC_D006_ConceptualModel_a.ai
Reference: N/A



Legend:

Scale N/A		Springvale Angus Place Conceptual Hydrogeology (after RPS 2014a)
Coord. Sys. N/A		
Job No: 56421		
Client: Centennial Angus Place Pty Ltd		FIGURE 4.2b
Version: R02RevC	Date 27/08/2019	JBS&G
Drawn By: JZ	Checked By: JB	

4.4 Model Approach and Code

The redevelopment of the numerical groundwater model was initiated in response to the requirements of the Independent Monitoring Panel for Springvale Mine, namely to update the groundwater model to fit the observed changes to THPSS at Springvale.

The approach to the numerical groundwater model was MODFLOW for Unstructured Grid (MODFLOW-USG) (USGS, 2013), building upon previous work by the CSIRO undertaken using their proprietary model COSFLOW (CSIRO, 2007, 2013, 2015 and 2016).

For this assessment, an alternate version of MODFLOW-USG, referred to as MODFLOW USG-Transport, was available (Version 1.3.0, 14 May 2019) from GSI Environmental (2018).

USG-Transport incorporates solution to Richards Equation (variably saturated flow) via van Genuchten (1977, 1980) for the relationship between suction head and water saturation and via Brooks and Corey (1966) for the relationship between relative permeability and water saturation.

The approach in MODFLOW-USG Transport for variably saturated flow is the same as that used in a previous version of MODFLOW, MODFLOW-Surfact (HGL, 1996).

The numerical groundwater model was constructed using a Graphical User Interface, Groundwater Vistas, Version 7.24 Build 56. Those MODFLOW input files were then manipulated using custom-developed scripts (FORTRAN) prepared by JBS&G to facilitate calibration and uncertainty analysis through the PEST (Version 15) software suite (Watermark Numerical Computing, 2018a).

4.5 3rd Party Review of the Groundwater Model

The groundwater model has been subject to review by a third party, Dr Noel Merrick of HydroAlgorithmics Pty Ltd, as per the requirements of the NSW Aquifer Interference Policy (NSW Office of Water, 2012). The letter of review is provided in **Appendix H**.

4.6 Model Grid and Domain

The numerical model mesh utilises Quadtree Refinement and the domain is presented in **Figure 4.3**. Cell sizes range between 100m and 400m. **Figure 4.4** presents the mesh in the vicinity of the 1000 Panel Area.

Whilst there is a limitation with Quadtree Refinement in Groundwater Vistas when using 'Write Active Nodes Only' option, insofar as the Ghost Node Correction file is not available, this restriction was overcome by extending the region of 100m refinement to the maximum extent practicable.

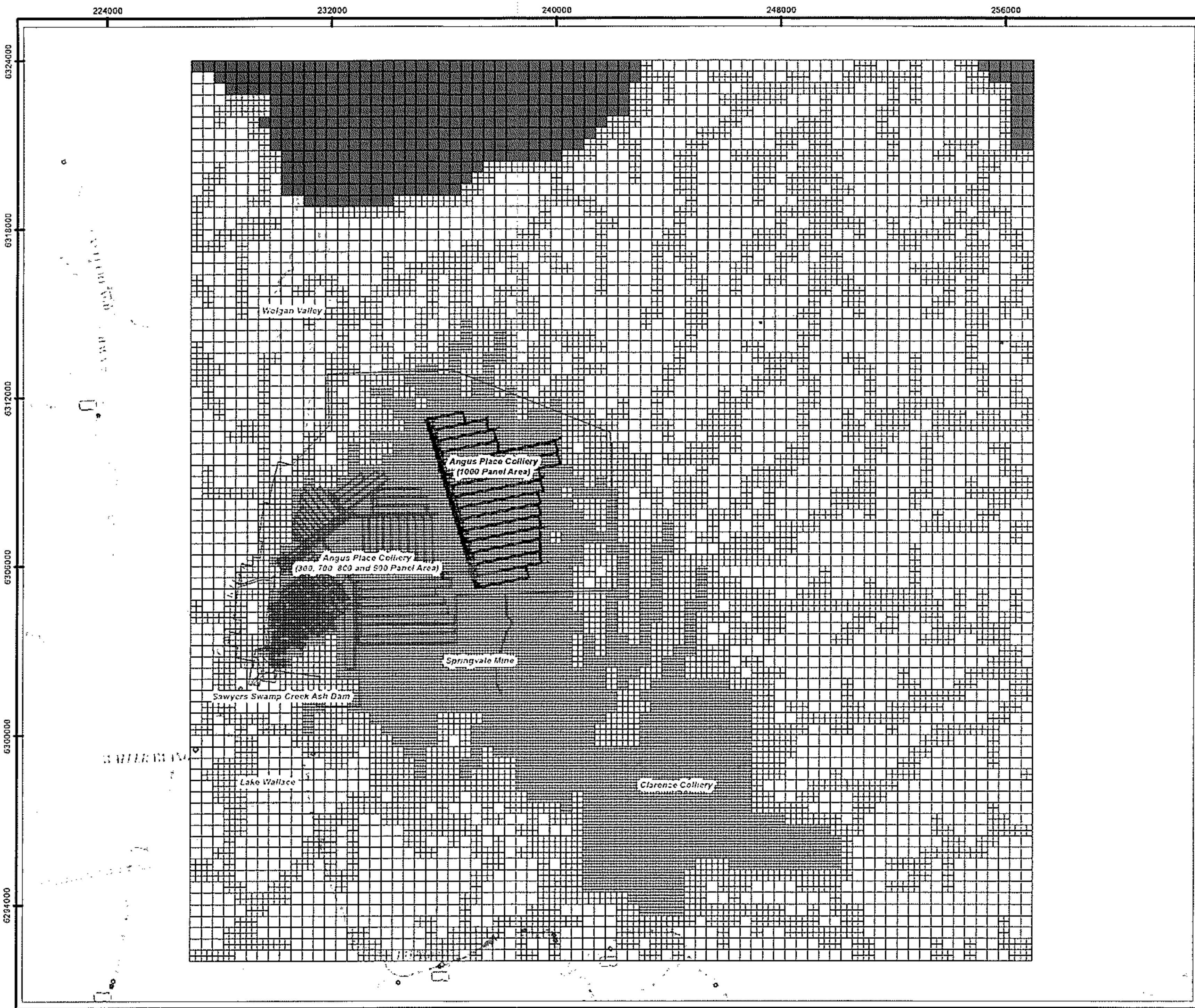
4.7 Model Layering

The groundwater model is based on 28 model layers, 80 major rows and 75 major columns. As discussed in **Section 4.5**, Quadtree Refinement was undertaken on the major rows and columns. The number of cells per layer, after application of Quadtree Refinement on major rows and columns, was 28353, of which 371 were no flow boundaries. **Table 4.3**, presented further below, identifies the hydrogeologic unit associated with each model layer.

The 'Write Active Nodes Only' option within Groundwater Vistas was utilised, thereby reducing the number of cells in the MODFLOW .DIS file from 793884 to 506058 across the 28 layers.

The model comprises a large number of layers, however, these were required to provide Richards Equation with an appropriate level of vertical discretisation. Model run-time, under load, was 13.5 hours for the calibration simulation and 30 hours for the combined calibration/prediction simulation.

It is noted that the excessive model run-time, considering the model only comprises S06058 cells, is due to the difficulties in solving the Richards Equation, which is a known issue in the groundwater modelling technical discipline/industry.



Legend:

- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- Model Mesh
- No Flow Boundary (NFB) Cells

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Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02RevB	Date: 06-Aug-2019
Drawn By: JZ	Checked By: JB
Scale 1:180,000	

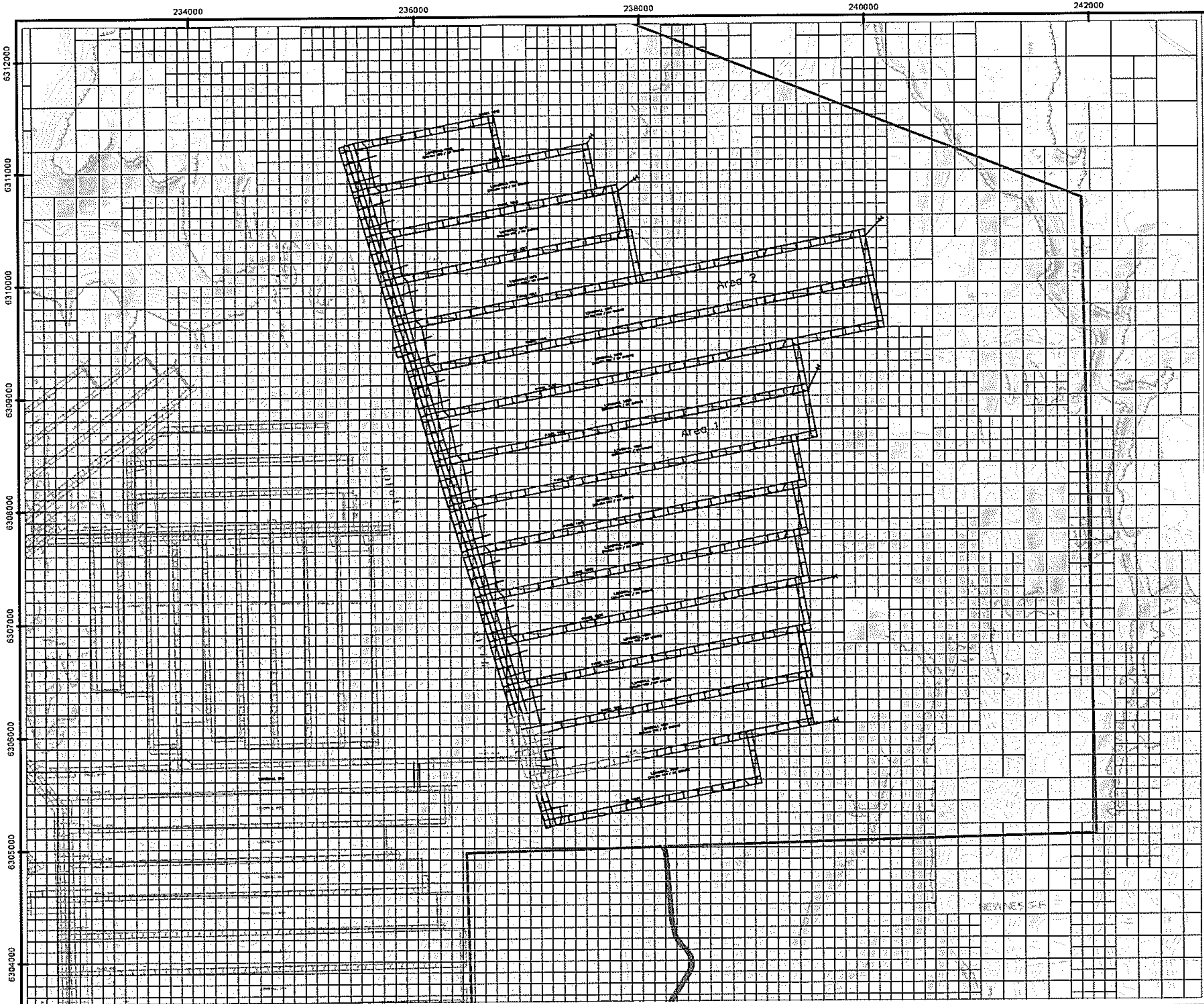
0 2.5 5
km

Coor. Sys. GDA 1994 MGA Zone 56

Model Mesh - Quadtree Refinement (100m to 400m) - Regional Extent

FIGURE: 4.3

File Name: N:\Projects\Centennial\Coal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02RevC_GW\R02RevB_D003_ModelGrid.mxd
Reference: © Department of Finance, Services & Innovation 2018



Legend:
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- Model Mesh

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02RevB | Date: 06-Aug-2019

Drawn By: JZ | Checked By: JB

Scale 1:45,000

0 0.75 1.5 km

Coor. Sys. GDA 1994 MGA Zone 56

Model Mesh - Quadtree Refinement (100m to 200m) - Vicinity of 1000 Panel Area

FIGURE: 4.4

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02RevC_GWR02RevB_D004_ModelGrid_1000PanelArea.mxd
Reference © Department of Finance Services & Innovation 2018

All model layers were set to LAYCON = 5 (variably saturated flow), except for Layer 25 to 28, which were set to LAYCON = 4 (confined/unconfined convertible type with upstream water table depth used to compute transmissivity).

Currently, however, USG-Transport, internally within the source code, sets all layers to LAYCON = 5, regardless of the setting in the .LPF file, when the RICHARDS keyword is included in the .BAS file (Groundwater Vistas, pers. comms., 2018). The issue of LAYCON = 5 being used in the lowermost regional layers, whilst important, did not, however, invalidate the model approach adopted by JBS&G.

Where a particular layer outcropped, JBS&G notes that it was 'pinched-out' and a seepage face element, with an appropriately high conductance applied, implemented immediately adjacent the 'pinch-out'. **Figure 4.5** presents the layout of the model in plan-view for various layers. Pink colour indicates where a layer is 'pinched-out' and yellow colour indicates where there is a DRN (Drain) boundary condition applied, whether that is a surface watercourse or swamp or a seepage face.

Figure 4.6 presents a cross-section view through the model, south-north. **Figure 4.7** presents a cross-section-view through the model, west-east. **Figure 3.14** presents the location of mining operations immediately adjacent Angus Place Colliery.

In **Figure 4.6** and **Figure 4.7** colouration mimics the hydrogeologic unit that is represented by the model layer (refer **Table 4.3**).

- Sandstone is Orange
- Shale is Grey
- Siltstone/Claystone is Brown
- Coal is Black
- Conglomerate is Tan Brown
- Carboniferous basement is Red/Pink

4.8 Model Geometry and Initial Values of Hydraulic Parameters

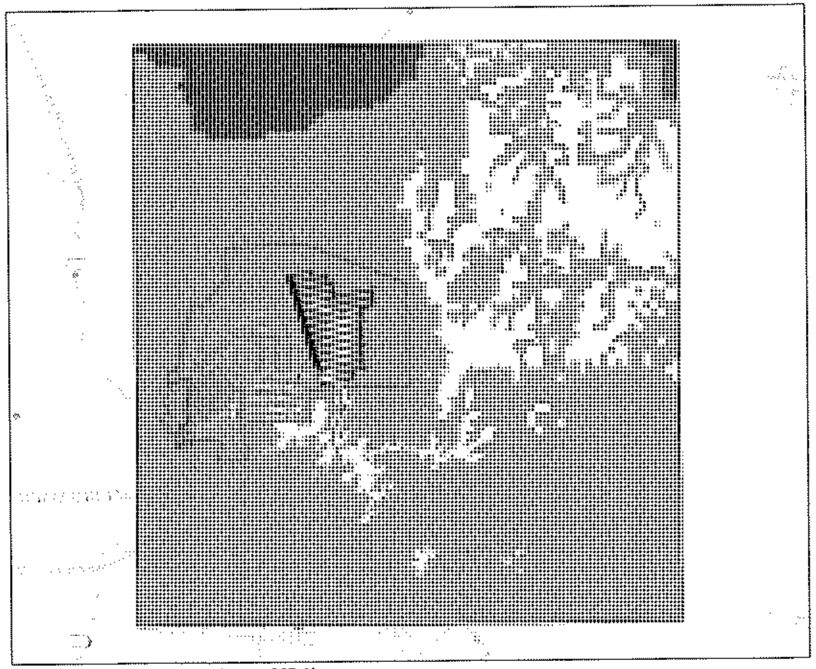
The groundwater model utilises previously developed Digital Elevation Models (DEMs) of the various geologic units obtained from regional data (NSW Department of Resources and Energy mapping project) and local geological data (McHugh, 2016).

Due to the requirement for continuous layers throughout the model (except for where layers were 'pinched-out'), the Narrabeen Group detail from McHugh (2016), above the Farmers Creek Formation, including the Burralow Formation aquitard plies, was extrapolated regionally.

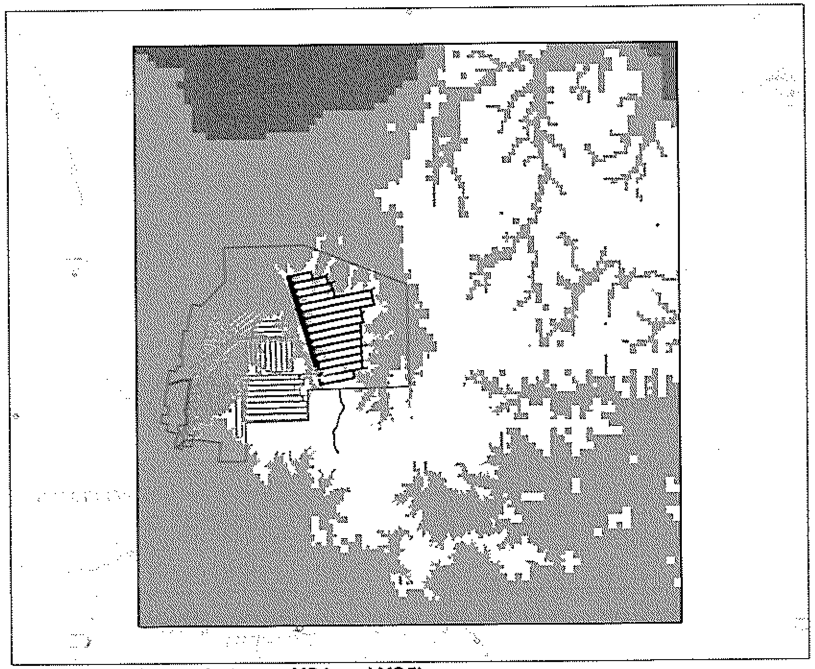
Table 4.3 presents a summary of the geologic units adopted in the groundwater model. Initial values for various parameters are also presented in **Table 4.3**. Those values include horizontal hydraulic conductivity, Kh or Kx (m/d); vertical hydraulic conductivity, Kz (m/d); Specific Storage, Ss (1/m); Porosity; van Genuchten's Alpha (m^{-1}); van Genuchten's Beta; residual saturation, Sr (or S_{wr}) and Brooks-Corey Exponent, BrooksN.

A discussion of the implementation of the variably saturated flow in MODFLOW-USG Transport is presented in **Appendix B** .

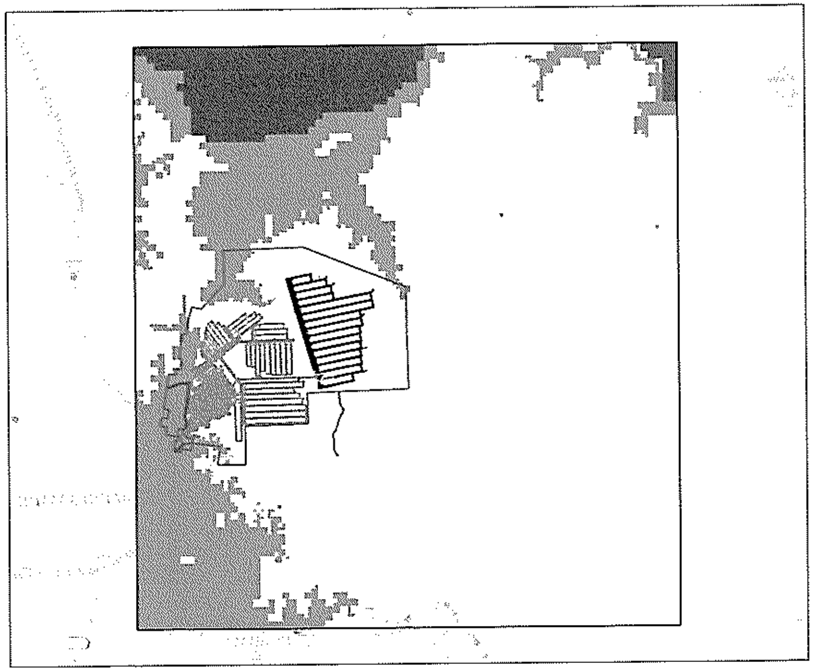
It is noted that the variably saturated flow properties, van Genuchten's Alpha and Beta, the residual saturation, Sr and the Brooks-Corey Exponent, BrooksN were initially submitted for calibration by PEST, however, were found to be quite unstable in the model and hence were FIXED at values based upon partial calibration. This is normal industry practice. It is also noted that whilst **Table 4.3** presents layer-based values for hydraulic properties, a Pilot Point methodology was used during model calibration.



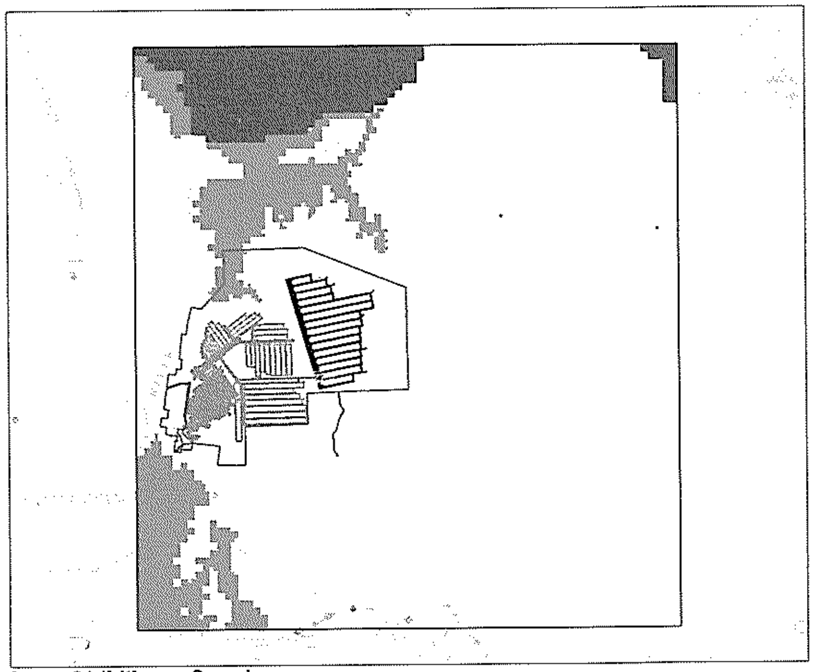
Layer 1 (Sandstone above YS1)



Layer 9 (Sandstone between YS4 and YS5)



Layer 18 (Katoomba Seam)



Layer 24 (Lithgow Seam)

Legend:

- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- Groundwater Model Domain
- No Flow Boundary (NFB) Cells
- 'Pinched-Out' Cells
- Drain (DRN) Cells

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Job No: 56421	
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Scale 1:400,000	

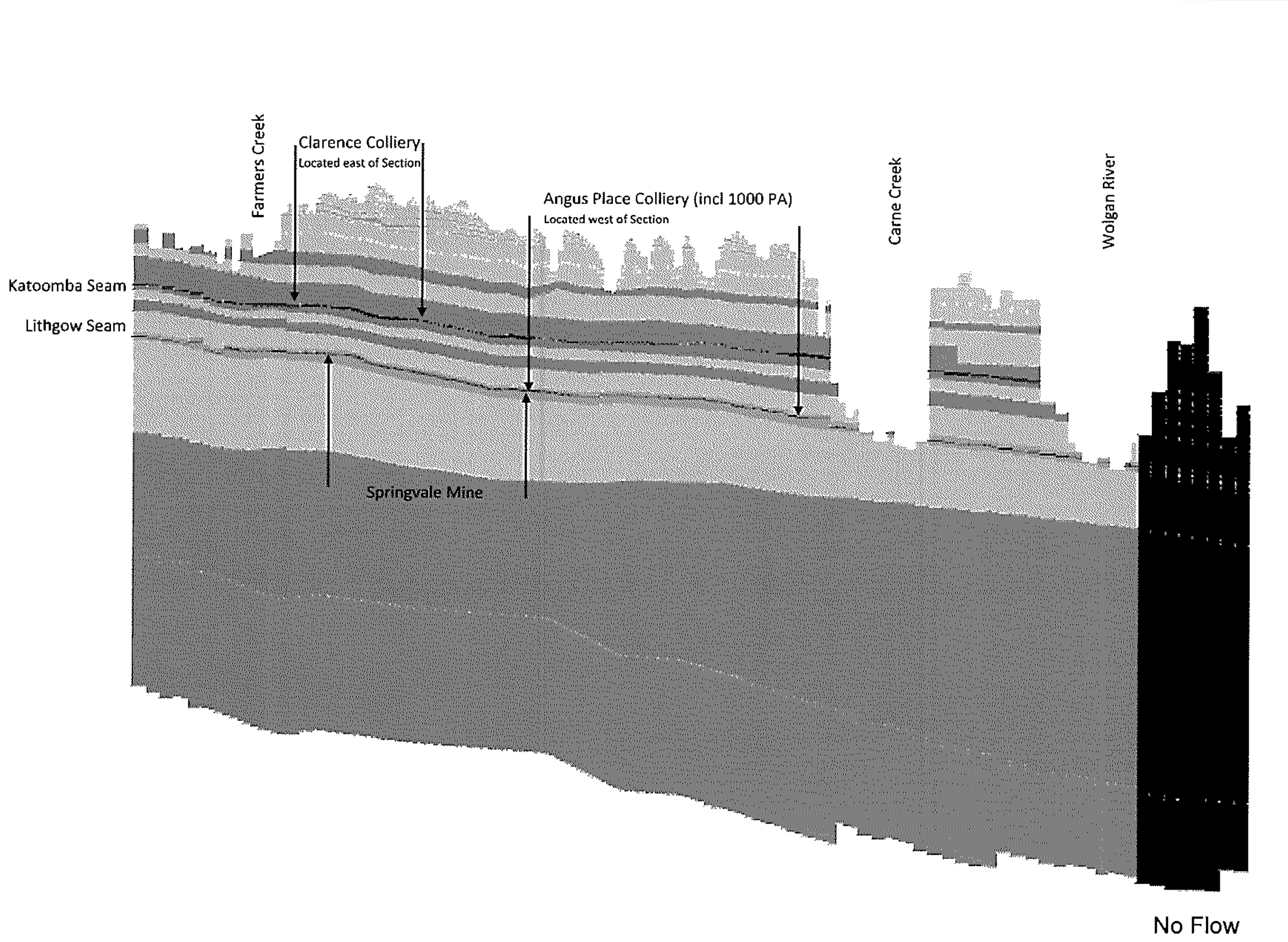
0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

Plan View of Selected Model Layers

FIGURE: 4.5

File Name N:\Projects\Centennial\Coal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02RevC_GW\R02RevB_D005_ModelLayerPlanView.mxd

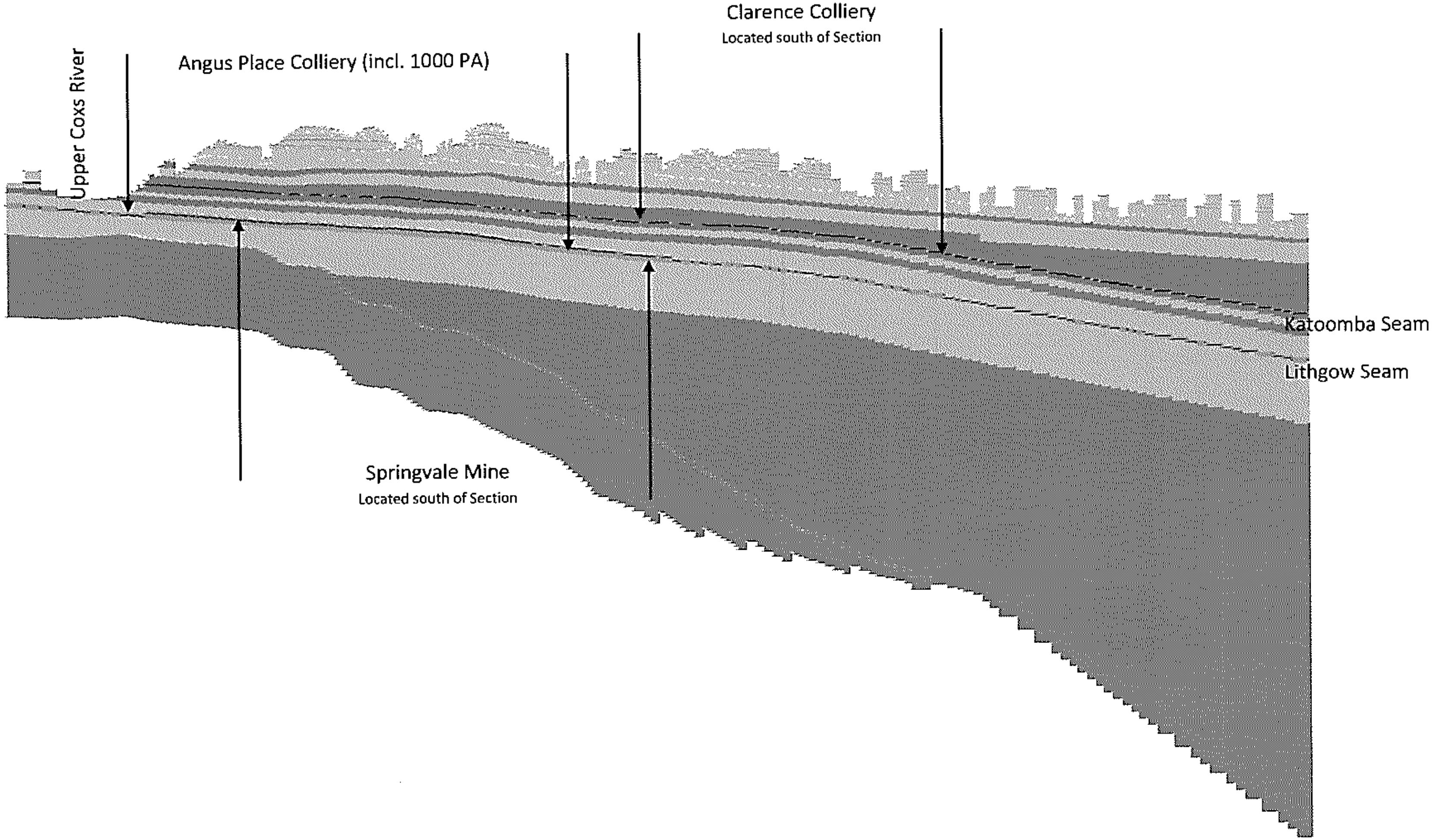


JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02RevB	Date: 29-Jul-2019
Drawn By: JZ	Checked By: JB
Scale Approximate	
Coord. Sys. N/A	

Cross-Section View through Model Layers (South-North) - Column 34

FIGURE: 4.6



Legend:

- Sandstone
- Shale
- Claystone/ Siltstone
- Coal
- Conglomerate
- Granite

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Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02RevB	Date: 29-Jul-2019
Drawn By: JZ	Checked By: JB

Scale Approximate

Coord. Sys. N/A

Cross-Section View through Model Layers (West-East) - Row 48

FIGURE: 4.7

Document Path n:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02RevB_GW\R02RevB_D006_ModelLayerCrossSection_WE.ai
Reference N/A

Table 4.3: Model Geometry and Initial Values of Hydraulic Properties

Layer	Class	Unit	SubUnit	Kh (m/d)	Aniso.	Kz (m/d)	Ss (1/m)	Porosity	α (m⁻¹)	β	S_{wr}	BrooksN
1	Sandstone/Regolith	Burralow Formation	Sandstone	8.64E-02	5	1.73E-02	8.00E-06	0.20	1.8	8.2	0.30	3.6
2	Shale	-	YS1	8.64E-03	10	8.64E-04	2.00E-06	0.35	1.5	9.0	0.40	4.3
3	Sandstone/Regolith	-	Sandstone	8.64E-02	5	1.73E-02	8.00E-06	0.20	1.8	8.2	0.30	3.6
4	Shale	-	YS2	8.64E-03	10	8.64E-04	2.00E-06	0.35	1.5	9.0	0.40	4.3
5	Sandstone/Regolith	-	Sandstone	8.64E-02	5	1.73E-02	8.00E-06	0.20	1.8	8.2	0.30	3.6
6	Shale	-	YS3	8.64E-03	10	8.64E-04	2.00E-06	0.35	1.5	9.0	0.40	4.3
7	Sandstone/Regolith	-	Sandstone	8.64E-02	5	1.73E-02	8.00E-06	0.20	1.8	8.2	0.30	3.6
8	Shale	-	YS4	8.64E-03	10	8.64E-04	2.00E-06	0.35	1.5	9.0	0.40	4.3
9	Sandstone/Regolith	-	Sandstone	8.64E-02	5	1.73E-02	8.00E-06	0.20	1.8	8.2	0.30	3.6
10	Shale	-	YS5	8.64E-03	10	8.64E-04	2.00E-06	0.35	1.5	9.0	0.40	4.3
11	Sandstone/Regolith	-	Sandstone	8.64E-02	5	1.73E-02	8.00E-06	0.20	1.8	8.2	0.30	3.6
12	Shale	-	YS6	8.64E-03	10	8.64E-04	2.00E-06	0.35	1.5	9.0	0.40	4.3
13	Quartzose sandstone	Banks Wall Sandstone	BW1	8.64E-02	5	1.73E-02	8.00E-06	0.25	1.9	8.5	0.32	3.6
14	Quartzose sandstone	-	BW2	8.64E-02	5	1.73E-02	8.00E-06	0.25	1.9	8.5	0.32	3.6
15	Claystone	Mt York Claystone	n/a	8.64E-03	10	8.64E-04	6.00E-06	0.45	1.3	9.5	0.55	4.5
16	Quartzose to quartz-lithic sandstone	Burra-Moko Sandstone	n/a	8.64E-02	5	1.73E-02	8.00E-06	0.25	1.9	8.5	0.32	3.6
17	Claystone/Shale/Sandstone	Caley Formation	n/a	8.64E-03	10	8.64E-04	6.00E-06	0.40	1.5	9.0	0.40	4.3
18	Coal	Katoomba Seam	n/a	4.32E-02	5	8.64E-03	1.00E-05	0.22	1.6	5.0	0.30	3.9
19	Claystone/Shale	Farmers Creek Formation	n/a	8.64E-03	10	8.64E-04	6.00E-06	0.40	1.4	9.0	0.45	4.3
20	Lithic sandstone/Claystone/Quartz-Lithic Sandstone	Gap Sandstone/State Mine Creek Formation/Angus Place Formation (Watts Sandstone)	n/a	4.32E-02	5	8.64E-03	8.00E-06	0.25	1.9	8.7	0.33	3.4
21	Mudstone/Siltstone/Claystone (Marine Incursion)	Denman Formation	n/a	8.64E-03	10	8.64E-04	6.00E-06	0.40	1.3	9.5	0.55	4.2
22	Sandstone/Mudstone (Lower delta plain)	Glen Davis / Long Swamp Formation	n/a	4.32E-02	5	8.64E-03	8.00E-06	0.20	1.5	9.0	0.45	3.6
23	Conglomerate (Fluvial)	Blackmans Flat Conglomerate / Lidsdale Coal Seam	n/a	4.32E-02	10	4.32E-03	5.00E-06	0.25	3.0	6.0	0.30	3.5
24	Coal (Fluvial)	Lithgow Seam	n/a	4.32E-02	5	8.64E-03	1.00E-05	0.22	1.6	5.0	0.30	3.9
25	Conglomerate (Fluvial)	Marrangaroo Conglomerate	n/a	4.32E-02	10	4.32E-03	5.00E-06	0.25	3.0	6.0	0.30	3.5
26	Sandstone (Shoreline complex - delta front)	Nile Subgroup	n/a	4.32E-02	5	8.64E-03	8.00E-06	0.20	1.9	8.5	0.35	3.7
27	Siltstone/Sandstone (Shoreline)	Shoalhaven Group	n/a	8.64E-03	10	8.64E-04	6.00E-06	0.40	1.6	9.5	0.35	4.1
28	Tuff/Granite	Carboniferous	n/a	8.64E-03	1	8.64E-03	9.00E-07	0.06	2.5	4.0	0.65	3.3

The values for porosity in **Table 4.3** were informed from the literature (Brooks-Corey, 1966 and van Genuchten, 1980) as well as generally available information. It is highlighted that the porosity values in the literature, from soil science, are higher (sandstone is 25% in the sample presented in Brooks-Corey, 1966, with a residual water content of 15%; hence the 'available water' is 10%) than values that would be typically adopted in hydrogeology for specific yield (for sandstone, a typical value might be <6%, and potentially lower), noting that specific yield is a saturated flow approximation and does not consider additional 'yield' under soil suction.

4.9 Model Temporal Discretisation

Solution of the Richards Equation requires the volumetric water content function to be available, which depends on porosity. Porosity is therefore stored in place of Specific Yield, Sy. The Graphical User Interface does not generate the storage parameters, when the model is steady-state, hence a quasi steady-state period for Stress Period[1] 1 (SP1) was adopted.

Due to the long model run-time, Stress Period 2 was agglomerated to represent the period 1 January 1979 to 31 December 1993. Relevant changes to the model with respect to mining activity at the adjacent operation at Springvale Mine and Clarence Colliery were included, as well as regional mining operations as relevant.

Due to the requirements of Richards Equation, namely that the current state of the volumetric water content function/saturation state be available as an initial condition, the prediction version of the model incorporates the calibration period and the prediction period, including recovery.

Table 4.4 presents a summary of the temporal discretisation.

Table 4.4: Model Temporal Discretisation

Stress Period	Time-Steps	Time-Step Multiplier	Duration	SP Start Date	SP End Date
Calibration					
1	10, with output at TS10	2	40000 days	-	-
2	10, with output at TS10	2	5479 days	1/01/1979	31/12/1993
3 to 101	5, with output at TS4 and TS5	2.5	90 to 92 days	1/01/1994	30/09/2018
Simulation (combined calibration, prediction and recovery period)					
1	10, with output at TS10	2	40000 days	-	-
2	10, with output at TS10	2	5479 days	1/01/1979	31/12/1993
3 to 182	5, with output at TS4 and TS5	2.5	90 to 92 days	1/01/1994	31/12/2038
183 to 186	5, with output at TS5	2.5	181 to 184 days	1/01/2039	31/12/2040
187	5, with output at TS5	2.5	365 days	1/01/2041	31/12/2041
188	5, with output at TS5	2.5	730 days	1/01/2042	31/12/2043
189 to 190	5, with output at TS5	2.5	1826 to 1827 days	1/01/2044	31/12/2053
191	5, with output at TS5	2.5	90 days	1/01/2054	31/03/2054
192	5, with output at TS5	2.5	275 days	1/04/2054	31/12/2054
193	5, with output at TS5	2.5	731 days	1/01/2055	31/12/2056
194	5, with output at TS5	2.5	1826 days	1/01/2057	31/12/2061
195	5, with output at TS5	2.5	2557 days	1/01/2062	31/12/2068
196	5, with output at TS5	2.5	3652 days	1/01/2069	31/12/2078
197	5, with output at TS5	2.5	4748 days	1/01/2079	31/12/2091
198	5, with output at TS5	2.5	6209 days	1/01/2092	31/12/2108
199	5, with output at TS5	2.5	7305 days	1/01/2109	31/12/2128

The calibration version of the model comprised quarterly stress periods, with 5 timesteps per period, using a time-step increase multiplier of 2.5. The prediction version of the model also comprised quarterly stress periods, with 5 timesteps per period. It is noted that quarterly stress periods were

[1] A stress period in MODFLOW is a duration of time where boundary conditions are held constant, be they drainage cells associated with mining, recharge values, general head boundaries, drainage cells associated with seepages etc.

selected, as opposed to monthly stress periods, due to model run-time constraints. This is normal practice in such circumstances and is not considered to materially affect the findings from the groundwater model study undertaken.

The duration of the calibration model was therefore 109.5 years for SP1, prior to 1 January 1979 to 31 December 1993 for SP2 and then 1 January 1994 through to 31 October 2018 for SP3 to SP101.

The duration of the prediction model was 109.5 years for SP1, prior to 1 January 1979 to 31 December 1993 for SP2 and then 1 January 1994 through to 31 December 2128 to SP199.

4.10 Model Boundary Conditions

4.10.1 Inputs

4.10.1.1 Recharge

Recharge to the groundwater model was based on a recharge factor applied to the SILO gridded rainfall data (collated into quarterly intervals as per **Table 4.4**). The distribution of SILO grids (zoning) is presented in **Figure 3.2**.

A FORTRAN script was written by JBS&G to allow adjustment of the recharge factor between iterations of PEST. That recharge factor was applied to the same rainfall file each time. It is noted that the rainfall file contained data for each stress period and for each SILO grid.

The initial values of the recharge factors are presented in **Table 4.5** below.

Table 4.5: Initial Values of Recharge Factor

Recharge Zone	Recharge Factor	Recharge Zone	Recharge Factor
1 (F4)	0.15	19 (F7)	0.08
2 (G4)	0.08	20 (G7)	0.18
3 (H4)	0.08	21 (H7)	0.18
4 (I4)	0.12	22 (I7)	0.18
5 (J4)	0.15	23 (J7)	0.18
6 (K4)	0.12	24 (K7)	0.12
7 (F5)	0.10	25 (F8)	0.08
8 (G5)	0.08	26 (G8)	0.12
9 (H5)	0.08	27 (H8)	0.15
10 (I5)	0.18	28 (I8)	0.18
11 (J5)	0.18	29 (J8)	0.18
12 (K5)	0.12	30 (K8)	0.15
13 (F6)	0.12	31 (F9)	0.10
14 (G6)	0.15	32 (G9)	0.08
15 (H6)	0.15	33 (H9)	0.10
16 (I6)	0.18	34 (I9)	0.10
17 (J6)	0.18	35 (J9)	0.15
18 (K6)	0.18	36 (K9)	0.12

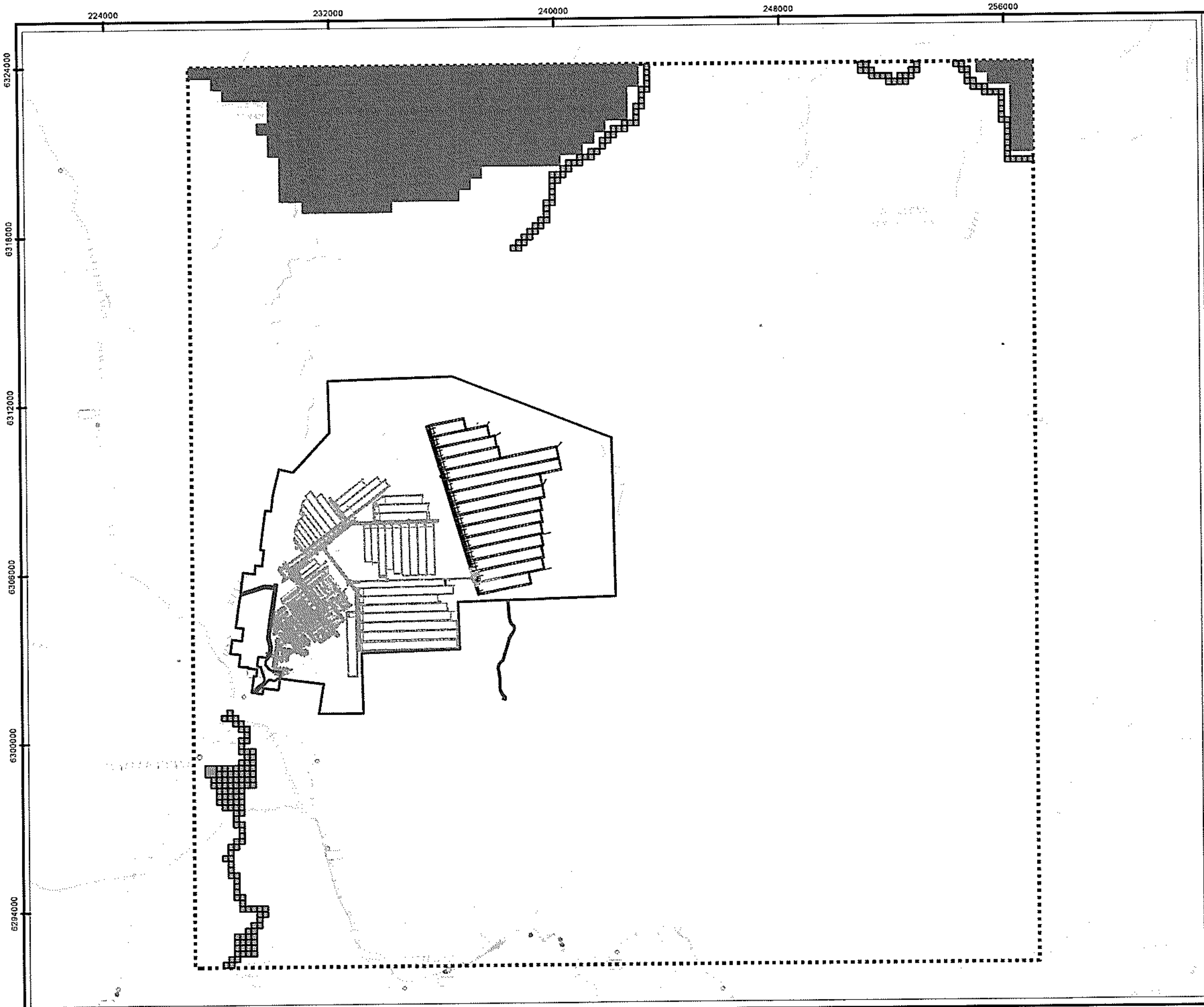
In the prediction simulation, median rainfall conditions were derived from the NARCliM dataset and used for the prediction simulation period of June 2019 through to 31 December 2128. Scaling of the NARCliM dataset was undertaken with respect to each SILO grid in order to provide a continuous rainfall record.

For the climate change simulations, presented further below, as noted in **Section 3.2**, the NARCliM dataset was utilised to obtain a 'Lowest Cumulative Rainfall, Higher Cumulative Evapotranspiration' scenario as well as a 'Highest Cumulative Rainfall, Lower Cumulative Evapotranspiration' scenario.

4.10.1.2 River

River (RIV) boundary conditions were used to represent the Wolgan River and the Coxs River (Lake Wallace through to Lake Lyell).

Figure 4.8 presents the distribution of the RIV boundary conditions.



Legend:

- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- Groundwater Model Domain
- No Flow Boundary (NFB) Cells
- River (RIV) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02RevB	Date: 06-Aug-2019
Drawn By: JZ	Checked By: JB
Scale 1:180,000	
0 3 6 km	
Coor. Sys. GDA 1994 MGA Zone 56	

Location of River Boundary (Layers 20 to 28, as applicable)

FIGURE: 4.8

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02RevC_GW\R02RevB_D008_LocationOfRiverBoundary.mxd
Reference © Department of Finance Services & Innovation 2018

The RIV boundaries were applied to the relevant active nodes and occurred in Layer 20 through to Layer 28 of the model.

The conductance values for the RIV, which are grid cell size dependent, were set based on an assumed hydraulic conductivity of the streambed of 8.64E-02m/d, a streambed thickness of 0.5m and an assumed width of 5m. The conductance parameters of river cells were not changed during model calibration.

The approach to ephemeral watercourses is presented in **Section 0**.

4.10.2 Outputs

4.10.2.1 Evapotranspiration

Evapotranspiration from the groundwater model was based on an evapotranspiration factor applied to the SILO gridded FAO56 data (collated into quarterly intervals as per **Table 4.4**). The distribution of SILO grids (zoning) is presented in **Figure 3.3**.

A FORTRAN script was written by JBS&G to allow adjustment of the evapotranspiration factor between iterations of PEST. That evapotranspiration factor was applied to the same FAO56 file each time. It is noted that the evapotranspiration file contained data for each stress period and for each SILO grid.

The initial values of the evapotranspiration factors are presented in **Table 4.6** below.

It is noted that an extinction depth of 3m was applied to all zones. The extinction depth was set at 3m to, partly, account for the limitation of the default MODFLOW Recharge package, insofar consideration of soil moisture deficit. This is despite the root depth, for swamps, being such that they are much less than 3m. This is considered to be a reasonable approach and consistent with industry norms.

Table 4.6: Initial Values of Evapotranspiration (ET) Factor

ET Zone	ET Factor	ET Zone	ET Factor
1 (F4)	0.50	19 (F7)	0.45
2 (G4)	0.45	20 (G7)	0.60
3 (H4)	0.45	21 (H7)	0.60
4 (I4)	0.55	22 (I7)	0.60
5 (J4)	0.55	23 (J7)	0.55
6 (K4)	0.50	24 (K7)	0.50
7 (F5)	0.45	25 (F8)	0.45
8 (G5)	0.40	26 (G8)	0.60
9 (H5)	0.45	27 (H8)	0.60
10 (I5)	0.60	28 (I8)	0.60
11 (J5)	0.60	29 (J8)	0.50
12 (K5)	0.50	30 (K8)	0.50
13 (F6)	0.50	31 (F9)	0.50
14 (G6)	0.60	32 (G9)	0.45
15 (H6)	0.60	33 (H9)	0.45
16 (I6)	0.60	34 (I9)	0.50
17 (J6)	0.60	35 (J9)	0.50
18 (K6)	0.50	36 (K9)	0.50

In the prediction simulation, median rainfall conditions were derived from the NARCliM dataset and used for the prediction simulation period of June 2019 through to 31 December 2128. Scaling of the NARCliM dataset was undertaken with respect to each SILO grid in order to provide a continuous rainfall record.

For the climate change simulations, presented further below, as noted in **Section 3.2**, the NARCliM dataset was utilised to obtain a 'Lowest Cumulative Rainfall, Higher Cumulative Evapotranspiration' scenario as well as a 'Highest Cumulative Rainfall, Lower Cumulative Evapotranspiration' scenario.

4.10.2.2 General Head Boundary

A General Head Boundary (GHB) is applied to the eastern edge of the model domain, in Layer 27 and is illustrated in **Figure 4.9**.

The quasi steady-state heads (mAHD) are also presented in **Figure 4.9**.

From **Figure 4.9**, the GHB serves to impart an easterly trend to groundwater levels, which is consistent with the earlier unpublished versions of the model, whose domain extended much further to the east.

A FORTRAN script was written by JBS&G to allow adjustment of the conductance values of the GHB between iterations of PEST. That was implemented by changing the hydraulic conductivity (m/d) and saturated thickness (m), as a combined factor (K-T) factor. The resultant conductance value was then held constant throughout the simulation and comprised five (5) separate zones, roughly of equal interval from south to north in **Figure 4.9**.

4.10.2.3 Ephemeral Watercourses and Swamps (DRN)

Ephemeral watercourses and swamps are represented in the model using the Drain (DRN) boundary condition. The location of the DRN boundary conditions (yellow) is illustrated in **Figure 4.10**.

Figure 4.10 presents all of the watercourse boundaries in a single figure in plan view. In the model, because cells are 'pinched-out' where the layer outcrops, the actual layer the DRN boundary condition is applied to, is noted to be variable.

The different size yellow squares in **Figure 4.10** reflect the different cell sizes in the model. Different cell sizes were accommodated for when determining the conductance.

The conductance values for the DRN, which are grid cell size dependent, were initially set based on an assumed hydraulic conductivity of the streambed of 8.64E-02m/d, a streambed thickness of 0.5m and an assumed width of 2m.

The ratio of hydraulic conductivity and streambed thickness (K-M factor) was included in the calibration model, however, a single K-M factor was calibrated for all surface watercourses.

The elevation of the ephemeral watercourses and swamps were set at 0.05m below the top of the relevant cell. This was a necessary assumption due to grid cell size with respect to swamps, as swamp piezometers needed to be co-located with the centre of the nearest DRN cell, else the difference in elevation between adjacent cells would otherwise be too large.

In the context of the above, this is considered a reasonable approach in JBS&G's technical experience.

4.10.2.4 Seepage Faces (DRN)

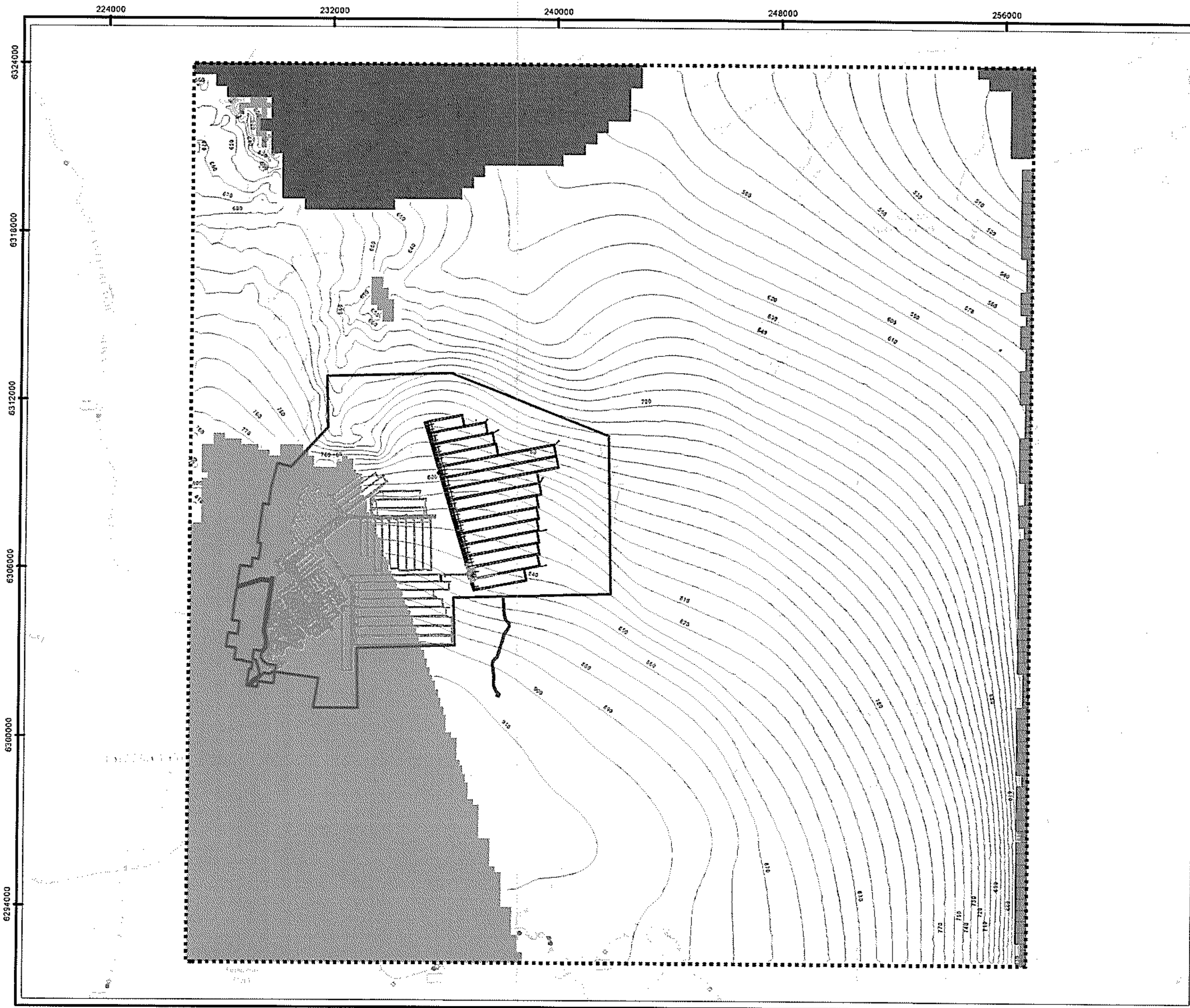
Seepage faces were set wherever a model layer 'pinched-out'.

Due to the very large number of these seepage faces (38739 cells), a FORTRAN script had to be written by JBS&G to process these from the .DIS file.

Figure 4.5 presents a plan view of various model layers. Where the model layer 'pinched-out', as represented by pink colour, a seepage face was applied immediately adjacent, represented by yellow colour.

The conductance values for the seepage face DRNs, which are also grid cell size dependent, were set based on an assumed hydraulic conductivity of 2m/d, an assumed thickness of 1m and an assumed width of 1m. The length parameter was obtained from the grid cell size. Resultant conductance ranged between 200m^2/d and 800m^2/d and is considered a reasonable value for this purpose.

The elevation of the seepage faces were set at +0.5m above the bottom of the relevant cell.



Legend:

- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- Groundwater Model Domain
- No Flow Boundary (NFB) Cells
- 'Pinched-Out' Cells
- Drain (DRN) Cells
- General Head Boundary (GHB) Cells
- Groundwater Contour (m AHD)

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02RevB | Date: 06-Aug-2019

Drawn By: JZ | Checked By: JB

Scale 1:180,000

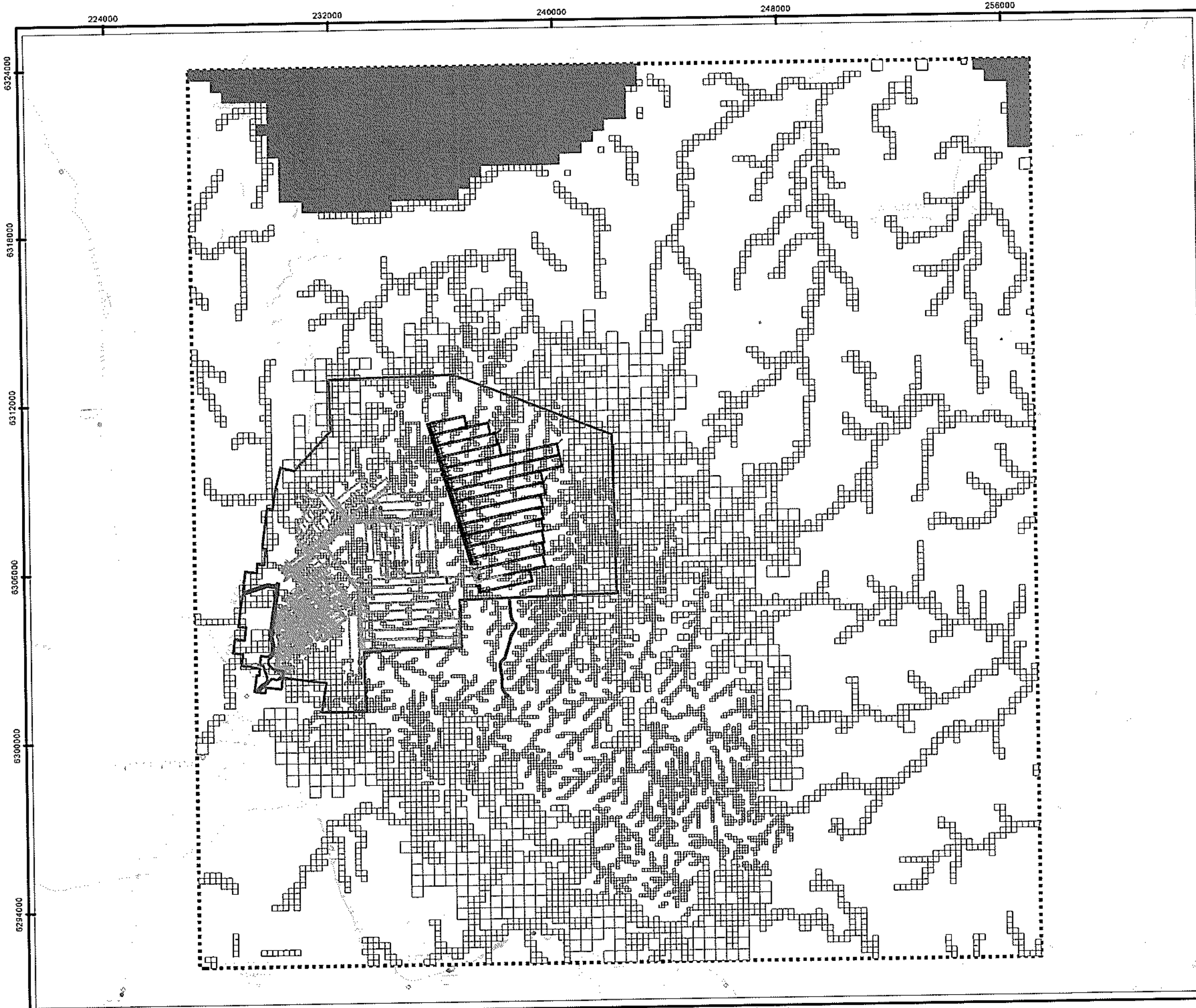
0 3 6 km

Coor. Sys. GDA 1994 MGA Zone 56

Location of General Head Boundary (Layer 27)

FIGURE: 4.9

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\DeliveryMaps\R02RevC_GW\R02RevB_D009_LocationOfGeneralHeadBoundary.mxd



Legend:

- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- Groundwater Model Domain
- No Flow Boundary (NFB) Cells
- Drain Boundary Condition

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02RevB | Date: 06-Aug-2019

Drawn By: JZ | Checked By: JB

Scale 1:180,000

0 3 6 km

Coor. Sys. GDA 1994 MGA Zone 56

Location of Drain Boundary Condition (ephemeral watercourses and swamps)

FIGURE: 4.10

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02RevC_GW\R02RevB_D010_LocationOfDrainBoundary.mxd
Reference © Department of Finance Services & Innovation 2018

The conductance value of the seepage faces was not adjusted during model calibration.

4.10.2.5 Mine Dewatering (DRN)

Depressurisation of the Lithgow Seam (Layer 24) at Angus Place Colliery and Springvale Mine and the Katoomba Seam (Layer 18) at Clarence Colliery was incorporated into the model as drain (DRN) cells.

Other mining operations in the region, such as at Baal Bone Colliery, and at Invincible Colliery, were also included in the model. Those regional mining operations target the Lithgow Seam.

A 'Stacked Drain' approach was adopted to represent depressurisation above the mined cell. In the 'Stacked Drain' methodology, DRN cells were added to every layer above target seam up until the Height of Fracturing, Zone A, which was based on the Tammetta (2013) equation.

Figure 4.11 presents the depth below ground surface to the top of the Height of Fracturing, Zone A,

From **Figure 4.11**, there are model cells where the Height of Fracturing, Zone A, exceeds ground surface.

It is noted that where a 'Stacked Drain' encountered a seepage face or an ephemeral watercourse or swamp, the 'Stacked Drain' cell was omitted. The reason for this approach was to maintain consistency when extracting model mass balance with respect to surface water catchments.

To account for the expected lower conductance at the top of the 'Stacked Drains' compared to the higher conductance at the bottom of the 'Stacked Drains', two K-M values were calibrated for each mining area. Mining areas were, for example, Springvale Mine Longwalls, Angus Place Colliery District 800 (including 300 and 700) Longwalls, Angus Place District 900 Longwalls and Angus Place Colliery Bord and Pillar area and Clarence Colliery Longwalls and Continuous Miner areas.

The conductance of the mining DRN cells were set with an assumed hydraulic conductivity of 0.5m/d, an assumed thickness of 1m and a width and length of 100m (all cells containing mining were refined to 100m). The resultant initial conductance was therefore 5000m^2/d.

It is noted that underground storage of water at Angus Place Colliery (District 800 and District 900) and at Clarence Colliery (Sump 301) were also accommodated via the DRN boundary conditions. The elevation of the relevant DRN cells were amended at the relevant time to allow recovery or 'filling' of those areas. For Angus Place Colliery, this includes the current changes in operation associated with Modification S, as documented in JBS&G (2018).

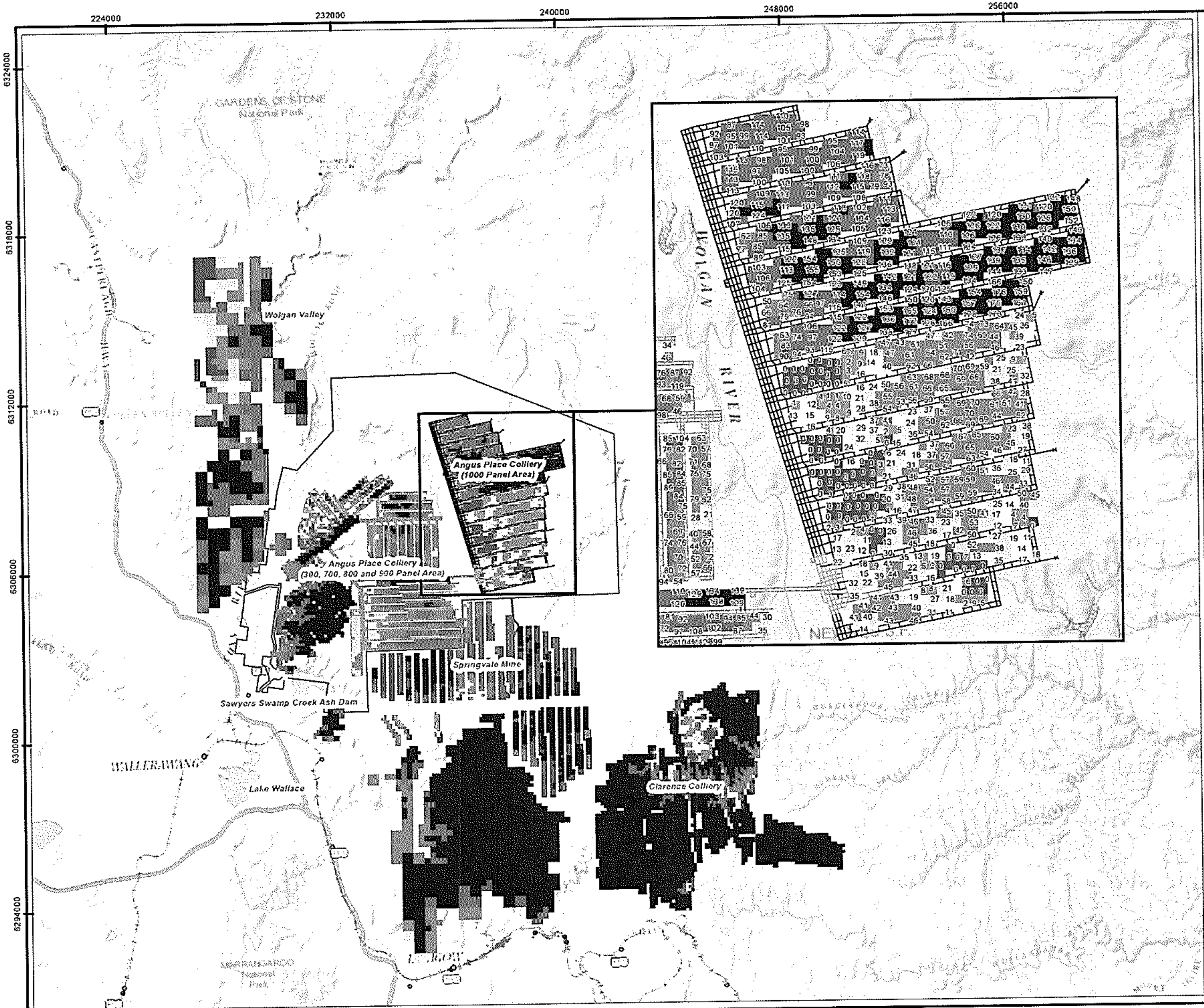
The current mine plans for Springvale Mine and Angus Place Mine Extension were incorporated into the prediction simulation. The mine plan for the 1000 Panel Area is presented in **Appendix C**.

Following completion of mining at Springvale, in the model, the Springvale Mine was transferred into Care & Maintenance operation and maintained in a dewatered state at a target groundwater elevation until 2053. Details of the Proposed Case and Null Case is presented in **Section 4.14**.

Dewatering at Clarence Colliery was assumed to continue until the 31 December 2041 (SP187).

For other mining operations in the region, Invincible Colliery, was assumed to be maintained in a dewatered state until 31 December 2025 (SP130). At Baal Bone Colliery, it was assumed to be maintained in a dewatered state until 31 October 2018 (SP101). These assumptions, if they are not correct, are not significant with respect to Springvale Mine and Angus Place Colliery as Baal Bone and Invincible Colliery are located on the opposite side of the Coxs River and are, essentially 'dry' mines, according to the model.

Figure 4.12 presents an example of mining cells in Layer 24 (Lithgow Seam) at several stress periods from September 2025 (SP129) through to December 2053 (SP190). The grid cell size in **Figure 4.12** is 100m and there is a one cell gap between adjacent mining cells.



JBS&G

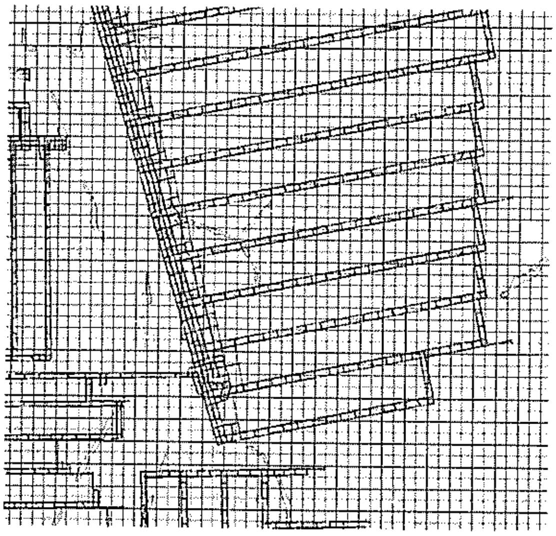
Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02RevC	Date: 27-Aug-2019
Drawn By: JZ	Checked By: JB
Scale 1:180,000	
Coor. Sys. GDA 1994 MGA Zone 56	

Fracture Height (Tammetta, 2013):

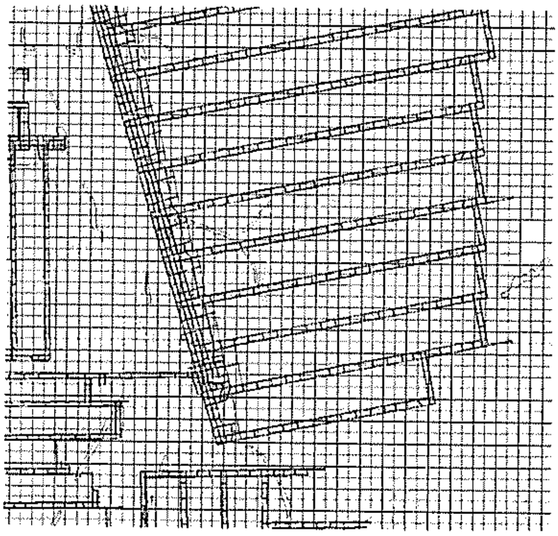
Depth to Zone A-B Interface below Ground Surface (m)

FIGURE: 4.X

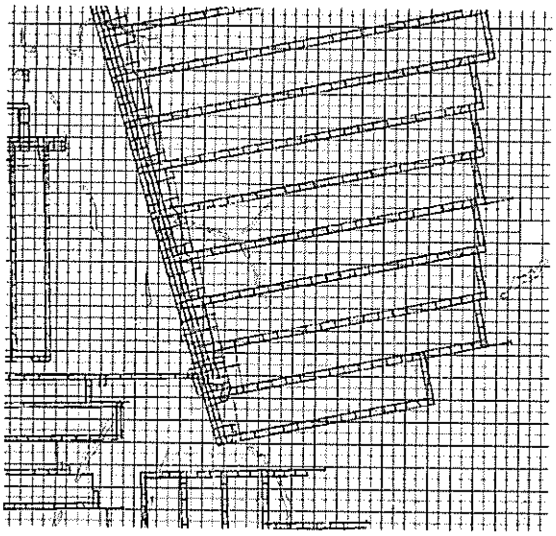
File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02RevC_GW\R02RevC_D005_HANFractured.mxd
Reference © Department of Finance Services & Innovation 2018



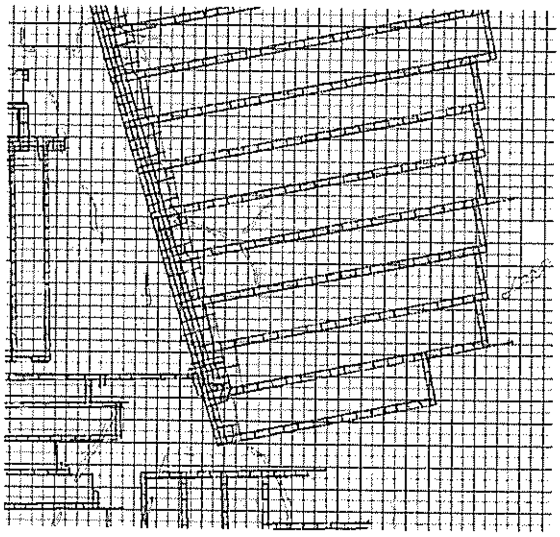
September 2025 (SP129)



December 2028 (SP142)



December 2031 (SP154)



December 2053 (SP190)

- Drain (DRN) cells

Figure 4.12: Example of Mining Cells (DRN) at Angus Place Colliery (1000 Panel Area) – Layer 24 (Lithgow Seam)

4.11 Subsidence-Induced Changes to Hydraulic Properties

During model calibration, it was identified that the 'Stacked Drains' methodology was required to be used in order to match observed dewatering rates and observed declines in water table level within THPSS at Springvale Mine. Accordingly, a 'full' profile of changes to hydraulic properties was applied only after cessation of mine dewatering. An exception was that the uppermost cell of the 'full' profile was applied during mine dewatering, to represent near-surface cracking.

Due to the 'full' profile of changes to hydraulic properties not being observed at operations within the model domain, calibration was only undertaken with respect to parameters associated with near-surface cracking. This is considered appropriate.

4.11.1 Approach for Longwalls

Time-Varying Materials (TVM) module for MODFLOW-USG was used to implement the subsidence-induced changes to hydraulic properties associated with mining.

As noted above, the changes to hydraulic properties commenced in the stress period following completion of mine dewatering, except for the uppermost cell above the 'Stacked Drain'.

Implementation of this change in MODFLOW-USG required development of a FORTRAN script to prepare the .TVM file. The Tammetta (2013) and Ditton (DgS, 2014, 2015) methods have both been included in that script, as well as the upper 95th equations.

Tammetta (2013) is based on regression analysis, therefore the 95th equation reflects the 95th percentile upper fit of the equation. Ditton's (2014, 2015) method is based on dimensional analysis, however, again is fitted to observation data, hence the 95th percentile fit to the data informs the equation constants and exponents.

The results presented in this report use Tammetta (2013) 'mean', and not the upper 95th equation.

It is noted that Tammetta (2013) method significantly overpredicts the height of depressurisation when mined thickness is equal to 3.4m or above and is considered a conservative approach.

Figure 4.13 presents the conceptual approach to the FORTRAN script developed by JBS&G for the TVM Module. There are five zones in the approach: the Caved Zone (goaf); Zone A (continuous cracking; height of free drainage); Zone B (Constrained Zone, vertical dilation of bedding plies leading to higher horizontal hydraulic conductivity and some change to vertical hydraulic conductivity); Zone C (Elastic Zone, negligible change to vertical permeability, some dilation of bedding planes); Zone D (Surface Cracking; change to vertical permeability).

At the interface between Zone A and B, a narrow transition was introduced to account for physical separation between these zones observed in the physical subsidence models in the academic literature. Similarly, a reduced magnitude but still narrow transition was introduced between Zone B and C. **Figure 4.14** presents the conceptual subsidence model from CSIRO (2013).

The approach adopted for delineation of the elevation of the Caved Zone Interface, A-B Interface, B-C Interface and C-D Interface as is follows:

- Caved-Zone A Interface:
  - Top of Seam plus Height of Caved Zone Multiplier * Mining Height (t)
- A-B Interface:
  - Top of Seam plus Height of Fracturing for Zone A (HoF_A)
    - where HoF_A determined from Tammetta's (2013) equation
    - where HoF_A determined from Ditton's (2014) equation.
- B-C Interface:
  - Top of Seam plus Height of Fracturing for Zone B (HoF_B)
    - where HoF_B was 1.5 * panel width was assumed (adapted from Figure 20 of IEPMC, 2018), since Tammetta's equation is only for HoF_A
    - where HoF_B was Ditton's (2015) equation.
- C-D Interface:
  - Ground Surface minus 10m (10m was assumed based on a general expectation of near-surface cracking to 10-15m, as presented in RPS (2014a) at the time; further detail is presented in the Subsidence Assessment Report).

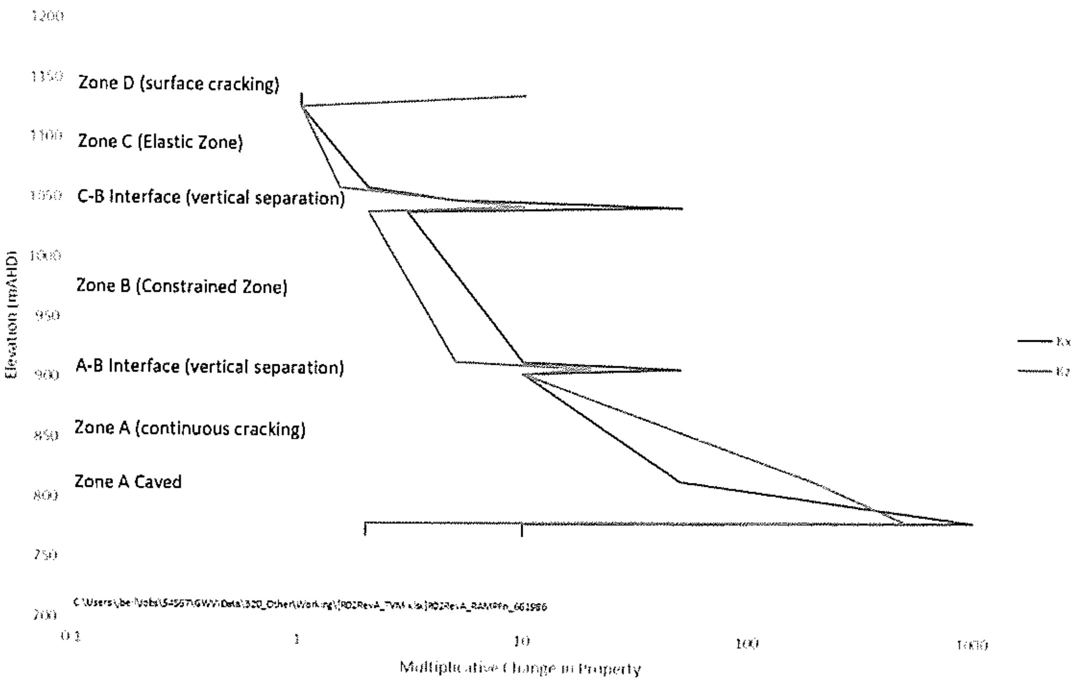


Figure 4.13: Conceptual Model of Implementation of Subsidence-Induced Change to Hydraulic Properties

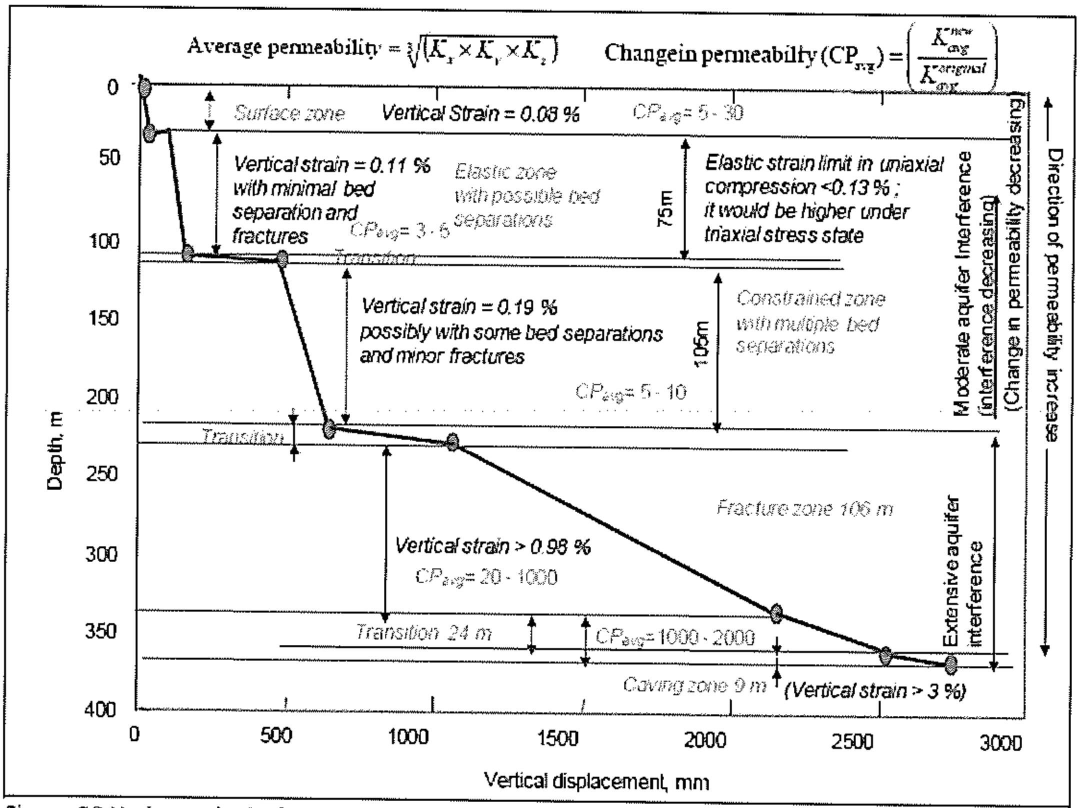


Figure 28 Hydrogeological response model for Springvale Colliery (ACARP C18016)

Figure 4.14: Conceptual Model of Subsidence-Induced Change to Hydraulic Properties and Displacement (after Figure 28 of CSIRO (2013))

Table 4.7 presents the default values for the various zones used in the subsidence-induced change to hydraulic properties. It is noted that storage properties were not changed due to known issues with the head correction factor that is internal to the MODFLOW-USG code.

If the A-B Interface or B-C Interface intersects ground surface, then the subsidence profile is truncated such that the maximum change from **Table 4.7** is applied, as relevant.

An example of the implementation of the subsidence model for Longwalls is presented in **Appendix D**.

Table 4.7: Initial Values for Zonation of Subsidence-Induced Change to Hydraulic Properties

#	Sub-Surface Zone	Top of Zone	Bottom Of Zone	Zone Thickness	Kx (mult.)	Kz (mult.)	Ss (mult.)	Sy (mult.)
1	D (Surface)	Ground	C-D_Interface	0	1	10	1	1
2	C (Elastic)	C-D_Interface	C_Upper	10	1	1	1	1
3	C (Elastic)	C_Upper	B-C_DilationAbove	10	2	1.5	1	1
4	B (Constrained)	B-C_DilationAbove	B-C_Interface	5	5	5	1	1
5	B (Constrained)	B-C_Interface	B-C_DilationBelow	0	50	10	1	1
6	B (Constrained)	B-C_DilationBelow	A-B_DilationAbove	5	3	2	1	1
7	B (Constrained)	A-B_DilationAbove	A-B_Interface	5	10	5	1	1
8	A (Fractured)	A-B_Interface	A-B_DilationBelow	0	50	20	1	1
9	A (Fractured)	A-B_DilationBelow	CavedA_Interface	5	10	10	1	1
10	A (Caved)	CavedA_Interface	Top of Seam	0	50	200	1	1
11	Mined Seam	Top of Seam	Bottom of Seam	0	1000	500	1	1
12	Basement	Bottom of Seam	Basement_Upper	0	10	2	1	1
13	Basement	Basement_Upper	n/a	10	10	2	1	1

4.11.2 Approach for Roadways

During early testing of the groundwater model during model calibration at Springvale Mine, and by inference at Angus Place Colliery, roadways needed to be disabled to match observed dewatering rates. Accordingly, roadways were not enabled for either the model calibration or model prediction, including uncertainty analysis.

4.11.3 Approach for Bord & Pillar

A modification to the approach presented in **Section 4.11.1** was used for Bord & Pillar operations.

The intent of the modification was to allow the same approach to be used for both Longwalls and Bord & Pillar operations, however, with appropriate scaling to account for the significant difference in 'void width'.

It is noted that the nature of the Tammetta (2013) equation is such that it does not handle small panel widths. Accordingly, where Bord & Pillar operations were represented, the Ditton-Merrick formulation was used, with 'void width' used being a scaling factor on the resultant height of fracturing. It is noted that the 'void width' for Bord & Pillar areas was estimated approximately from the mine plans.

As well, the 'void width' obtained from the historical mine plans was adjusted during model calibration by multiplication by another scaling factor. The initial value of that other scaling factor, termed the 'B&P Effective Panel Width Factor' in the FORTRAN script, was 0.5. i.e. the 'void width' obtained from the mine plan was multiplied by 0.5 before being entered into the Ditton-Merrick formulation. These approximations were required to enable automated update of the change to hydraulic properties due to mining.

An example of the implementation of the subsidence model for Bord and Pillar mining cells is presented in **Appendix D**.

4.12 Model Calibration

4.12.1 Model Targets

A combination of targets were used in the calibration model.

The targets included:

- Head Targets (divided into those that were appropriate for quasi-steady-state calibration and those where heads were available, however, after potentially being impacted by mining)
  - Head data comprised of standpipe piezometer data (ridgeline piezometers and swamp piezometers) as well as vibrating wire piezometer data:
    - Data was filtered from daily data to monthly
    - Vibrating wire piezometers with anomalous trends were omitted.
- Change in Head Targets
  - These were derived by the TARGPESTU.exe utility provided by Groundwater Vistas. This utility takes a time-series hydrograph, separates the first value as a Head target and sets the remainder as a 'change in head' target. In this way, PEST focuses separately on 'Head' and 'Drawdown' targets:
    - It is noted that 'Drawdown' is the grouping used by PEST but, technically, when solving the Richards Equation, there is no drawdown (.DDN) file.
- Flux Targets
  - Operational dewatering rates to Springvale Mine, Angus Place Colliery and Clarence Colliery were included calibration datasets:
    - It is highlighted that whilst dewatering rates are similar to inflow rates, the former is complicated by underground water management, however, is the data that is available
    - It is noted that Clarence Colliery output is not presented in this report.
  - To provide PEST with two separate foci with respect to inflow, relative cumulative inflow and inflow rate were generated and considered:
    - A FORTRAN script had to be written to process the .CBB file between PEST iterations via the USGS ZonBudUSG.EXE utility.

In total, there were 18624 observations in the PEST .PST control file. Of those, 17702 were Head or Change in Head targets, with the remainder inflow or relative cumulative inflow. For the Head or Change in Head targets, these were obtained from 371 monitoring sites, of which approximately 25 sites were omitted due to various identified issues.

4.12.2 Calibration Approach

PEST_HP.exe was used to calibrate the groundwater model. 4334 parameters were included in the initial calibration attempt. The parameters included:

- horizontal and vertical hydraulic conductivity at Pilot Points
- specific storage and specific yield (used as porosity for Richards Equation at Pilot Points
- variably saturated flow parameters (partially calibrated)
- recharge factors (36 parameters)
- evapotranspiration factors (36 parameters)

- general head boundary conductances (5 parameter zones)
- drain conductances of 'Stacked Drains' (9 sets of Top and Bottom K-M factor)
- drain conductances of surface watercourses (1 value used for all watercourses)
- time-varying material properties (4 parameters)

The initial Jacobian matrix took 29 days to generate and several parameters of the 4334 needed to be FIXED to overcome corrupted sensitivities in that .JCO file. Also, as already mentioned, the variably saturated flow parameters were FIXED due to issues with model stability. From the initial Jacobian run, a Singular Value Decomposition (SVD) was prepared using the PEST utility SVDAPREP.EXE. SUPCALC.exe indicated that 456 super-parameters were recommended, and 456 were used.

The distribution of Pilot Points used in Layer 28 in the model is presented in **Figure 4.15**. The location of Pilot Points in other model layers is presented in **Appendix E**.

It is noted that, due to the very significant computation requirement, the number of Pilot Points were optimised in the upper part of the model where most of the layer was 'pinched-out'. The location of Pilot Points was informed by the presence of geological lineaments, which in turn are associated with the location of THPSS. Further detail on the conceptual model and the relationship with geological lineaments is presented in the Groundwater Impact Assessment.

4.12.3 Calibration Results

The model control file associated with the calibration simulation is:

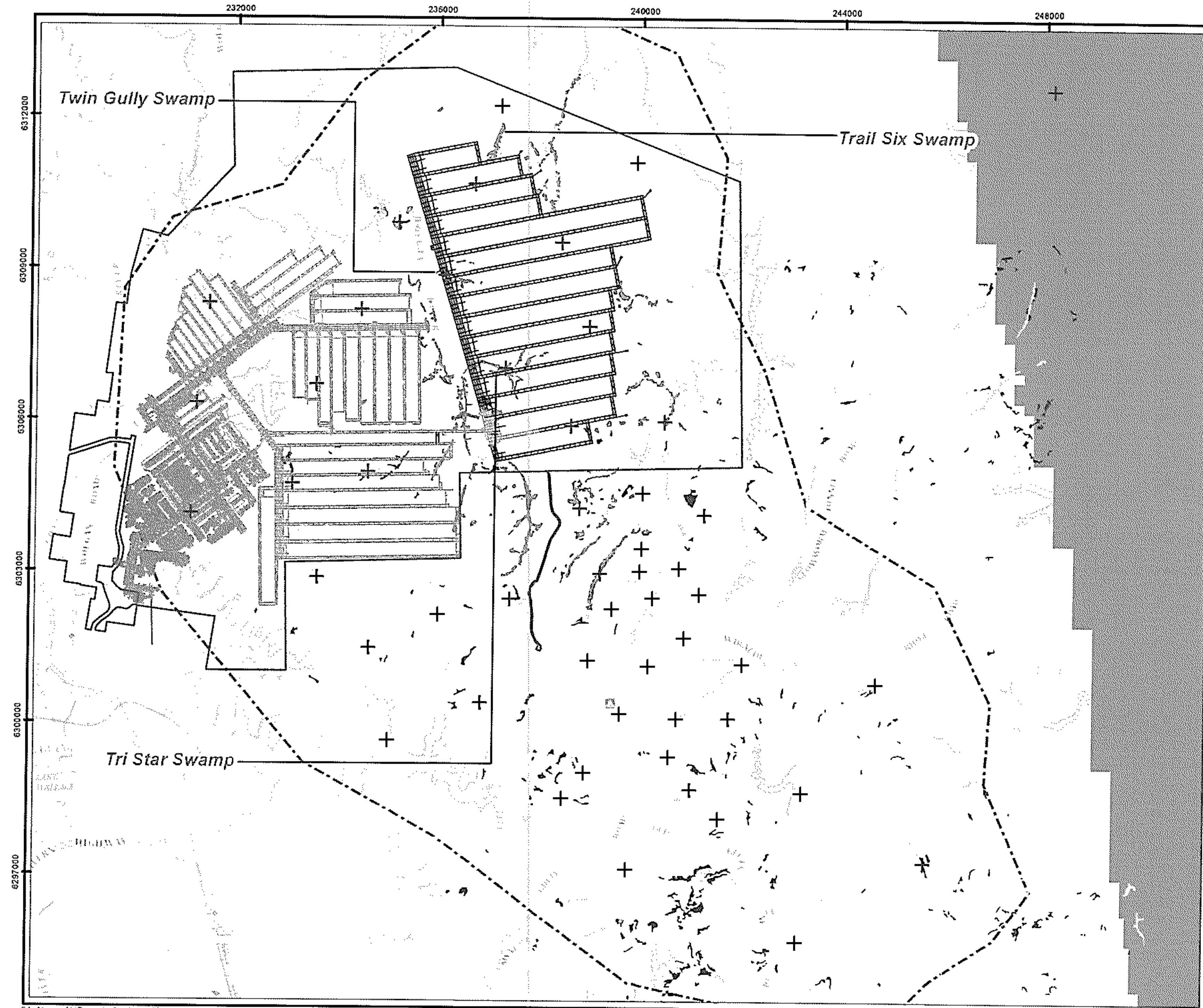
- R01RevC_CAL103-Oct18_01a.gwv

4.12.3.1 Model Parameters

Table 4.8 presents the calibrated values of recharge factor and **Table 4.9** presents the calibrated values of evapotranspiration factor. The location of zones is presented in **Figure 3.2**.

Table 4.8: Calibrated Values of Recharge Factor

Recharge Zone	Recharge Factor	Recharge Zone	Recharge Factor
1 (F4)	0.09	19 (F7)	0.01
2 (G4)	0.08	20 (G7)	0.40
3 (H4)	0.11	21 (H7)	0.40
4 (I4)	0.19	22 (I7)	0.19
5 (J4)	0.14	23 (J7)	0.35
6 (K4)	0.09	24 (K7)	0.06
7 (F5)	0.08	25 (F8)	0.04
8 (G5)	0.14	26 (G8)	0.06
9 (H5)	0.05	27 (H8)	0.40
10 (I5)	0.31	28 (I8)	0.40
11 (J5)	0.17	29 (J8)	0.15
12 (K5)	0.11	30 (K8)	0.15
13 (F6)	0.04	31 (F9)	0.07
14 (G6)	0.40	32 (G9)	0.04
15 (H6)	0.40	33 (H9)	0.02
16 (I6)	0.04	34 (I9)	0.25
17 (J6)	0.15	35 (J9)	0.07
18 (K6)	0.09	36 (K9)	0.06



Legend:

- Pilot Points (Layer 28)
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- Other Swamps (RPS 2019)
- Shrub Swamp (DEC 2006)
- Hanging Swamp (DEC 2006)
- 'Pinched-Out' Cells
- Pilot Point Region

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02RevB	Date: 06-Aug-2019
Drawn By: JZ	Checked By: JB
Scale 1:100,000	

0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Distribution of Pilot Points used in Model Calibration (Layer 28)

FIGURE: 4.15

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02RevC_GW\R02RevB_D012_PilotPoints_Layer28.mxd
Reference © Department of Finance Services & Innovation 2018

Table 4.9: Calibrated Values of Evapotranspiration (ET) Factor

ET Zone	ET Factor	ET Zone	ET Factor
1 (F4)	0.38	19 (F7)	0.65
2 (G4)	0.45	20 (G7)	0.65
3 (H4)	0.64	21 (H7)	0.65
4 (I4)	0.33	22 (I7)	0.65
5 (J4)	0.61	23 (J7)	0.20
6 (K4)	0.54	24 (K7)	0.65
7 (F5)	0.36	25 (F8)	0.45
8 (G5)	0.40	26 (G8)	0.17
9 (H5)	0.34	27 (H8)	0.20
10 (I5)	0.58	28 (I8)	0.65
11 (J5)	0.58	29 (J8)	0.39
12 (K5)	0.58	30 (K8)	0.37
13 (F6)	0.40	31 (F9)	0.38
14 (G6)	0.76	32 (G9)	0.45
15 (H6)	0.65	33 (H9)	0.65
16 (I6)	0.32	34 (I9)	0.65
17 (J6)	0.71	35 (J9)	0.44
18 (K6)	0.33	36 (K9)	0.53

Table 4.10 presents the calibrated values of hydraulic parameters. The spatial distribution of calibrated hydraulic parameters is presented in **Appendix E**, together with charts of the cumulative distribution of those hydraulic parameters. As noted above, the values of parameters associated with the variably saturated flow were FIXED at values obtained part way through calibration. The initial values were guided by the original studies by Brooks and Corey (1966) and van Genuchten (1980), including testing by Brooks and Corey on sandstone specimens.

It is highlighted that van Genuchten's Alpha parameter is scale-dependent, therefore has units of metres in the current model.

The shape of the relationship between relative permeability and pressure head (capillary) using the parameter values in **Table 4.10** is relatively steep and resembles what would be expected for medium sand, however, is appropriate for representing consolidated rock due to the low saturated hydraulic conductivity of consolidated rock. As each of the hydrogeological units is considered to behave more like consolidated rock, except at point of outcrop, rather than partially or extremely weathered rock, the values for parameters of variably saturated flow for each unit are quite similar.

Table 4.11 presents the K-M factor for the DRN mining cells. As discussed in **Section 4.10.2.3**, a FORTRAN script was prepared to allow changes to DRN conductances via altering the hydraulic conductivity and associated streambed thickness (K-M Factor(d^{-1})). Other attributes in the calculation of conductance are fixed, such as grid cell size. For surface watercourses the calibrated value of K-M factor was 2.20d^{-1}.

Table 4.10: Calibrated Values of Hydraulic Properties

Layer	Class	Unit	SubUnit	Kh (m/d) *Geomean	Kz (m/d) *Geomean	Ss (1/m) *Geomean	Porosity *Geomean	α (m^{-1})	β	S_{wr}	BrooksN
1	Sandstone/Regolith	Burralow Formation	Sandstone	6.60E-02	1.58E-03	1.62E-06	0.19	2.5	7.0	0.32	3.5
2	Shale	-	YS1	8.37E-02	4.24E-03	6.80E-06	0.29	2.4	8.0	0.35	5.1
3	Sandstone/Regolith	-	Sandstone	2.56E-02	7.01E-03	1.85E-06	0.22	2.5	7.6	0.25	3.0
4	Shale	-	YS2	7.76E-04	2.29E-05	7.92E-06	0.33	1.8	9.6	0.38	4.0
5	Sandstone/Regolith	-	Sandstone	1.14E-01	1.54E-02	2.08E-06	0.16	2.8	7.3	0.31	3.9
6	Shale	-	YS3	5.33E-02	3.48E-03	7.35E-06	0.35	1.7	6.9	0.39	4.2
7	Sandstone/Regolith	-	Sandstone	8.10E-02	4.10E-03	2.01E-06	0.19	2.0	6.5	0.29	4.8
8	Shale	-	YS4	1.79E-02	6.08E-04	7.86E-06	0.29	2.1	7.4	0.47	5.2
9	Sandstone/Regolith	-	Sandstone	1.68E-02	2.31E-03	1.89E-06	0.17	1.6	7.9	0.52	5.2
10	Shale	-	YS5	2.09E-02	1.81E-03	7.46E-06	0.38	1.6	8.4	0.73	5.2
11	Sandstone/Regolith	-	Sandstone	1.16E-01	1.34E-02	2.00E-06	0.20	1.7	6.9	0.56	5.2
12	Shale	-	YS6	1.42E+00	1.10E-01	7.59E-06	0.37	1.8	7.7	0.71	5.1
13	Quartzose sandstone	Banks Wall Sandstone	BW1	1.86E-02	2.42E-03	8.05E-06	0.23	1.6	5.6	0.33	4.2
14	Quartzose sandstone	-	BW2	9.08E-04	1.60E-04	5.63E-06	0.23	1.9	8.2	0.28	3.2
15	Claystone	Mt York Claystone	n/a	3.88E-04	2.61E-05	7.98E-06	0.41	1.5	9.3	0.70	4.3
16	Quartzose to quartz-lithic sandstone	Burra-Moko Sandstone	n/a	6.38E-03	1.20E-03	5.98E-06	0.27	2.6	9.4	0.35	4.1
17	Claystone/Shale/Sandstone	Caley Formation	n/a	8.47E-04	7.18E-05	9.14E-06	0.41	1.7	7.1	0.40	3.5
18	Coal	Katoomba Seam	n/a	7.17E-03	1.26E-03	5.89E-06	0.21	1.7	4.0	0.27	3.5
19	Claystone/Shale	Farmers Creek Formation	n/a	3.34E-04	3.27E-05	7.71E-06	0.37	1.5	9.4	0.38	3.8
20	Lithic sandstone/Claystone/Quartz-Lithic Sandstone	Gap Sandstone/State Mine Creek Formation/Angus Place Formation (Watts Sandstone)	n/a	2.54E-02	4.64E-03	5.62E-06	0.23	2.3	7.7	0.43	5.1
21	Mudstone/Siltstone/Claystone (Marine Incursion)	Denman Formation	n/a	4.25E-04	2.54E-05	7.12E-06	0.38	1.8	8.6	0.45	4.1
22	Sandstone/Mudstone (Lower delta plain)	Glen Davis / Long Swamp Formation	n/a	1.09E-01	4.40E-02	4.58E-06	0.19	1.5	7.8	0.70	5.2
23	Conglomerate (Fluvial)	Blackmans Flat Conglomerate / Lidsdale Coal Seam	n/a	1.39E-02	1.43E-03	9.52E-06	0.26	3.3	5.0	0.29	3.4
24	Coal (Fluvial)	Lithgow Seam	n/a	1.95E-02	3.98E-03	4.74E-06	0.20	2.0	4.3	0.30	3.4
25	Conglomerate (Fluvial)	Marrangaroo Conglomerate	n/a	4.16E-02	4.08E-03	7.41E-06	0.26	3.2	4.3	0.30	3.1
26	Sandstone (Shoreline complex - delta front)	Nile Subgroup	n/a	6.78E-03	1.28E-03	5.88E-06	0.22	2.1	8.1	0.28	3.2
27	Siltstone/Sandstone (Shoreline)	Shoalhaven Group	n/a	4.36E-04	4.48E-05	9.72E-07	0.41	1.3	8.7	0.33	3.9
28	Tuff/Granite	Carboniferous	n/a	1.34E-02	1.18E-02	1.62E-06	0.06	2.1	3.5	0.70	2.5

Table 4.11: Calibrated Values of DRN K-M Factor (d^{-1}) (Mining)

DRN Zone	Description	Top of Stack Value (d^{-1})	Bottom of Stack Value (d^{-1})
1 (313 and 213)	Springvale Longwalls	0.18	0.18
2 (312 and 212)	Clarence Longwalls	0.38	0.41
6 (308 and 208)	Invincible Longwalls	0.22	0.27
7 (307 and 207)	Clarence Continuous Miner	0.52	0.64
8 (306 and 206)	Invincible Bord & Pillar	0.25	0.40
9 (305 and 206)	Baal Bone Bord & Pillar	0.25	0.74
10 (304 and 204)	Angus Place Bord & Pillar	0.26[1]	0.25
11 (303 and 203)	Baal Bone Longwalls	0.18[1]	0.17
12 (302 and 202)	Angus Place District 900 Longwalls	0.22	0.30
13 (301 and 201)	Angus Place District 800 Longwalls	0.29[1]	0.28

Note 1. the FORTRAN script prevented the Top of Stack Value exceeding the Bottom of Stack Value, as that would be inconsistent with the conceptual model.

Table 4.12 presents the calibrated K-T factor (m^2/d) for the GHB cells that are located on the eastern boundary of the model, in Layer 27.

Table 4.12: Calibrated Values of GHB K-T Factor (m^2/d)

GHB Zone	Description	Initial Value (m^2/d)	Calibrated Value (m^2/d)
1	Northern End	8.6	8.9
2	-	17.3	18.5
3	-	17.3	13.6
4	-	17.3	13.9
S	Southern End	17.3	15.8

Table 4.13 presents the calibrated values of the Time-Varying Material properties input file. It is noted that only Kx and Kz for Zone 1 and the location of C-D interface was calibrated.

It is also noted that Ss and Sy (porosity when LAYCON=5) were not changed in the model as it was identified that changes to storage with MODFLOW-USG invokes a head-correction term that needs to be disabled (Dr Noel Merrick, 3rd party reviewer, pers. comms.). That head-correction term led to instability in the model.

The calibrated value of the 'B&P Effective Panel Width Factor', discussed in **Section 4.11.3**, was 0.45.

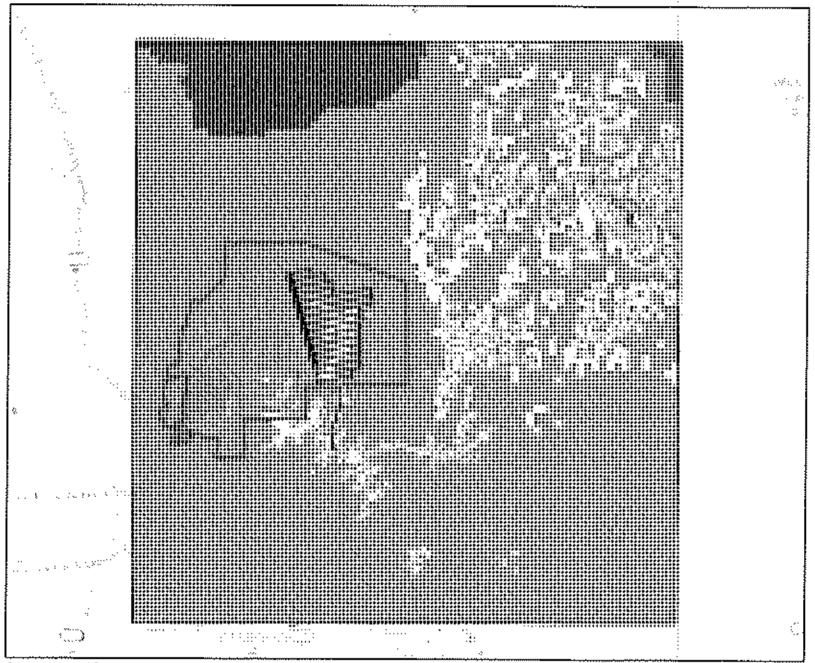
Table 4.13: Calibrated Values for Zonation of Subsidence-Induced Change to Hydraulic Properties

#	Sub-Surface Zone	Top of Zone	Bottom Of Zone	Zone Thickness	Kx (mult.)	Kz (mult.)	Ss (mult.)	Sy (mult.)
1	D (Surface)	Ground	C-D_Interface	0	1.23	8.48	1	1
2	C (Elastic)	C-D_Interface	C_Upper	9.31	1	1	1	1
3	C (Elastic)	C_Upper	B-C_DilationAbove	10	2	2	1	1
4	B (Constrained)	B-C_DilationAbove	B-C_Interface	5	S	5	1	1
5	B (Constrained)	B-C_Interface	B-C_DilationBelow	0	50	10	1	1
6	B (Constrained)	B-C_DilationBelow	A-B_DilationAbove	5	3	2	1	1
7	B (Constrained)	A-B_DilationAbove	A-B_Interface	5	10	S	1	1
8	A (Fractured)	A-B_Interface	A-B_DilationBelow	0	50	20	1	1
9	A (Fractured)	A-B_DilationBelow	CavedA_Interface	5	10	10	1	1
10	A (Caved)	CavedA_Interface	Top of Seam	0	50	200	1	1
11	Mined Seam	Top of Seam	Bottom of Seam	0	1000	500	1	1
12	Basement	Bottom of Seam	Basement_Upper	0	10	2	1	1
13	Basement	Basement_Upper	n/a	10	10	2	1	1

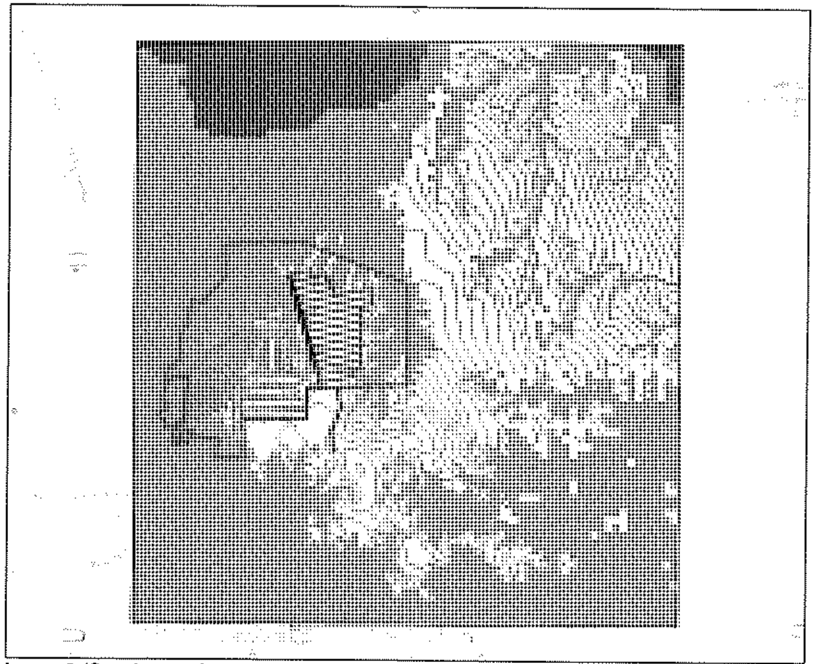
4.12.3.2 Modelled Groundwater Elevation

Groundwater elevations in several layers are presented in **Figure 4.16** and are quasi-steady-state results. The contour interval in **Figure 4.16** is 10m.

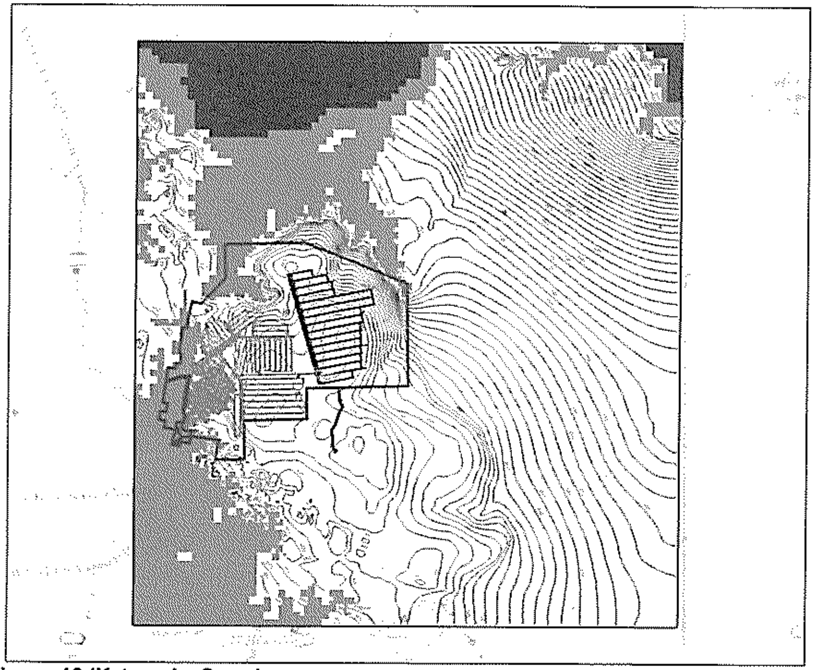
Figure 4.17 presents the equivalent model output to **Figure 4.16**, however, as pressure head in mH2O.



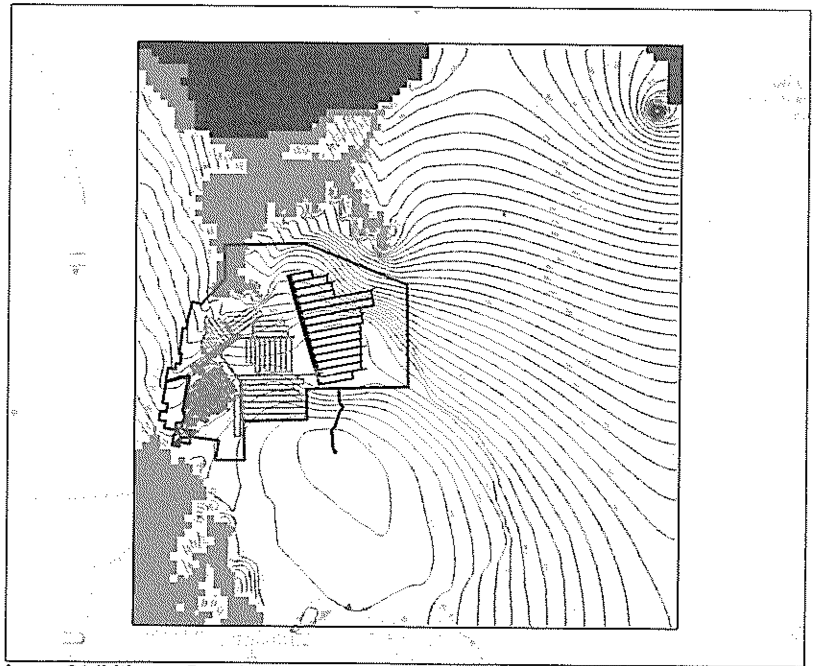
Layer 1 (Sandstone above YS1)



Layer 9 (Sandstone between YS4 and YS5)



Layer 18 (Katoomba Seam)



Layer 24 (Lithgow Seam)

Legend:

- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- Groundwater Model Domain
- No Flow Boundary (NFB) Cells
- 'Pinched-Out' Cells
- Drain (DRN) Cells
- Groundwater Contour (m AHD)

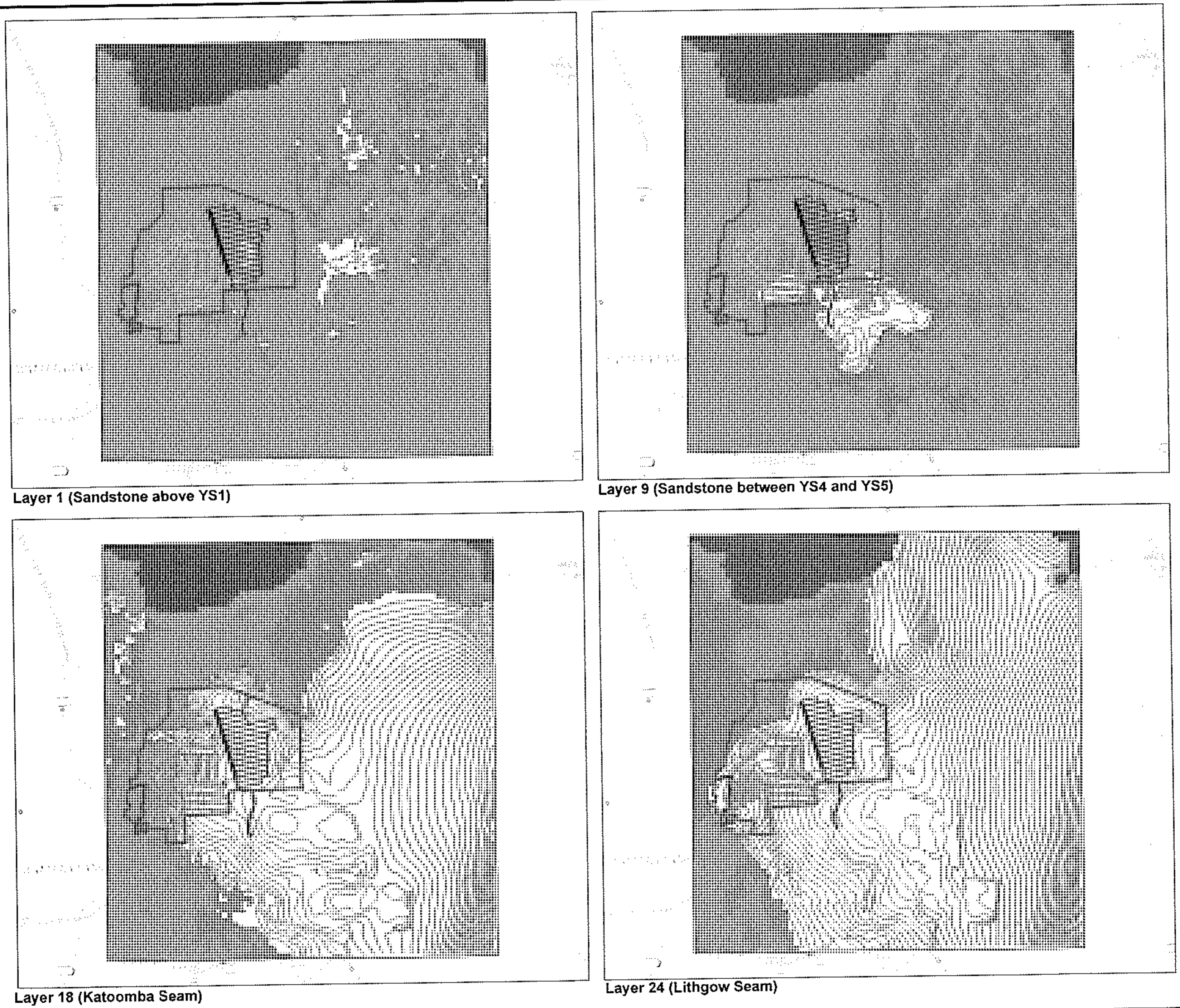
JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 02-Sep-2019
Drawn By: JZ	Checked By: JB
Scale 1:400,000	
0 5 10 km	
Coor. Sys. GDA 1994 MGA Zone 56	

Modelled Groundwater Elevation – Quasi Steady-State (SP1TS10)

FIGURE: 4.16

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D018_GroundwaterElevation_QSteadyState.mxd
Reference: © Department of Finance, Services & Innovation 2018



Legend:

- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- Groundwater Model Domain
- No Flow Boundary (NFB) Cells
- 'Pinched-Out' Cells
- Pressure Head (m) ≤0
- Pressure Head (m H2O)

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:400,000	

0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

Modelled Pressure Head – Quasi Steady-State (SP1TS10)

FIGURE: 4.17

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D018a_PressureHead_QSteadyState.mxd
Reference: © Department of Finance, Services & Innovation 2018

From **Figure 4.16**, the groundwater flow direction in Layer 1 is influenced by local topography, however, at depth (Layer 9, Layer 18 and Layer 24) is in a north-easterly direction.

The influence of the Wolgan Valley in **Figure 4.16** in Layer 24 is also apparent.

Figure 4.18 presents the modelled groundwater elevation at the end of the calibration simulation in October 2018 (SP101TS5).

From **Figure 4.18**, the influence of depressurisation of the Lithgow Seam (Layer 24) at Springvale Mine is apparent and is also apparent in the overlying Katoomba Seam (Layer 18).

Figure 4.19 presents the equivalent model output to **Figure 4.18**, however, as pressure head in mH2O.

4.12.3.3 Model Water Balance

The global water balance from the groundwater model was extracted at several Stress Periods to provide an indication of relative contribution of each of the relevant components. These data were obtained from the MODFLOW Listing (.LST) file.

It is noted that output from the Listing file uses 4 decimal places, therefore the same precision is used in the tables presented below. i.e. ignoring the concept of significant figures in this instance.

Table 4.14 presents the global water balance from the groundwater model at the end of quasi steady-state period (SP1TS10).

Table 4.14: Model Water Balance – Quasi Steady-State (SP1TS10)

Component	Groundwater Inflow (m3/d)	Groundwater Outflow (m3/d)
Storage	7589.7598	5607.2746
Constant Head	0.0000	0.0000
Drains	-	209953.3165
River Leakage	8526.7236	2767.9077
Evapotranspiration	-	168705.1094
Head Dependent Boundary Conditions	-	1425.2755
Recharge	372343.5938	-
Total	388460.0772	388458.8837
	Inflow – Outflow	1.1935
	Percent Discrepancy	0.00%

From **Table 4.14**, recharge is the dominant inflow into the groundwater model and outflow is via surface drains and evapotranspiration, in that order. From **Table 4.14**, the mass balance error is 1.19m^3/d (0.01L/s) which is less than 0.1%, on a percent basis, and is therefore consistent with the guideline value noted in **Section 4.2**, with respect to a Class 2 model.

Table 4.15 presents the global water balance from the groundwater model in October 2018 (TS101TS5).

Table 4.15: Model Water Balance – End of Calibration Period – October 2018 (SP101TS5)

Component	Groundwater Inflow (m3/d)	Groundwater Outflow (m3/d)
Storage	70857.0900	5662.6776
Constant Head	0.0000	0.0000
Drains	-	151872.8479
River Leakage	7156.5898	2827.7632
Evapotranspiration	-	83951.3906
Head Dependent Boundary Conditions	-	1400.9713
Recharge	167700.1719	-
Total	245713.8518	245715.6506
	Inflow – Outflow	-1.7988
	Percent Discrepancy	-0.00%

Legend:

- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- Drain (DRN) Cells
- Groundwater Contour (m AHD)

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:150,000	

0 1.5 3
km

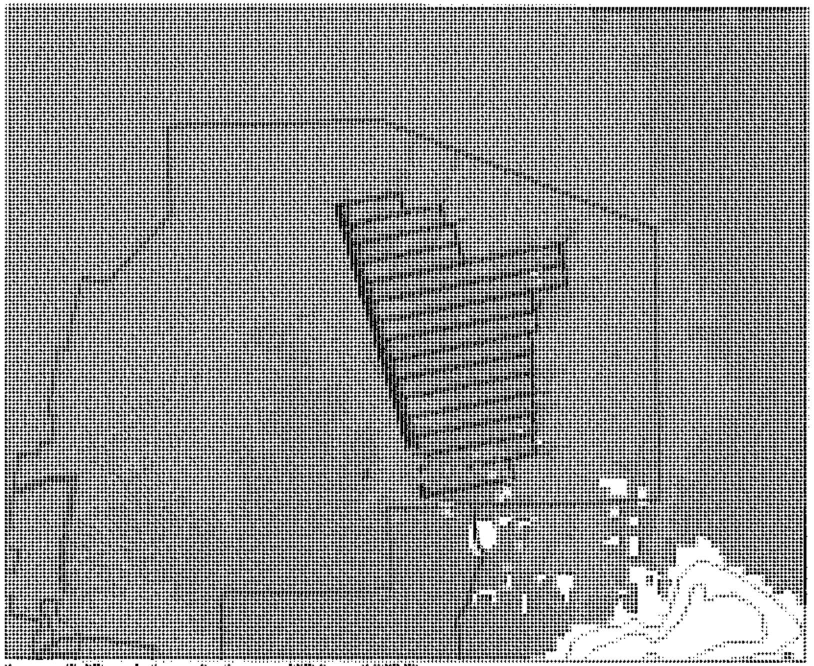
Coor. Sys. GDA 1994 MGA Zone 56

Modelled Groundwater Elevation – October 2018 (SP101TS5)

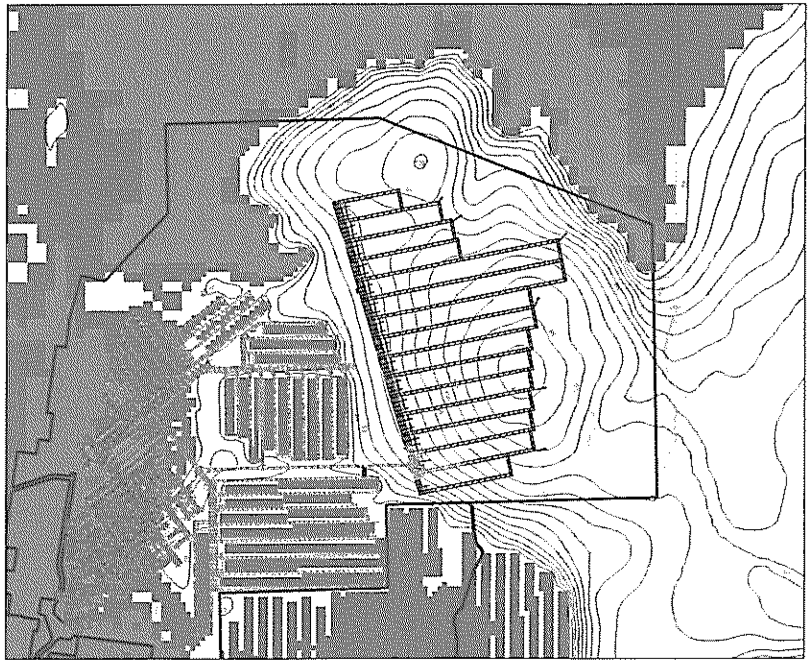
FIGURE: 4.18

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D019_GroundwaterElevation_Oct2018.mxd
Reference: © Department of Finance, Services & Innovation 2018

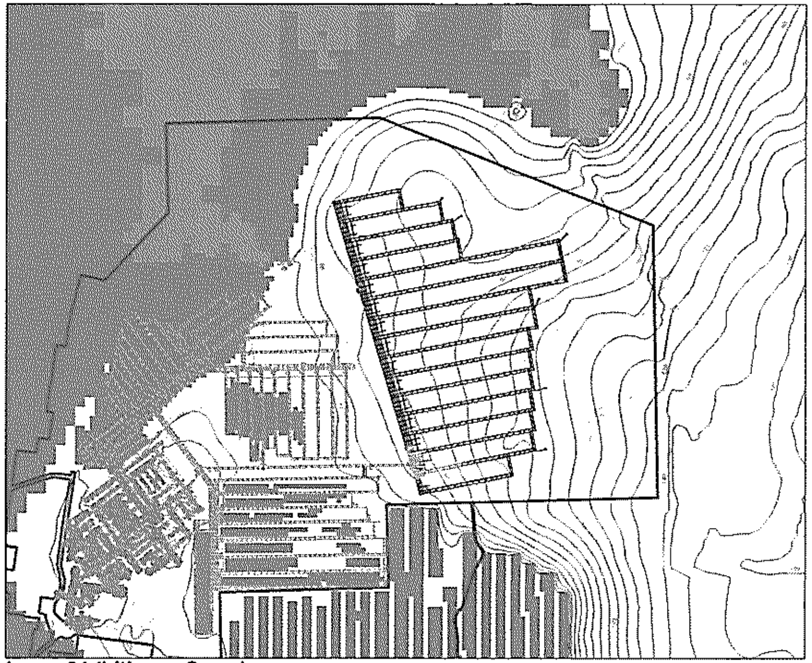
Layer 1 (Sandstone above YS1)



Layer 9 (Sandstone between YS4 and YS5)



Layer 18 (Katoomba Seam)



Layer 24 (Lithgow Seam)

Legend:

- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- Groundwater Model Domain
- No Flow Boundary (NFB) Cells
- 'Pinched-Out' Cells
- Pressure Head (m) ≤0
- Pressure Head (m H2O)

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:150,000	

0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Modelled Pressure Head – October 2018 (SP101TS5)

FIGURE: 4.19

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D019a_PressureHead_Oct2018.mxd
Reference: © Department of Finance, Services & Innovation 2018

From **Table 4.15**, in October 2018, recharge is the dominant inflow into the groundwater model and outflow is drains (surface drains as well as mine dewatering) and evapotranspiration, in that order. From **Table 4.15**, the mass balance error is -1.80m^3/d (0.02L/s), which again is less than 0.1%.

4.12.3.4 Observed Vs Modelled Heads

Figure 4.20 presents the observed versus modelled heads in mAHD.

In **Figure 4.20**, Group 1 was Angus Place Colliery and Springvale Mine standpipe piezometers; Group 2 was Angus Place Colliery and Springvale Mine vibrating wire piezometers; Group 3 was Angus Place Colliery and Springvale Mine swamp piezometers; Group 4 was Angus Place and Springvale Mine shallow aquifer piezometers and Clarence Colliery swamp piezometers; Group 5 was Clarence Colliery vibrating wire piezometers.

From **Figure 4.20**, the Scaled Root Mean Square (sRMS) error is 6.6% and the Root Mean Square Error (RSME) is 30.1m. The Australian Groundwater Modelling Guidelines (AGMG) (Barnett et. al., 2012) suggests a sRMS of 10% is an indicator of reasonable calibration.

Figure 4.21 presents the observed versus modelled change in hydraulic head in metres. The group descriptions provided for **Figure 4.20** are the same as that used in **Figure 4.21**.

The equivalent plot to **Figure 4.20** from the COSFLOW model (after Figure 36 of CSIRO (2013)) is presented in **Figure 4.22**. It is noted that CSIRO (2013) used transient data for validation, rather than calibration. It is also noted that there was not an equivalent figure to **Figure 4.21** presented in CSIRO (2013).

The grouping in **Figure 4.22** is as follows: 'above_myc' is above Mt York Claystone; 'MYC, aq3, KAT' is Mt York Claystone, AQ3 (aquifer definition adopted by COSFLOW and summarised in McHugh (2016), AQ3 is Burra-Moko Head Sandstone and Caley Formation combined) and Katoomba Seam; 'sp2 + aq2' where SP is Semi-Permeable layer (SP2 is siltstone below Katoomba Seam and AQ2 is aquifer above Denman Formation); 'below aq2' is below the AQ2

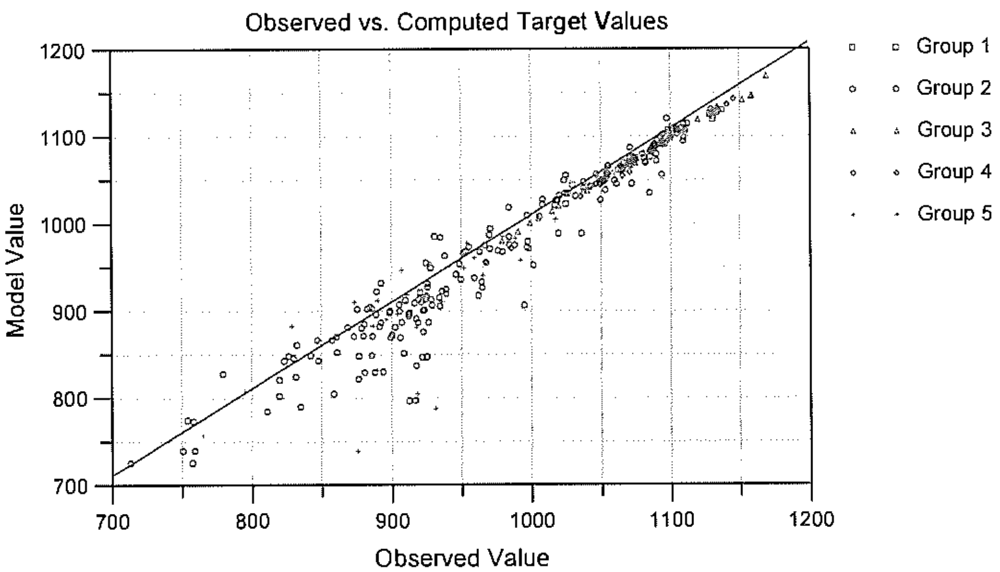


Figure 4.20: Observed versus Modelled Heads (mAHD)

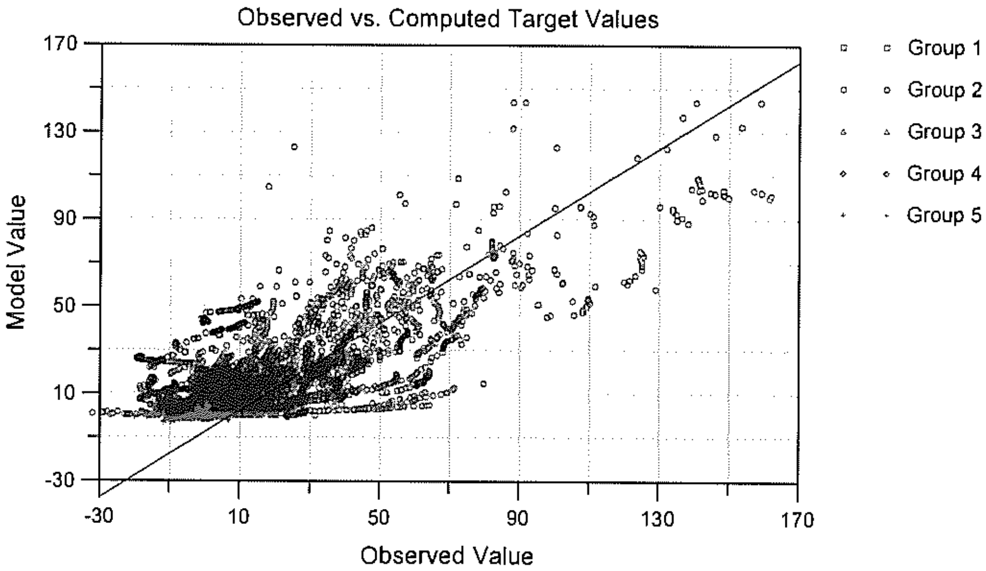


Figure 4.21: Observed versus Modelled Change in Heads (m)

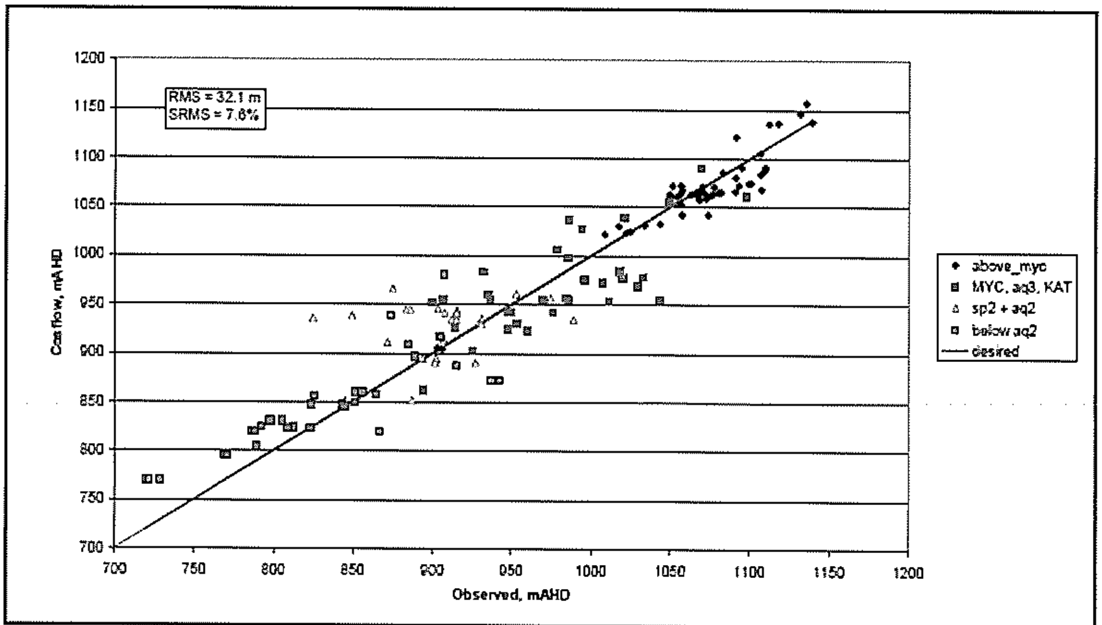


Figure 41 Scatter plot for transient validation

Figure 4.22: Observed versus Modelled Heads in the COSFLOW Model (after Figure 41 of CSIRO (2013))

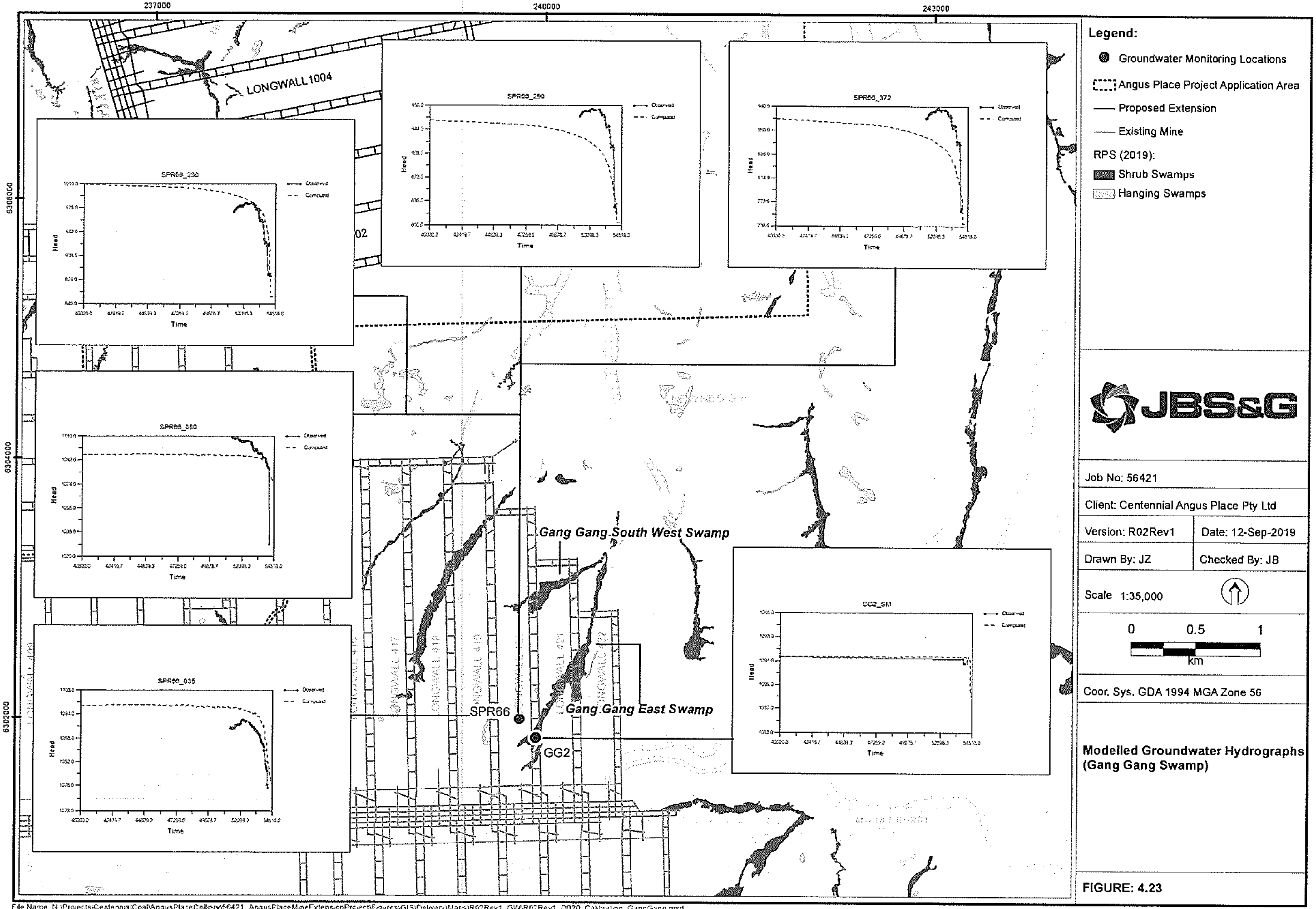
Selected groundwater contour plots are presented next, focusing on:

- Gang Gang Swamp Catchment at Springvale Mine:
    - This location is used to confirm the performance of the groundwater model with respect to replicating observed changes to THPSS.
- Wolgan River Swamp Upper Swamp
- Tri-Star Swamp
- Wolgan River Swamp
- Twin Gully Swamp
- Crocodile Swamp
- Birds Rock Swamp
- Trail Six Swamp.

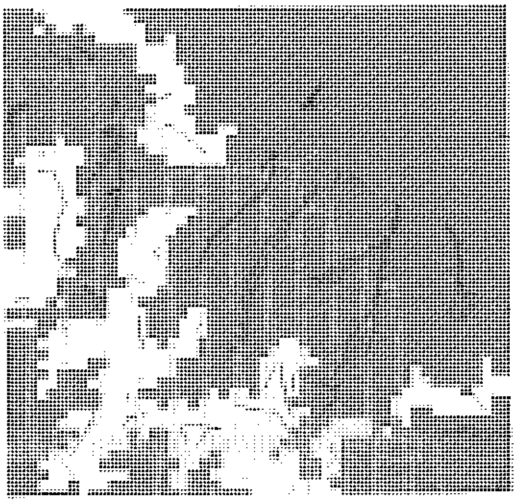
4.12.3.5 Gang Gang Swamp Catchment at Springvale Mine

Figure 4.23 presents the location of Carne West Swamp and Gang Gang Swamp South West and Gang Gang Swamp East in relation to the Springvale longwalls. The location of monitoring points that are discussed below are also presented in **Figure 4.23**.

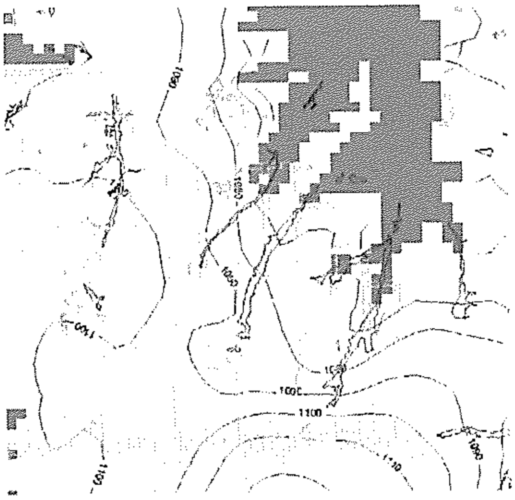
Figure 4.24 presents the modelled groundwater elevation in the Gang Gang Swamp catchment in October 2018 (SP101TS5). Selected hydrographs in the vicinity of Gang Gang Swamp catchment are presented in **Figure 4.23**.



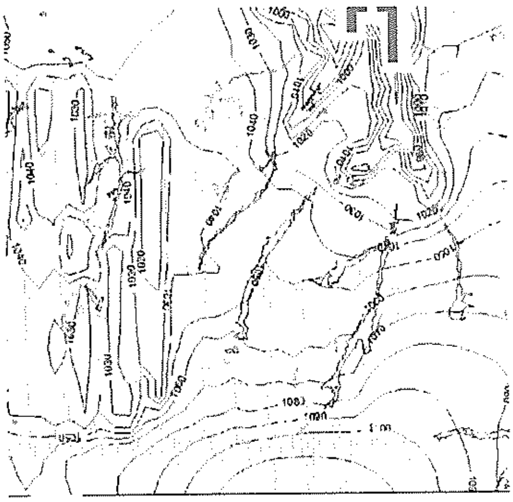
File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D020_Calibration_GangGang.mxd
Reference © Department of Finance, Services & Innovation 2018



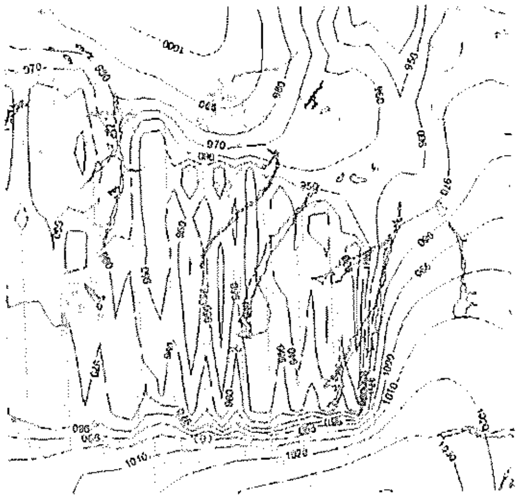
Layer 1 (Sandstone above YS1)



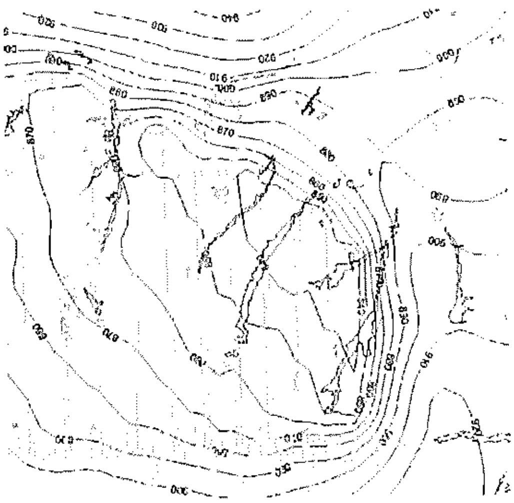
Layer 9 (Sandstone between YS4 and YS5)



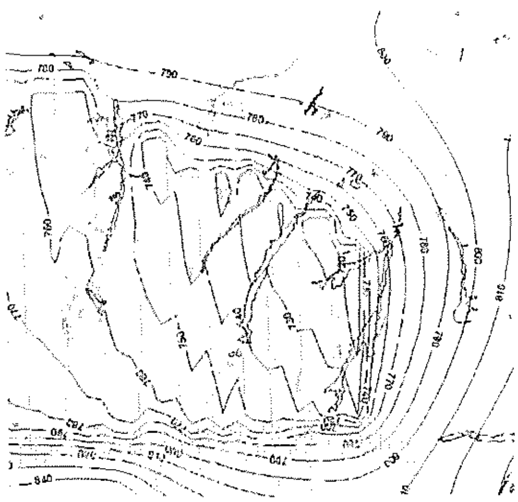
Layer 13 (Banks Wall Sandstone)



Layer 15 (Mt York Claystone)



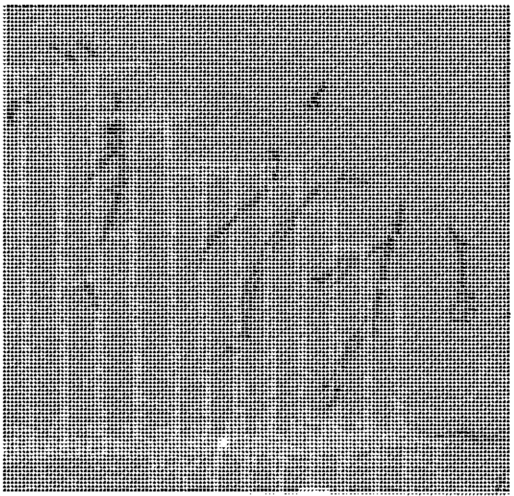
Layer 18 (Katoomba Seam)



Layer 24 (Lithgow Seam)

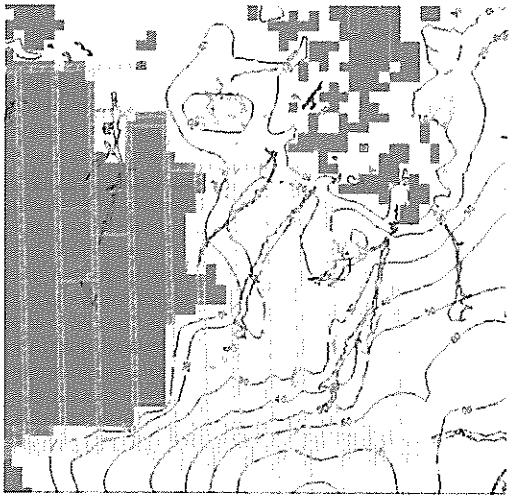
▨ - 'Pinched-out' cells - Drain (DRN) cells

Figure 4.24: Modelled Groundwater Elevation (Gang Gang Swamp Catchment) – October 2018 (SP101TS5)



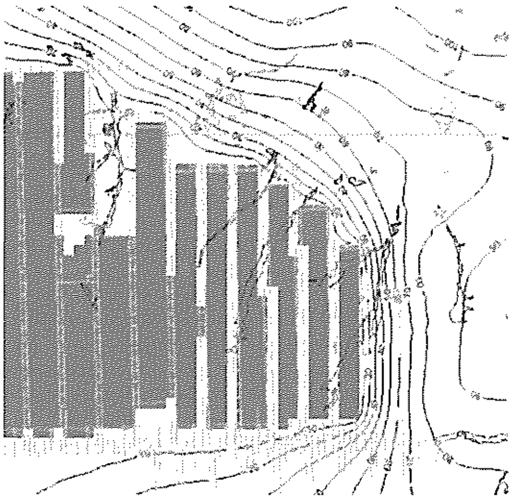
Layer 1 (Sandstone above YS1)

Layer 9 (Sandstone between YS4 and YS5)

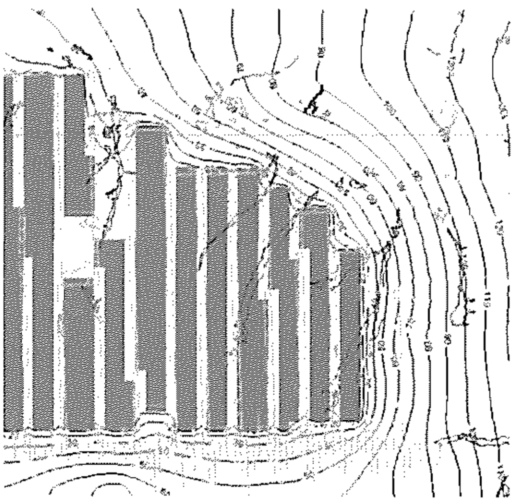


Layer 13 (Banks Wall Sandstone)

Layer 15 (Mt York Claystone)



Layer 18 (Katoomba Seam)



Layer 24 (Lithgow Seam)

▩ - 'Pinched-out' cells ▩ - Pressure Head (m) ≤ 0

Figure 4.25: Modelled Pressure Head (mH2O) (Gang Gang Swamp Catchment) – October 2018 (SP101TS5)

From **Figure 4.24**, the depressurisation is observed to propagate vertically through the Layer 15 (Mt York Claystone) and into Layer 13 (Banks Wall Sandstone). The height of the Stacked Drain cells is evident in Layer 15 in **Figure 4.24**.

From **Figure 4.23**, the change to groundwater elevation due to mining is well-matched in the model.

It is noted that, in an earlier version of the current numerical groundwater model, that a configuration comprising DRN cells in the mining layer, accompanied by changes to hydraulic properties overlying the mining cells was attempted, but could not simultaneously match observed dewatering rates and changes to groundwater level. An alternative approach, 'Stacked Drains' was therefore adopted.

4.12.3.6 Wolgan River Swamp Upper Swamp

Currently, swamp monitoring piezometers are not installed in the shrub swamp located along the Wolgan River.

Accordingly, output from the calibration simulation is not presented with respect to this swamp, with respect to groundwater hydrographs, however, results from model simulations incorporating predictive uncertainty are presented in **Section 4.14** below.

Figure 4.26 presents modelled groundwater elevation in the vicinity of Wolgan River Swamp Upper Swamp in October 2018 (SP101TS5).

Figure 4.27 presents the equivalent output to **Figure 4.26**, however, expressed as pressure head in mH2O.

In Layer 13 (Banks Wall Sandstone) and below in **Figure 4.26**, the modelled groundwater elevation in the 1000 Panel Area is mounded. This reflects the topographic influence of the Wolgan River to the west and Carne Creek to the east.

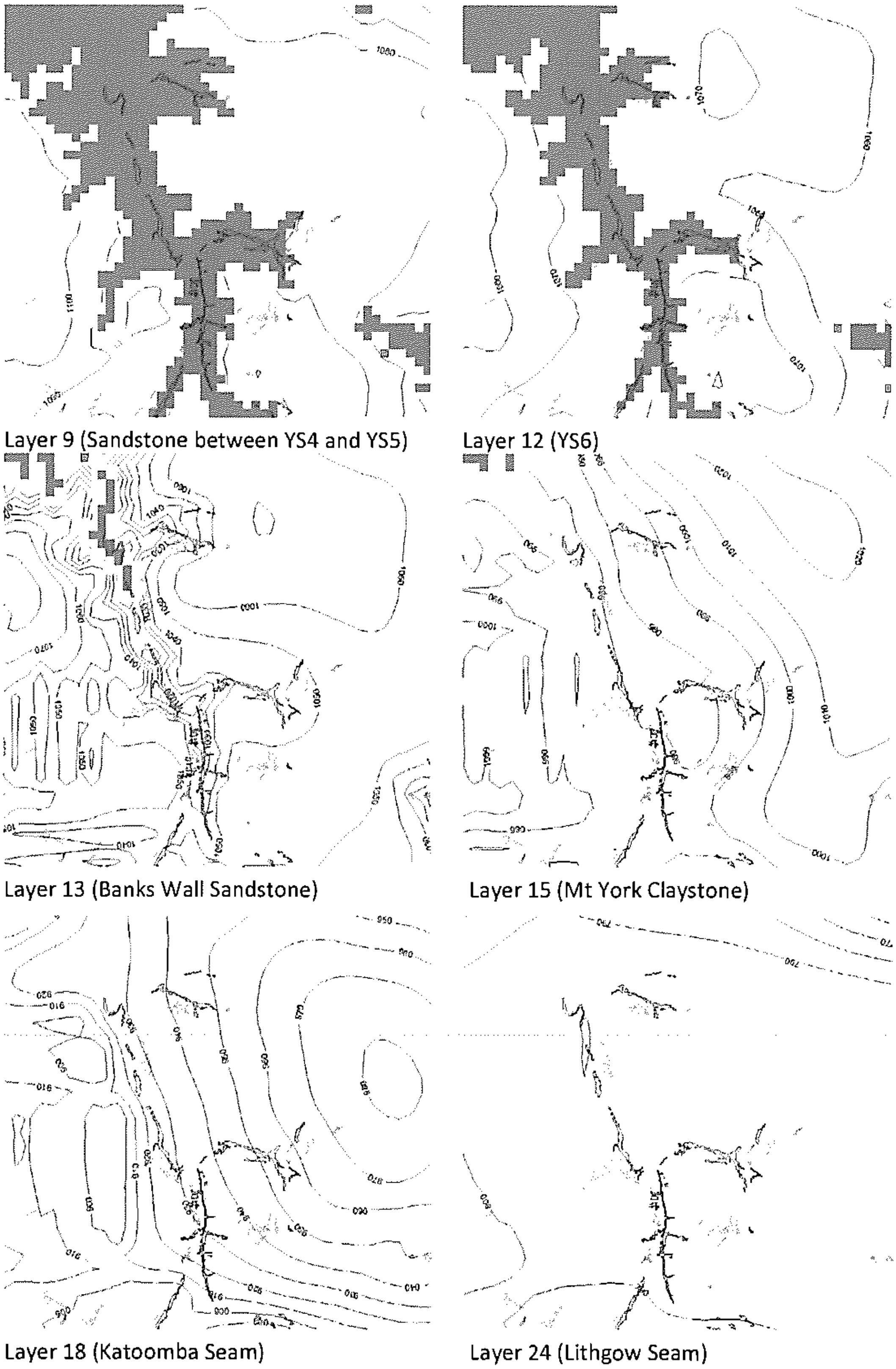
4.12.3.7 Tri-Star Swamp Catchment

Figure 4.28 presents the location of Tri-Star Swamp and Twin Gully Swamp in relation to the proposed 1000 Panel Area at Angus Place Colliery. The location of monitoring piezometers, which comprise both standpipe piezometers and vibrating wire piezometers is also presented in **Figure 4.28**.

Figure 4.26 presents modelled groundwater elevation in the Tri-Star Swamp catchment in October 2018 (SP101TS5) and **Figure 4.27** presents the same model output, however, expressed as pressure head in mH2O. Selected hydrographs in the vicinity of Tri-Star Swamp are presented in **Figure 4.28**.

From **Figure 4.28**, the fit to observed groundwater levels at monitoring piezometers is acceptable, in terms of elevation, and is considered fair for the response to changes. This was considered reasonable considering that there were only a limited number of Pilot Points available for calibration due to the significant computational burden in model calibration.

The location of Pilot Points in Layer 28 is presented in **Figure 4.15**. The location of Pilot Points in other model layers is presented in **Appendix E**. The spatial distribution of calibrated hydraulic parameters are also presented in **Appendix E**.



- 'Pinched-out' cells - Drain (DRN) cells

Figure 4.26: Modelled Groundwater Elevation (Wolgan River Swamp Upper Swamp, Tri-Star Swamp, Wolgan River Swamp and Twin Gully Swamp Catchments) – October 2018 (SP101TS5)

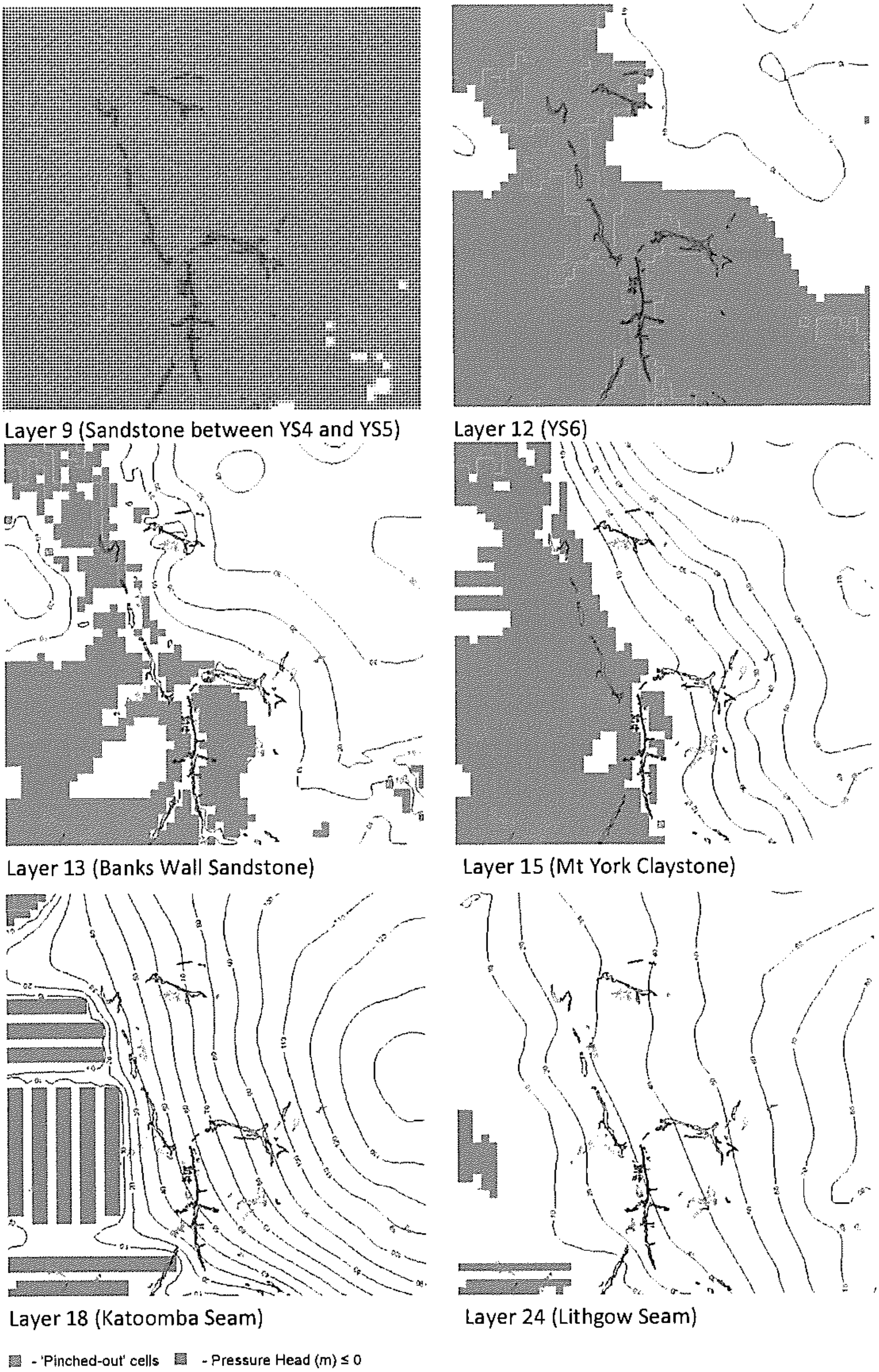
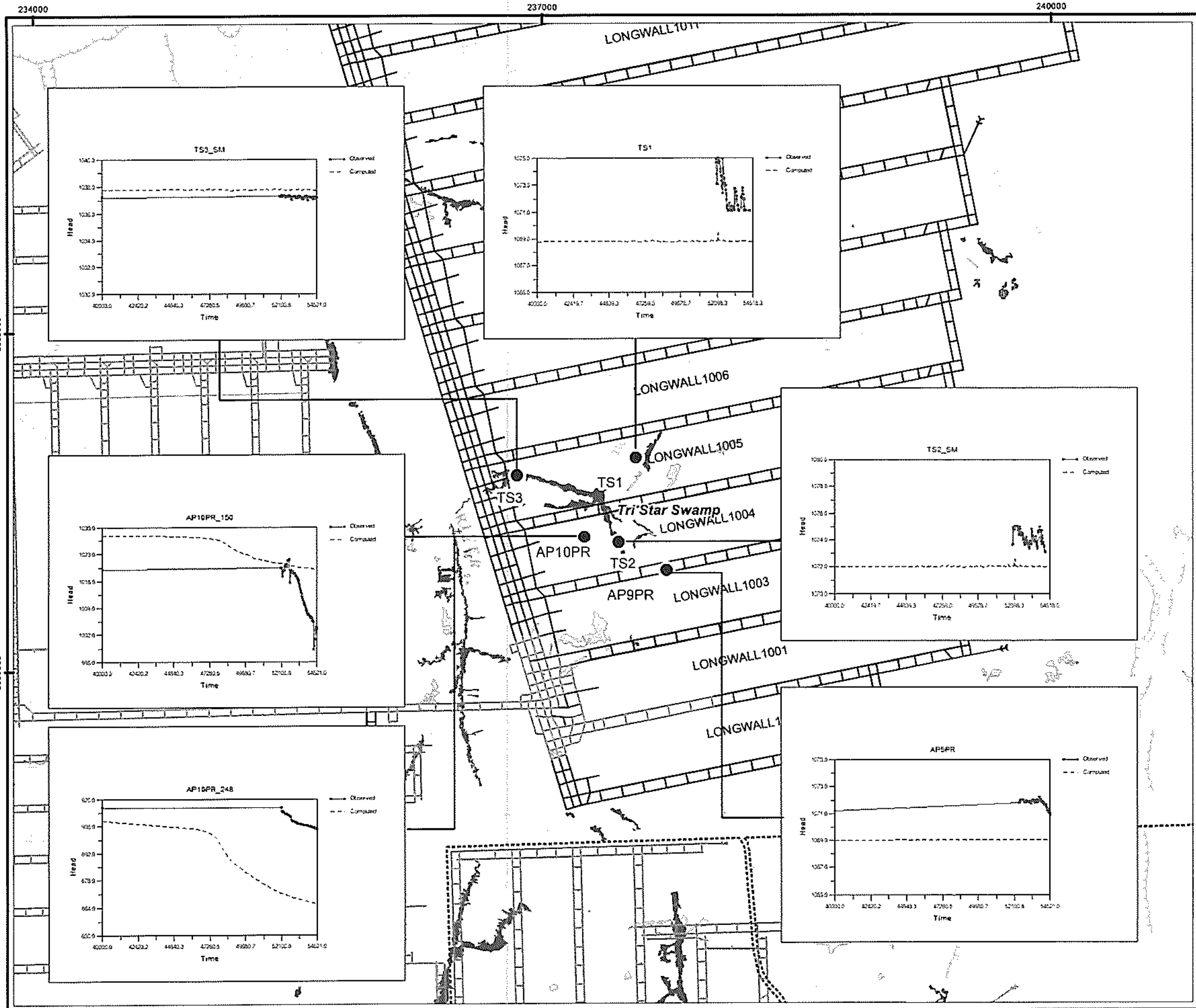


Figure 4.27: Modelled Pressure Head (mH2O) (Wolgan River Swamp Upper Swamp, Tri-Star Swamp, Wolgan River Swamp and Twin Gully Swamp Catchments) – October 2018 (SP101TS5)



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 13-Sep-2019
Drawn By: JZ	Checked By: JB
Scale 1:30,000	

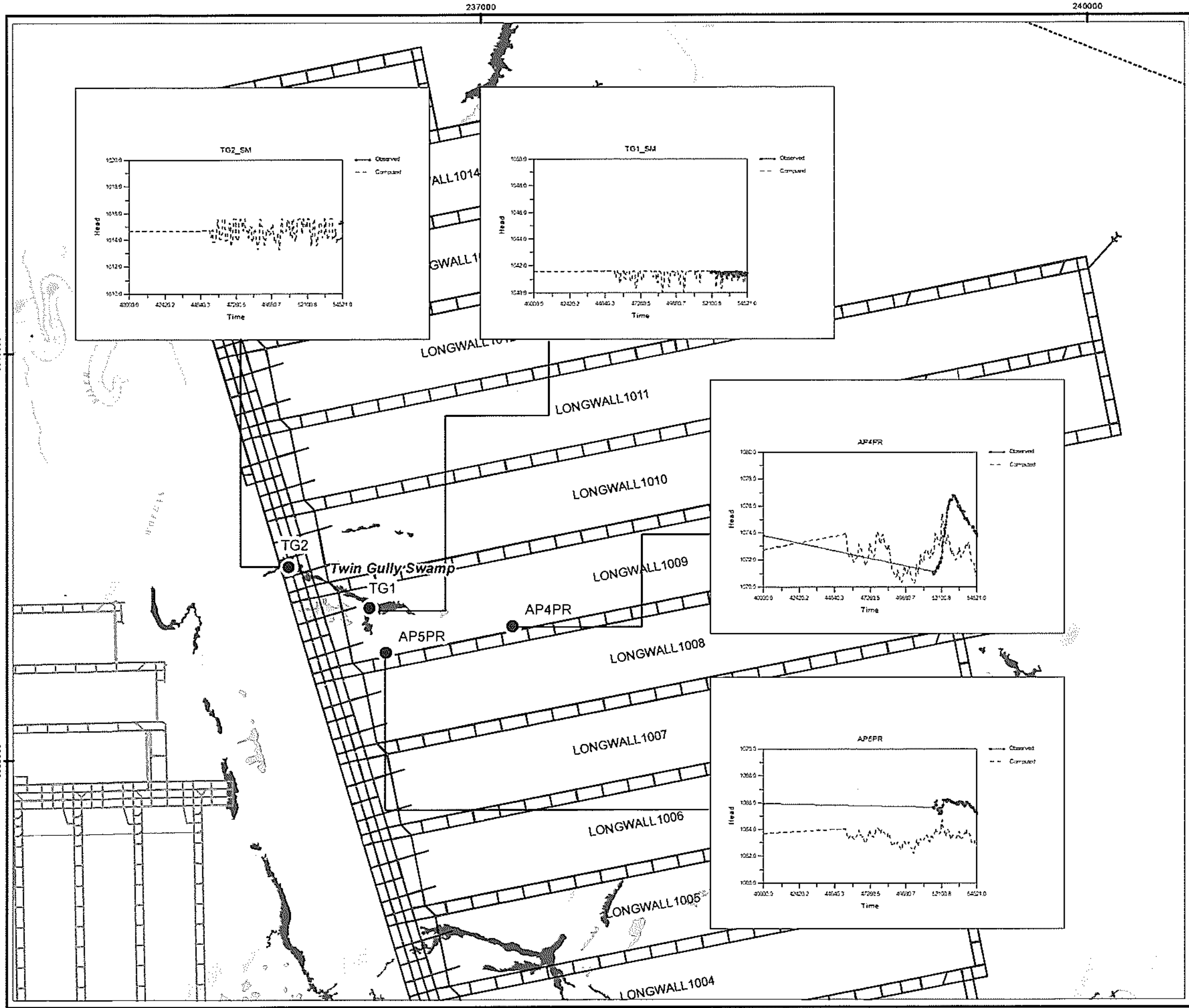
0 0.5 1
km

Coor. Sys. GDA 1994 MGA Zone 56

Modelled Groundwater Hydrographs (Tri Star Swamp)

FIGURE: 4.28

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D021_Calibration_TriStar.mxd
Reference © Department of Finance, Services & Innovation 2018



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 13-Sep-2019
Drawn By: JZ	Checked By: JB
Scale 1:25,000	

0 0.5 1
km

Coor. Sys. GDA 1994 MGA Zone 56

Modelled Groundwater Hydrographs (Twin Gully Swamp)

FIGURE: 4.29

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D022_Calibration_TwinGully.mxd
Reference © Department of Finance, Services & Innovation 2018

4.12.3.8 Wolgan River Swamp

Currently, swamp monitoring piezometers are not installed in the shrub swamp located along the Wolgan River.

Accordingly, hydrograph output from the calibration simulation is not presented with respect to this swamp, however, results from model simulations incorporating predictive uncertainty are presented in **Section 4.14** below.

Figure 4.26 presents modelled groundwater elevation in the vicinity of Wolgan River Swamp in October 2018 (SP101TS5) and **Figure 4.27** presents the equivalent data as pressure head (mH2O).

4.12.3.9 Twin Gully Swamp Catchment

Figure 4.26 presents modelled groundwater elevation in the Twin Gully Swamp catchment in October 2018 (SP101TS5). **Figure 4.27** presents the equivalent data, expressed as pressure head (mH2O).

Selected hydrographs in the vicinity of Twin Gully Swamp are presented in **Figure 4.29**.

From **Figure 4.29**, the fit to observed hydrographs is acceptable, both in terms of elevation as well as response of the piezometers to change.

4.12.3.10 Crocodile Swamp

Figure 4.30 presents modelled groundwater elevation in the vicinity of Crocodile Swamp and **Figure 4.31** presents the equivalent model output, expressed as pressure head in mH2O.

From **Figure 4.30**, the influence of outcropping model layers, as seepage faces, as well as surface watercourses, on local groundwater elevation is apparent.

Currently, a swamp monitoring piezometer is not installed in Crocodile Swamp.

Accordingly, hydrograph output from the calibration simulation is not presented with respect to Crocodile Swamp, however, results from model simulations incorporating predictive uncertainty is presented in **Section 4.14** below.

4.12.3.11 Birds Rock Swamp

Birds Rock Swamp is located to the north of Crocodile Swamp. **Figure 4.30** presents the groundwater elevation in the vicinity of Birds Rock Swamp and **Figure 4.31** presents the modelled pressure head (mH2O).

Currently, a swamp monitoring piezometer is not installed at Birds Rock Swamp.

Accordingly, output from the calibration simulation is not presented with respect to Birds Rock Swamp, however, results from model simulations incorporating predictive uncertainty are presented in **Section 4.14** below.

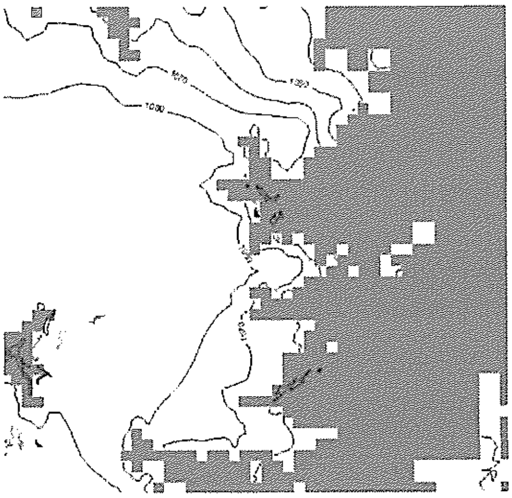
4.12.3.12 Trail Six Swamp Catchment

Trail Six Swamp is located at the northern end of the 1000 Panel Area, as indicated in **Figure 4.32**.

As indicated in **Figure 4.32**, Trail Six Swamp is not intended to be undermined, however, changes to the hydrologic regime in Trail Six Swamp are still expected.

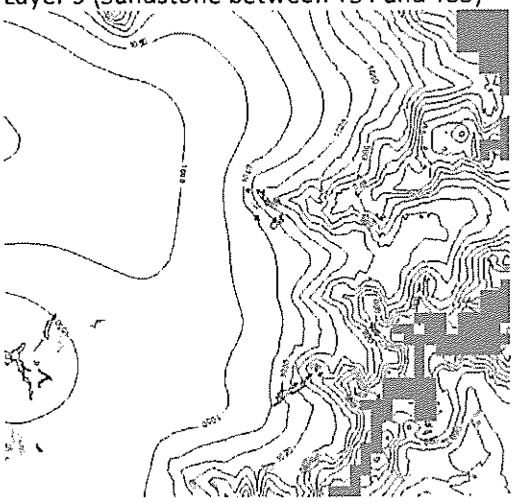
Figure 4.33 presents the modelled groundwater elevation in various layers in the vicinity of Trail Six Swamp catchment. Hydrographs of selected piezometers in the Trail Six Swamp catchment are presented in **Figure 4.32**.

From **Figure 4.33**, with respect to the catchment contributing to Trail Six Swamp, groundwater flow direction is to the northeast toward the Wolgan Valley. Groundwater contours in **Figure 4.33** indicate groundwater/surface water interaction along watercourses, which is expected.

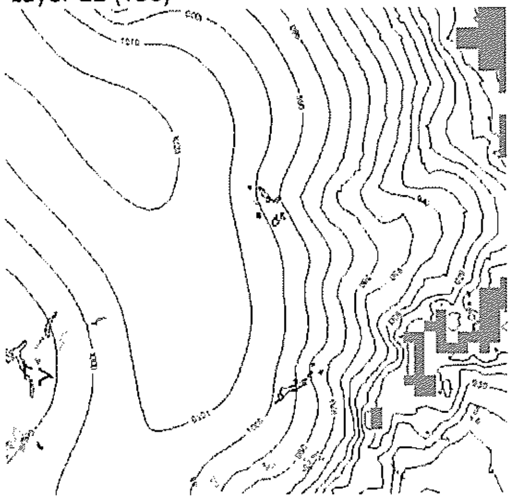


Layer 9 (Sandstone between YS4 and YS5)

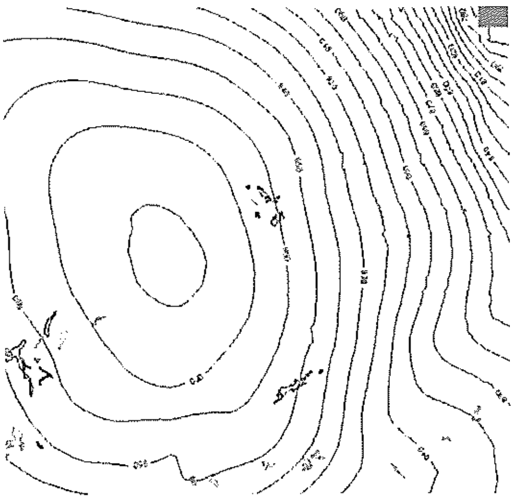
Layer 12 (YS6)



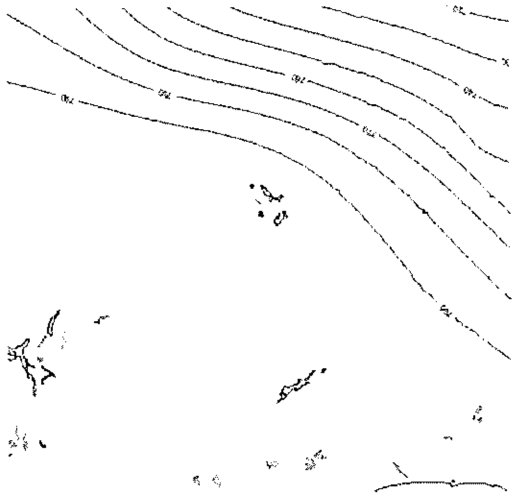
Layer 13 (Banks Wall Sandstone)



Layer 15 (Mt York Claystone)



Layer 18 (Katoomba Seam)



Layer 24 (Lithgow Seam)

- 'Pinched-out' cells - Drain (DRN) cells

Figure 4.30: Modelled Groundwater Elevation (Crocodile Swamp and Birds Rock Swamp Catchment) – October 2018 (SP101TS5)

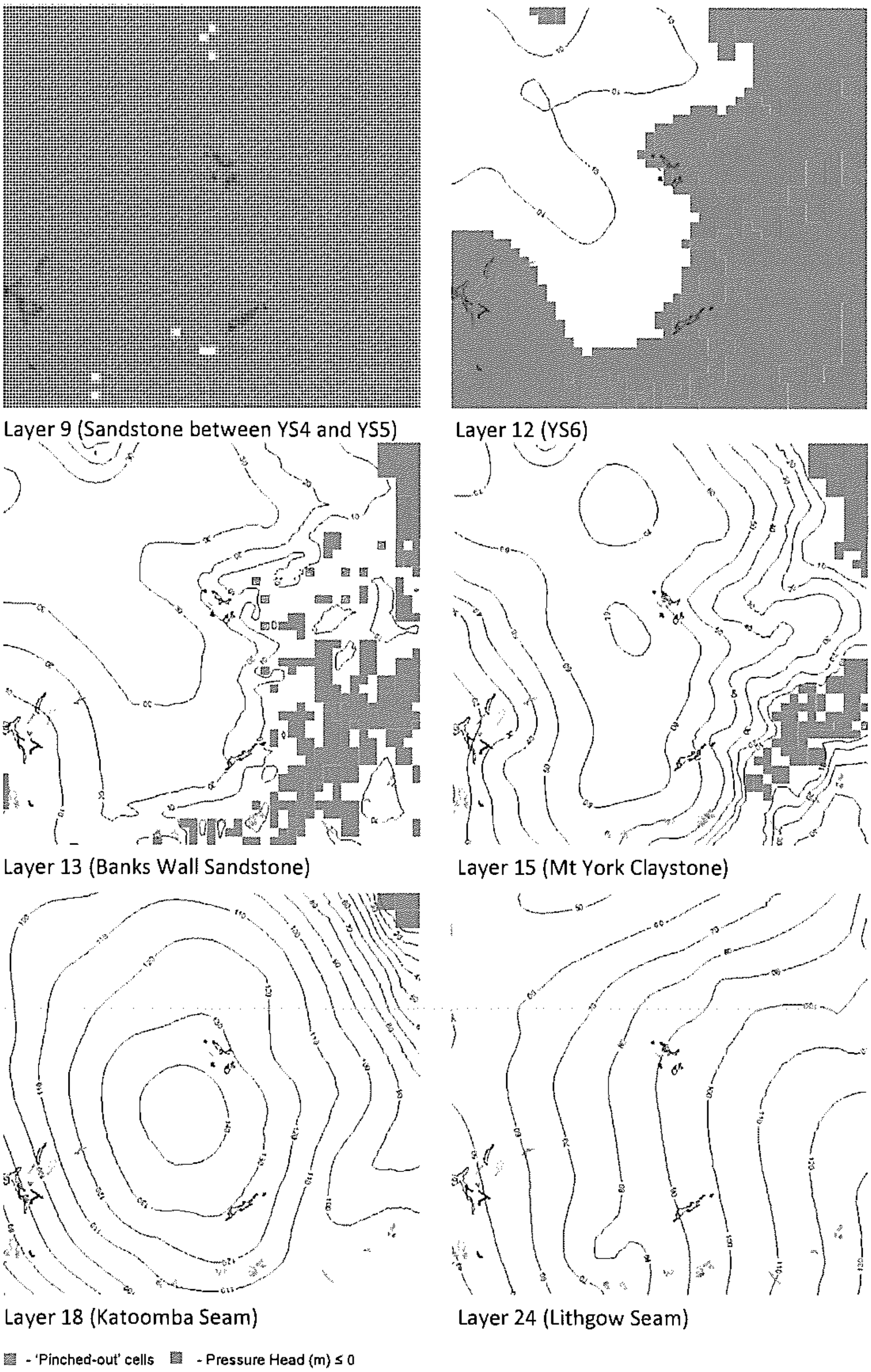
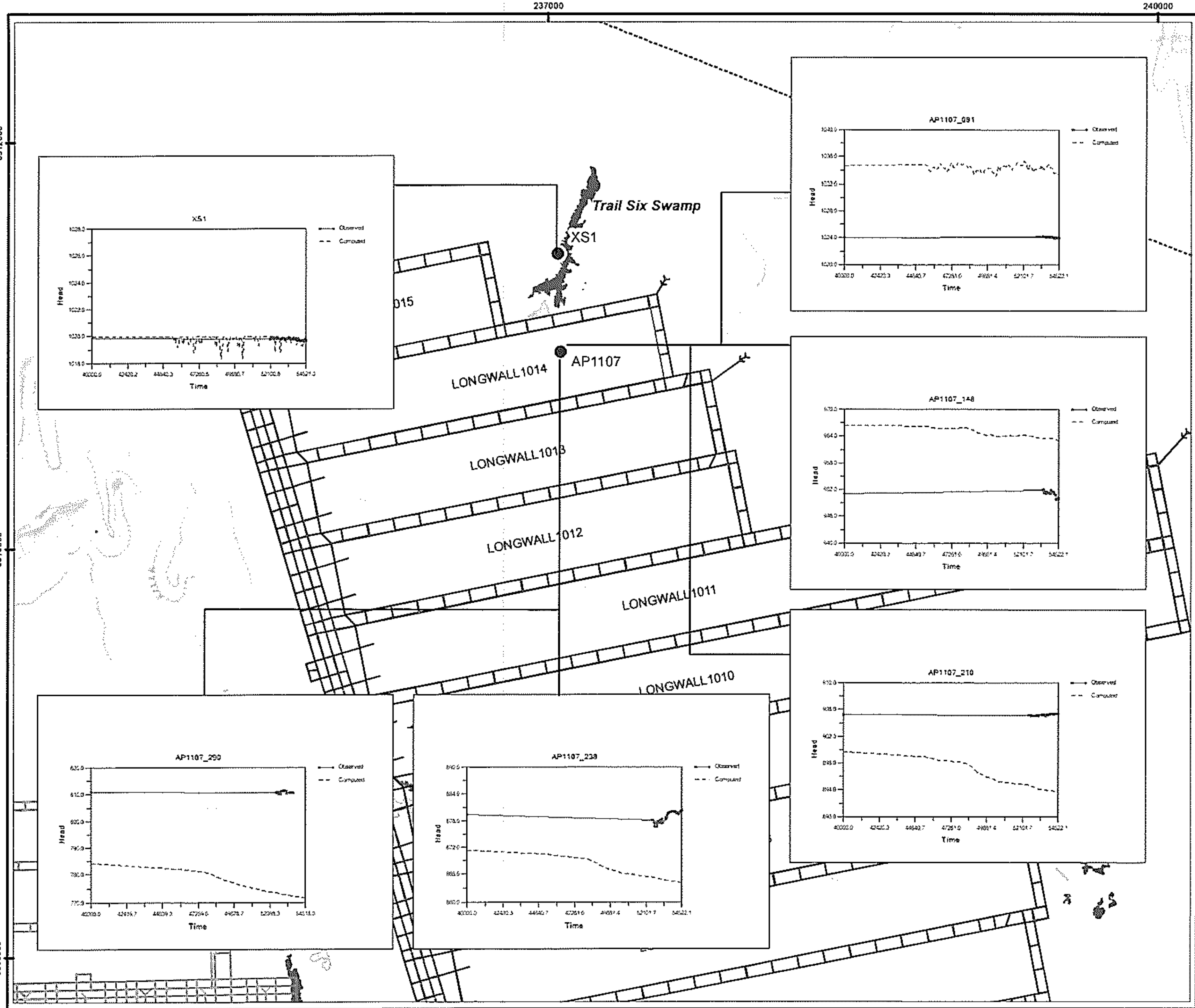


Figure 4.31: Modelled Pressure Head (mH2O) (Crocodile Swamp and Birds Rock Swamp Catchment) – October 2018 (SP101TS5)

From **Figure 4.32**, there is a good fit between modelled and observed water levels with respect to the swamp piezometer, XS1 and only a fair fit with respect to the vibrating wire piezometers at monitoring site AP1107. The behaviour of the response in the vibrating wire piezometers is reasonably matched but the groundwater elevation could be improved.

As noted above, there was a practical limitation in the groundwater model calibration due to the computational burden imposed with the use of Pilot Points. **Figure 4.15** presents the location of the Pilot Points adopted in Layer 28 in the model. The location of Pilot Points in other model layers is presented in **Appendix E**, together with the distribution of calibrated hydraulic parameters as well as the cumulative distribution charts of those parameters.



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1 | Date: 13-Sep-2019

Drawn By: JZ | Checked By: JB

Scale 1:25,000

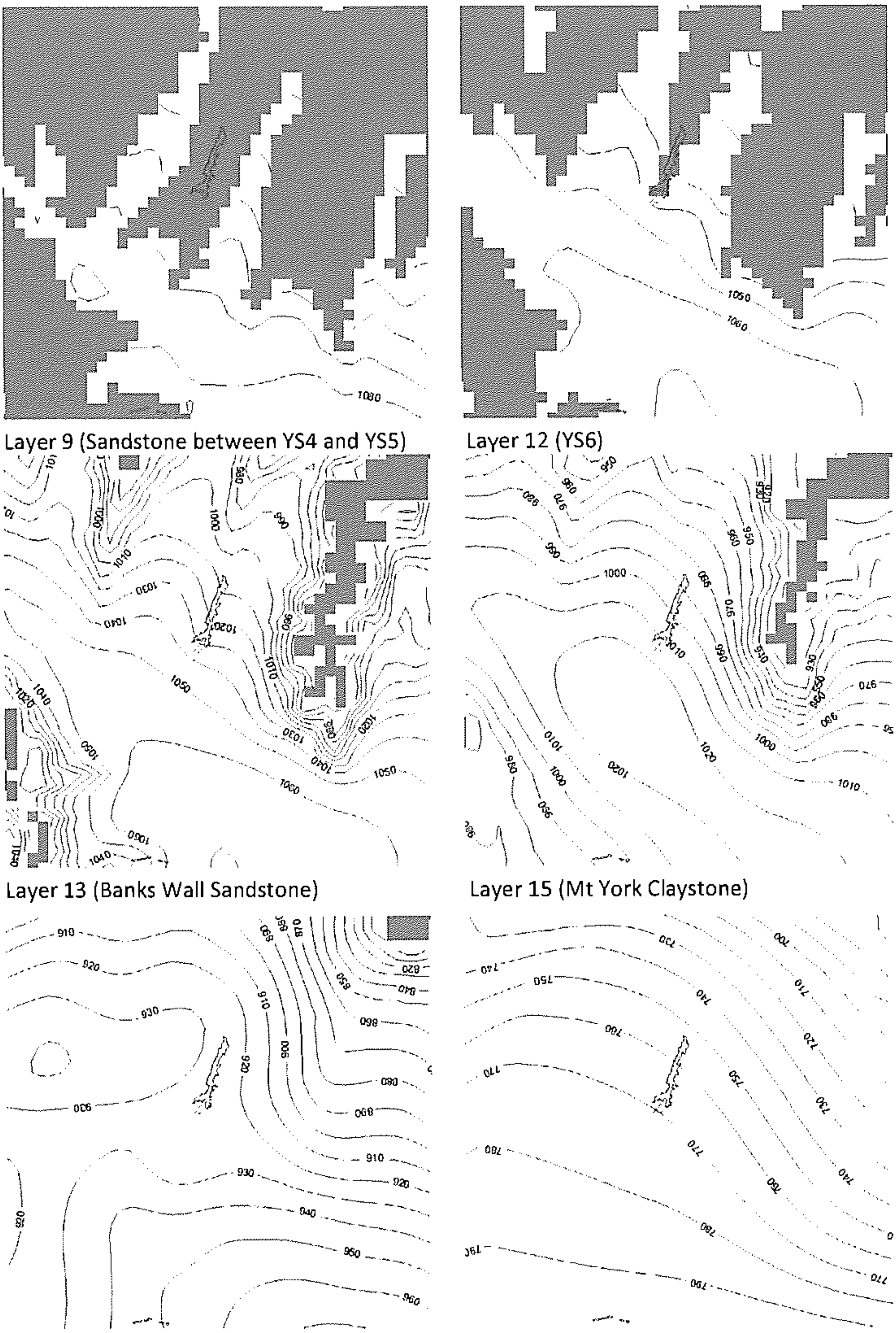
0 0.5 1 km

Coor. Sys. GDA 1994 MGA Zone 56

Modelled Groundwater Hydrographs (Trail Six Swamp)

FIGURE: 4.32

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D023_Calibration_TrailSix.mxd
Reference G Department of Finance, Services & Innovation 2018



Layer 9 (Sandstone between YS4 and YS5)

Layer 12 (YS6)

Layer 13 (Banks Wall Sandstone)

Layer 15 (Mt York Claystone)

Layer 18 (Katoomba Seam)

Layer 24 (Lithgow Seam)

- 'Pinched-out' cells - Drain (DRN) cells

Figure 4.33: Modelled Groundwater Elevation (Trail Six Swamp Catchment) – October 2018 (SP101TS5)

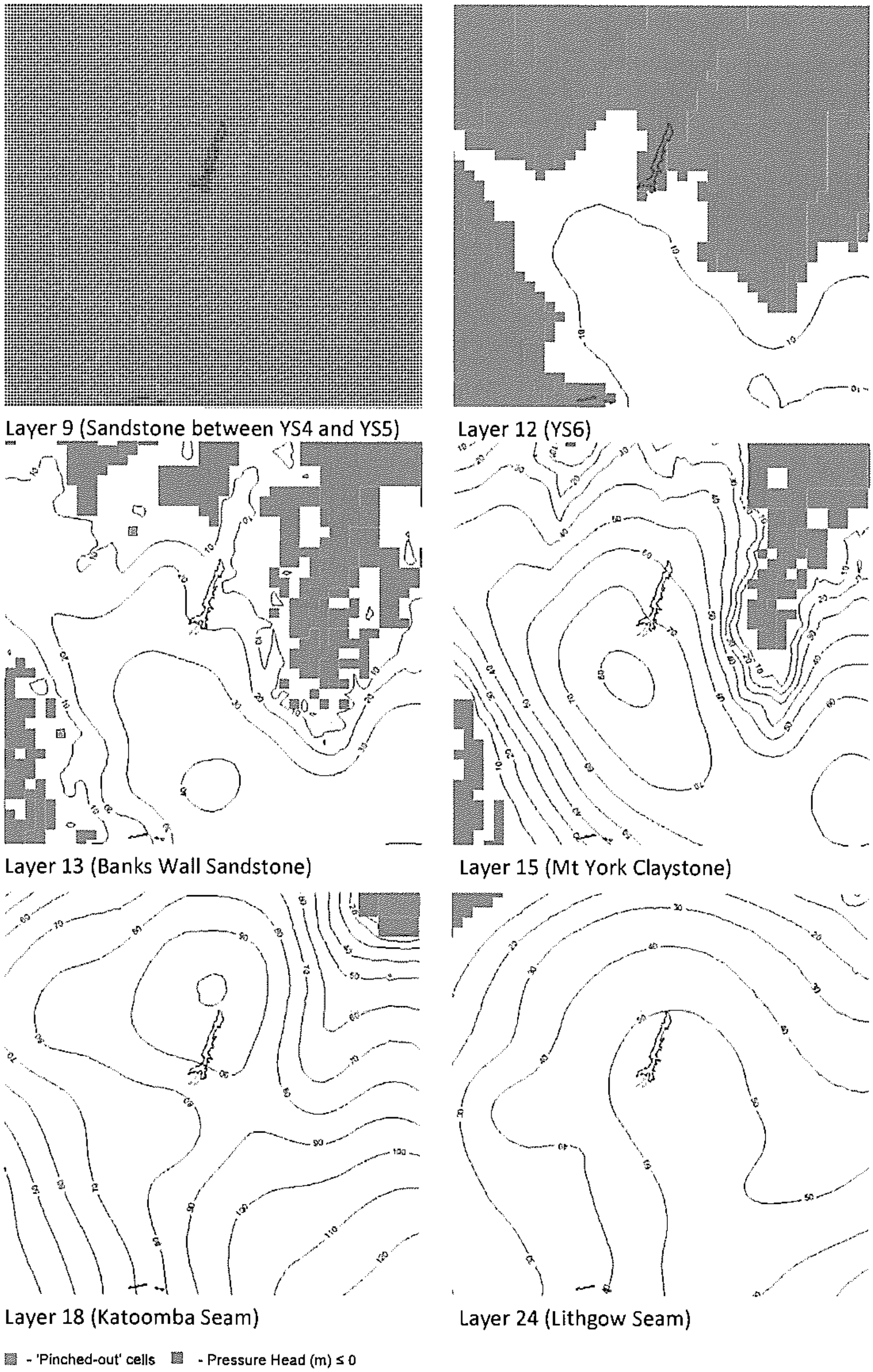


Figure 4.34: Modelled Pressure Head (mH2O) (Trail Six Swamp Catchment) – October 2018 (SP101TS5)

4.12.3.13 Mine Dewatering Rates

The dewatering rate at Springvale Mine and Angus Place Colliery was extracted from the model calibration between iterations of PEST and used to compare against observed flows. To ensure that PEST was focussed appropriately, the observed dewatering rate and the relative cumulative inflow were calculated.

Due to incomplete historical records of dewatering rate, especially in the early period of mining at Angus Place Colliery and Clarence Colliery, relative cumulative inflow was used rather than cumulative inflow. Relative cumulative inflow comprised commencing the cumulative calculation at a specified Stress Period, rather than from the beginning of the simulation.

Figure 4.35 presents the calibrated mine dewatering rate and relative cumulative dewatering rate at Angus Place Colliery. The modelled dewatering rate from the CSIRO COSFLOW model is also presented in **Figure 4.35**.

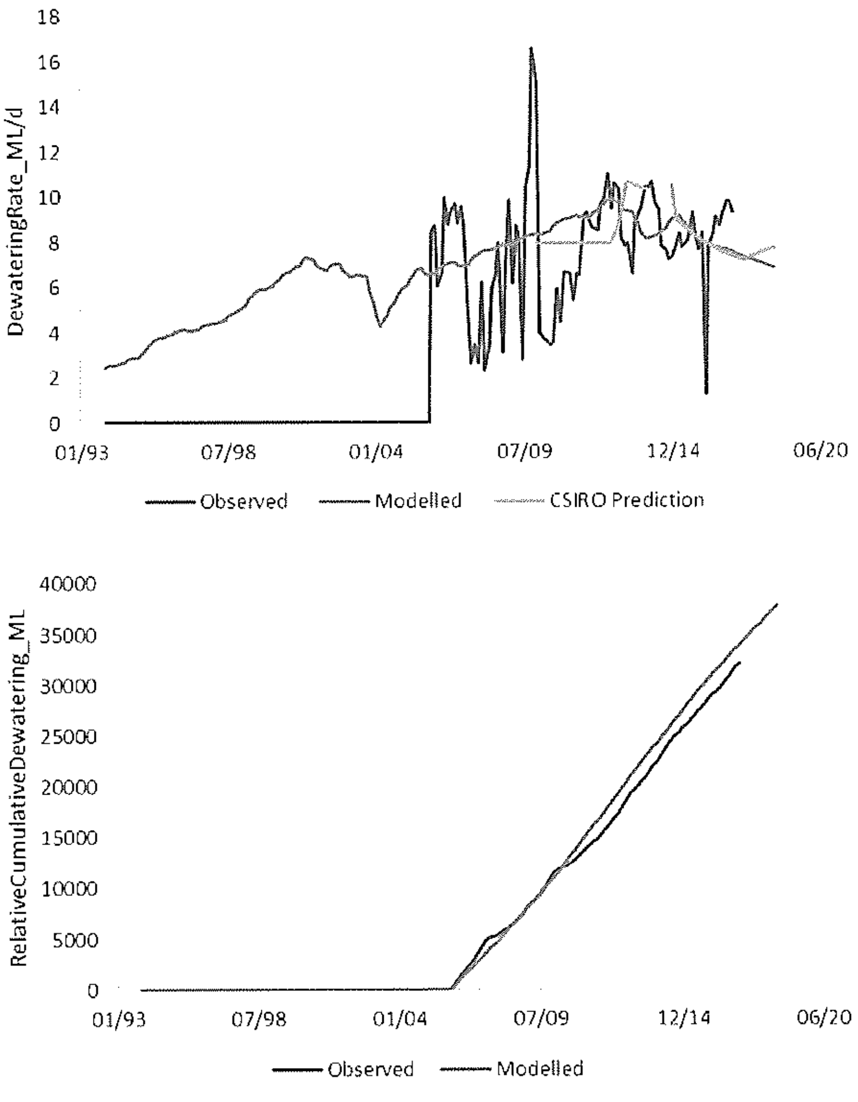


Figure 4.35: Modelled Mine Dewatering Rate – Angus Place Colliery (300, 700, 800 and 900 Panel Area)

From **Figure 4.35**, the fit to observed dewatering rate is considered reasonable, given the practical limitations, despite best endeavour, of metering and record keeping in underground water management. The large spike in observed dewatering rate in **Figure 4.35** is presumed to reflect operational decisions to pump large quantities of stored water in the period September 2009 to March 2010 rather than a significant change in the rate of groundwater inflow to the mine. Following the period September 2009 to March 2010, the rate of dewatering dropped significantly. From **Figure 4.35**, the modelled dewatering rate and relative cumulative dewatering rate show a good correlation, with the model slightly overpredicting relative to observed mine dewatering.

Figure 4.36 presents the modelled dewatering rate at Springvale Mine as well as the relative cumulative dewatering rate. The modelled dewatering rate from the COSFLOW model is also presented in **Figure 4.36**.

From **Figure 4.36**, the modelled dewatering rate and relative cumulative inflow rate show a reasonable correlation. In this instance, the model is marginally underpredicting mine dewatering rate relative to observed dewatering rates.

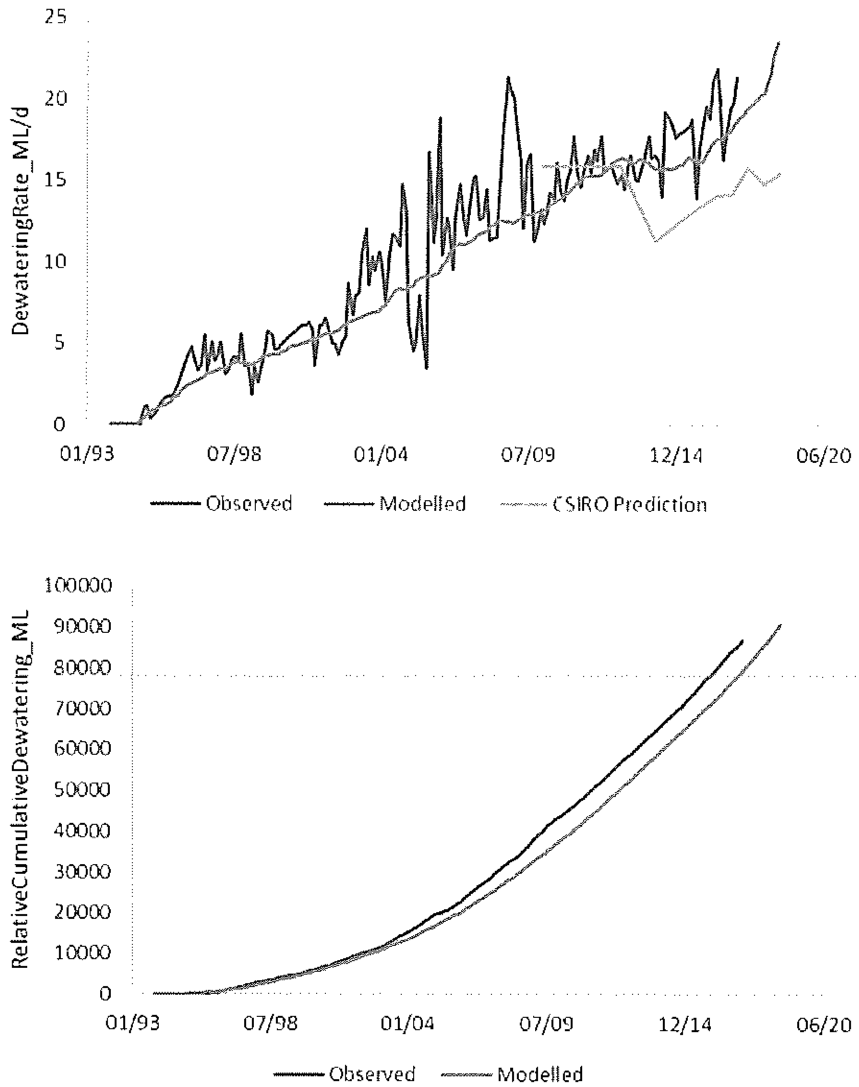


Figure 4.36: Modelled Mine Dewatering Rate – Springvale Mine

Figure 4.37 presents the calibrated mine dewatering rate to Springvale Mine and Angus Place Colliery in the COSFLOW Model (after Figure 49 of CSIRO (2013)), which was also considered acceptable at the time. It is noted that relative cumulative inflow or cumulative inflow was not considered in the COSFLOW model during its calibration, instead calibration was based on a fit to observation data, that being operational dewatering rates.

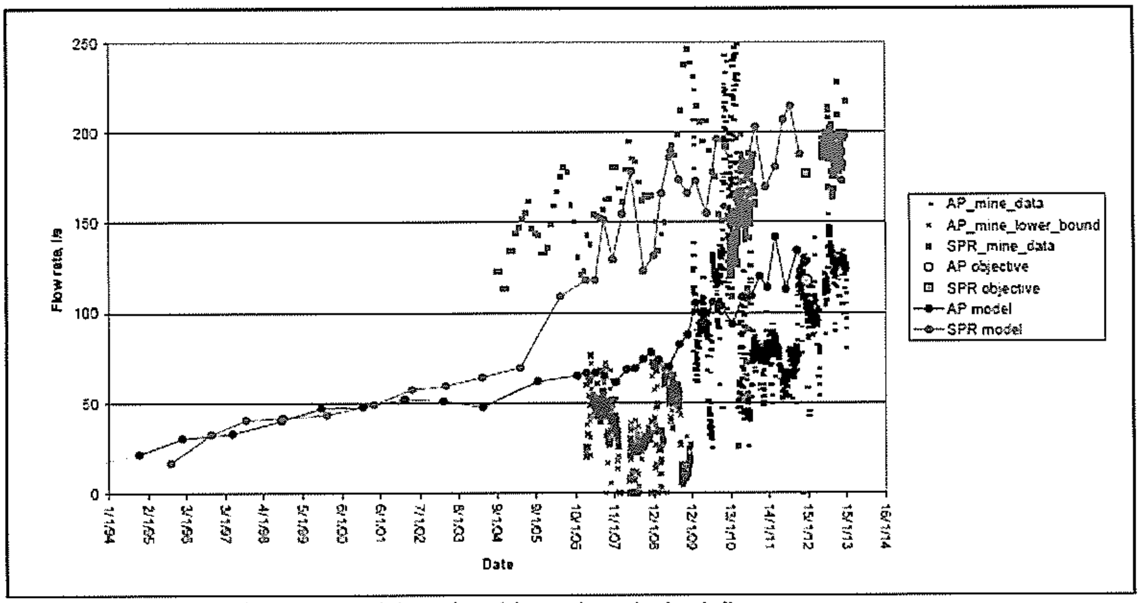


Figure 49 Comparison between model results with monitored mine inflow rates

Figure 4.37: Modelled Mine Dewatering Rate – Springvale Mine and Angus Place Colliery (after Figure 49 of CSIRO (2013))

4.12.4 Summary of Model Calibration

The results of model calibration are considered to be relatively good.

There is an acceptable match to observed mine dewatering rates and the change to water table level within Gang Gang Swamp catchment at Springvale Mine. The hydrologic response to mining at Gang Gang Swamp is important as adverse changes have been observed at this location.

As presented in RPS (2014a) changes were expected in THPSS due to mining, however, the magnitude of change was under-predicted in the COSFLOW model as configured at that time.

The modelled rate of mine dewatering at Angus Place Colliery, including the 300, 700, 800 and 900 Panel Area, as well as at Springvale Mine are similar in the modelling undertaken by JBS&G, to that predicted by the COSFLOW model. An exception is for Springvale Mine in the recent past, where observed dewatering rate has continued to increase, consistent with operational expectations. Whilst the updated model has captured this behaviour, the COSFLOW prediction remains relatively static at 12-15ML/d.

4.13 Sensitivity Analysis / Parameter Identifiability

The sensitivity of various parameters in the numerical groundwater model was determined using the parameter identifiability methodology presented in Watermark Numerical Computing (2018a).

Watermark Numerical Computing (2018a) explains that *"Doherty (2015) and Doherty and Hunt (2009) define the identifiability of a parameter as the square of the cosine of the angle between a parameter and its projection onto the calibration solution space."*, *"If the identifiability of a parameter is 1.0, then that parameter is completely estimable on the basis of the current calibration dataset."*, *"if a parameter has an identifiability of 0.0, then the calibration dataset is completely* *uninformative of that parameter; thus the parameter is completely insensitive as far as the calibration dataset is concerned"* and *"if the identifiability of a parameter is between 0.0 and 1.0 then information within the calibration dataset that pertains to that parameter is shared between it and other parameters; the parameter can therefore not be resolved uniquely."*.

The identifiability of the parameters in the transient calibration model, allowing for parameters that were FIXED, was determined using the PEST utility, IDENTPAR.EXE.

IDENTPAR.EXE was executed on the final version of the transient calibration simulation, however, using the initial full Jacobian matrix, rather than a recalculated full Jacobian matrix on the final calibrated parameter values. This was required because of time constraints associated with model run-times.

It is noted that the number of dimensions of the calibration solution space was set at 456, which was the recommendation from SUPCALC.EXE on the final version of the transient calibration simulation.

Figure 4.38 and **Figure 4.39** presents the identifiability of parameters. **Figure 4.38** presents the identifiability of all adjustable parameters for all identifiabilities. **Figure 4.39** presents the identifiability of all adjustable parameters with an identifiability greater than 0.4.

From **Figure 4.38**, a significant amount of the 4334 parameters are insensitive or, in other words, of limited identifiability. The threshold for insensitivity could be considered to be an identifiability of 0.3 or less.

Due to the number of points in **Figure 4.38**, reference is made to **Figure 4.39** and, as well, separate plots for different parameter groups are presented further below.

From **Figure 4.39**, sensitive parameters mostly include the Pilot Point values for hydraulic conductivity and storage, as well as some values of evapotranspiration and recharge factor.

Detailed discussion of parameter identifiability is presented with respect to individual parameter groups further below. Supporting charts are presented in **Appendix F**.

<u>Horizontal Hydraulic Conductivity</u>

From **Figure F.1**, most of the horizontal hydraulic conductivity Pilot Points have an identifiability of less than 0.3, which implies that they are not well-informed by the calibration dataset.

From **Figure F.1**, of the most sensitive parameters, most are associated with model layer 11 to 13. This was to be expected, as THPSS reside in Layer 13 and above. Layer 13 is the Banks Walls Sandstone and Layer 12 is the YS6 of the Burralow Formation.

<u>Vertical Hydraulic Conductivity</u>

From **Figure F.2**, the distribution of identifiability is similar to that for horizontal hydraulic conductivity (refer **Figure F.1**), with most of the vertical hydraulic conductivity Pilot Points having an identifiability of less than 0.3.

From **Figure F.2**, of the most sensitive parameters, there are points from most layers; however, Layer 15, which is the Mt York Claystone, features prominently.

<u>Specific Storage</u>

From **Figure F.3**, a significant proportion of the Pilot Points have an identifiability of 0.3 or more. It is interpreted that this is due to the extensive mine dewatering record available at Springvale Mine, Angus Place Colliery and Clarence Colliery with which to calibrate against.

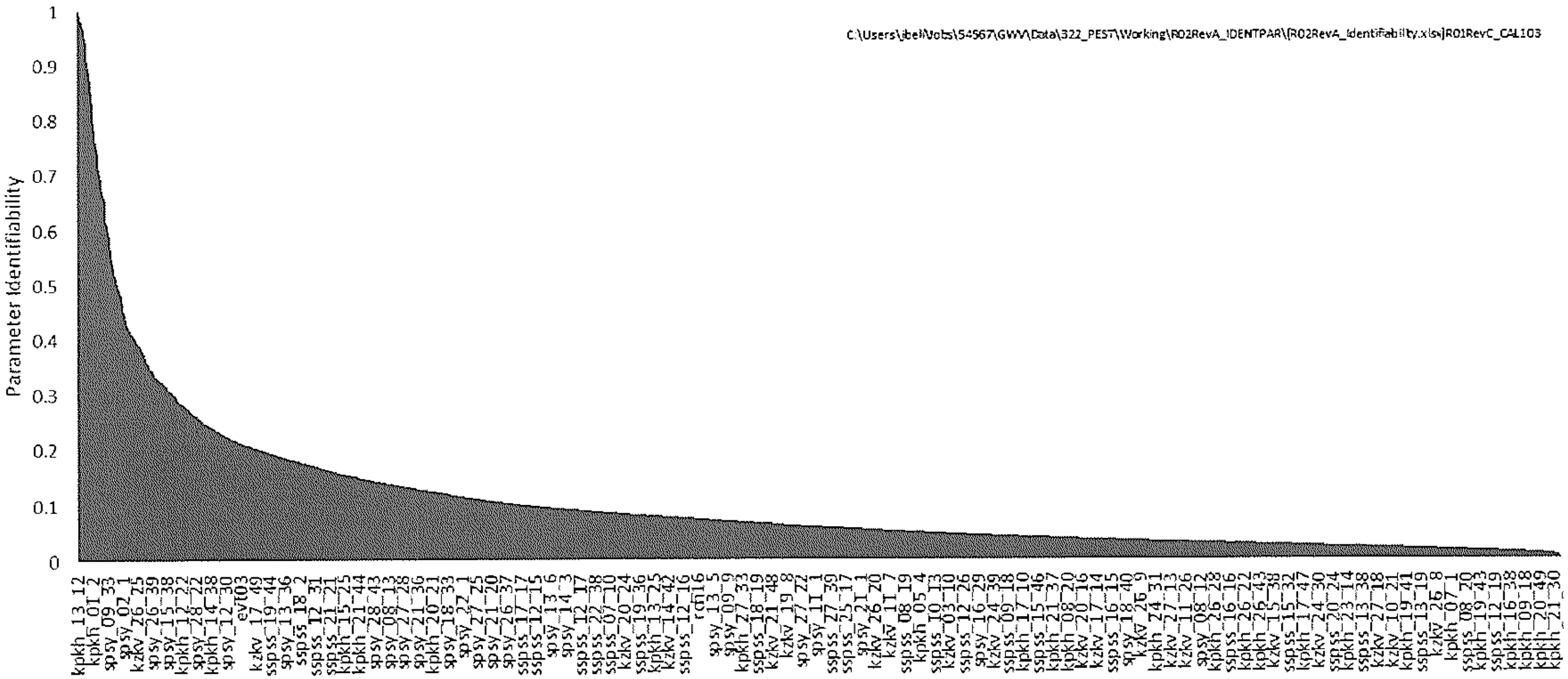


Figure 4.38: Parameter Identifiability – All Adjustable Parameters (all values)

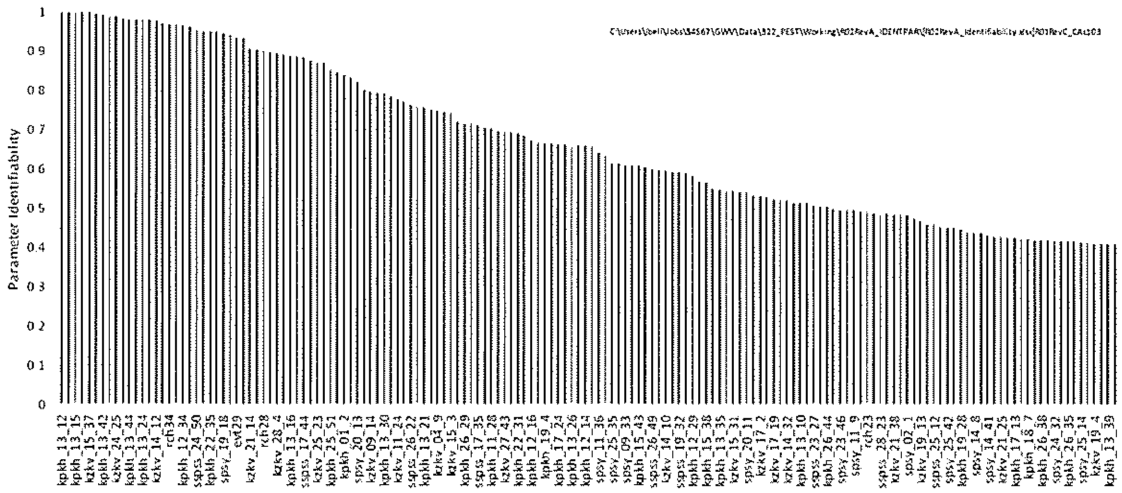


Figure 4.39: Parameter Identifiability – All Adjustable Parameters (Identifiability > 0.4)

Specific Yield (Porosity)

From **Figure F.4**, the distribution of identifiability is similar to that found for specific storage (refer **Figure F.3**), with a significant proportion of the Pilot Points having an identifiability of more than 0.3. It is noted that the specific yield parameter is used in MODFLOW-USG for porosity when solving the variably saturated flow equation.

Drainage K-M Factor

From **Figure F.5**, the K-M factor associated with surface watercourses (parameter DRN001) is very identifiable. The factors associated with the Stacked Drain implementation (300 series – top of Stacked Drain and 200 series – bottom of Stacked Drain) are moderately identifiable.

General Head K-T Factor

From **Figure F.6**, the identifiability of the K-T factors is low. This is expected since the General Head Boundary is located on the eastern edge of the model domain in Layer 27.

It is noted that just because a parameter is not identifiable does not imply that it is not a worthwhile parameter. Identifiability assessment merely indicates that the value of the parameter is not particularly informed by the calibration dataset. Accordingly, the value adopted for that parameter during predictive uncertainty will be far closer to the randomised derived value than a calibrated value.

Recharge Factor

From **Figure F.7**, those recharge parameters in close proximity to Springvale Mine, Angus Place Colliery and Clarence Colliery are reasonably informed by the calibration process. Recharge parameters further afield have reduced identifiability.

Evapotranspiration Factor

From **Figure F.8**, evapotranspiration parameters in close proximity to existing operations are reasonably informed by the calibration process, as per the findings presented in **Figure F.7** for recharge. Evapotranspiration parameters at distance from existing operations are not particularly identifiable.

Time-Varying Material

There are only four parameters that were included in the PEST control file associated with Time-Varying Material properties. As discussed in **Section 4.11**, because a 'full' profile of changes to hydraulic properties was only applied after cessation of dewatering and Angus Place Colliery and surrounding operations are still operational, only parameters associated with near-surface cracking were included in the parameter estimation step.

From **Figure F.9**, the identifiability of the included Time-Varying Material parameters is small.

4.14 Model Results incorporating Predictive Uncertainty

4.14.1 Approach to Predictive Uncertainty

The IESC (2018b) has recently issued an Information Guideline Explanatory Note on the approaches to uncertainty analysis. For this assessment, the selected uncertainty method was:

- *3. stochastic modelling with Bayesian probability quantification*

After model calibration, the calibrated parameter dataset was extracted and, with a parameter uncertainty file (based on expected 5th and 95th percentile range of values), used to generate 300 sets of randomised parameters via the Latin Hypercube Sampling technique (Watermark Numerical Computing, 2018a) facilitated by the PEST utility PEST2LHS.EXE and RunLHS.exe.

Table 4.16 presents the parameter uncertainty file used in the model simulations incorporating predictive uncertainty. It is noted that parameters that were FIXED during model calibration are not included in the parameter uncertainty file. It is noted that the example of lower of range and example of upper of range in **Table 4.16** was for illustration purposes. The Standard Deviation (in log space) is what is used as input to the randomised parameter value generation. It is also noted that the upper and lower bounds in the PEST control file were also honoured and if the randomised parameter value exceeded either of those bounds, it was curtailed back to the upper or lower bound.

Table 4.16: Adopted Values for Parameter Uncertainty Input Range

Parameter	Example Lower of Range	Example Upper of Range	Standard Deviation (in Log Space)	Units
Kh	0.10	10.0	0.5	m/d
Kz	0.10	10.0	0.5	m/d
Ss	2.50E-06	1.30E-05	0.18	1/m
Sy(Porosity)	0.10	0.20	0.08	-
DRN001 (K-M factor)	1.0	4.0	0.15	d^{-1}
DRN200 and 300 (K-M factor)	0.18	0.32	0.062	d^{-1}
Recharge factor	0.08	0.18	0.088	-
EVT factor	0.08	0.18	0.088	-
GHB (K-T factor)	8	15	0.068	m^2/d
TVM02	9	14	0.048	m
TVM14	0.5	2.0	0.151	-
TVM27	7	12	0.059	-
TVM100	0.3	0.6	0.075	-

After creation of the Latin Hypercube Sampling output file, which contains 300 sets of randomised parameter values, a FORTRAN script was used to generate the requisite PEST .PAR files.

During preparation of the .PAR files, parameters that were FIXED were incorporated into the .PAR file using their FIXED value.

The PEST utility PNULPAR.EXE was then used to superimpose "calibration knowledge" onto the 300 sets of randomised parameter values, whilst maintaining null space randomness. As will be discussed further below, of the 300 sets of parameter values, 299 sets of model simulations were successfully computed and the 10th and 90th percentile outputs determined with respect to 'drawdown' and change to groundwater contribution to surface water.

There were two additional steps of the Null Space Monte Carlo (NSMC) model that were not implemented, but were considered of limited consequence. The first was that the full Jacobian matrix was not recalculated centred on calibrated parameters, as that would have required a further 29 days of continuous computation. The second omission was the recalibration step (usually a single iteration) of PNULPAR generated parameter sets. The above steps may have assisted in reducing the spread of the predictive uncertainty results, but would not have increased it.

4.14.2 Model Setup

For the prediction simulations including uncertainty analysis, the following scenarios were considered:

Proposed Case:

- Dewatering at Angus Place Colliery (300, 700, 800 and 900 Panel Areas) will continue as per the requirements of approval of Angus Place Modification 5 and be maintained through to 31 December 2053
- Angus Place Colliery (1000 Panel Area) would commence on 1 July 2025 (LW1002) and complete on 31 October 2038 (LW910N on retreat), as per the Mine Schedule provided
- Angus Place Colliery (300, 700, 800, 900 and 1000 Panel Area) would be maintained in a dewatered state through to 31 December 2053. On 1 January 2054, dewatering at Angus Place Colliery would cease
- Mining at Springvale will complete on 28 February 2025 (LW424), as per the Mine Schedule provided (refer **Appendix C**), and dewatering will cease, temporarily, in the model from April 2025 through to December 2027. From January 2028, dewatering at Springvale Mine in the model will recommence to maintain groundwater elevation at 810mAHD. JBS&G notes that 810mAHD is the elevation (bottom of Lithgow Seam) such that access between Angus Place and Springvale (new connection between the mines) is maintained. The dewatered elevation of 810mAHD will be maintained from January 2028 (SP139) through to 31 December 2053 (SP190). On 1 January 2054, dewatering at Springvale will cease
- Clarence Colliery is included in the model for cumulative impact. Clarence will be maintained in its current state (301 Area sump included) through to 31 December 2041. On 1 January 2042, dewatering at Clarence would cease.

Null Case

- Dewatering at Angus Place Colliery (300, 700, 800 and 900 Panel Areas) will continue as per the requirements of approval of Angus Place Modification 5 and be maintained in a dewatered state through to 31 December 2029
- Angus Place Colliery (1000 Panel Area) would not commence on 1 July 2025
- Angus Place Colliery's consent expires on August 2024 (active mining) and it is assumed that Care & Maintenance would continue for another five years, so Angus Place Colliery is assumed to be maintained in a dewatered state until 31 December 2029. On 1 January 2030, pumps at Angus Place Colliery would be turned off
- Mining at Springvale will complete on 28 February 2025 (LW424), as per the Mine Schedule provided. Springvale would be maintained in a dewatered state (Care & Maintenance) for a further five years, until 31 December 2029. On 1 January 2030, pumps at Springvale Mine would be turned off
- Clarence Colliery is included in the model for cumulative impact. Clarence will be maintained in its current state (301 Area sump included) through to 31 December 2041. On 1 January 2042, dewatering at Clarence would cease.

In the Proposed Case and the Null Case, mining at other operations was kept the same.

4.14.3 Prediction Results

The model control file associated with the prediction simulation is:

- R02RevA_SIM200_02a.gwv

4.14.3.1 Model Parameters

As described in **Section 4.14.1**, Latin Hypercube Sampling was used as the basis of 300 sets of randomised parameter values. These values, once processed through PNULPAR.EXE to re-impart "calibration knowledge", were incorporated into individual PEST .PST files and executed serially.

As discussed in Watermark Numerical Modelling (2018a), there are additional steps that can be undertaken to re-calibrate the .PAR files after processing through PNULPAR.EXE, however, those steps were not undertaken as they were considered of limited consequence.

4.14.3.2 Modelled Difference in Groundwater Elevation

Of the 300 sets of randomised parameter values, 299 sets were successfully executed. The single set that was unsuccessful was due to model run failure. Model run failure occurs where the model crashes and does not produce output. It is noted that the CONVERGE keyword was used in the Solver Settings with the Stacked Drains methodology. The resultant model mass balance for each model run was less than 0.1%. A minor exception was the very last two Stress Periods (SP198 and SP199), where some model runs did not reach the target HCLOSE limit before the 300 outer iterations limit imposed in the Solver Settings was reached. This was of limited consequence and those Stress Periods were interpreted carefully and/or were omitted.

From the 299 sets of successful model runs, several sets of FORTRAN scripts were written by JBS&G to process the output files to identify the 'envelope' of 10th, 33rd, 50th, 66th and 90th percentile difference in groundwater elevation.

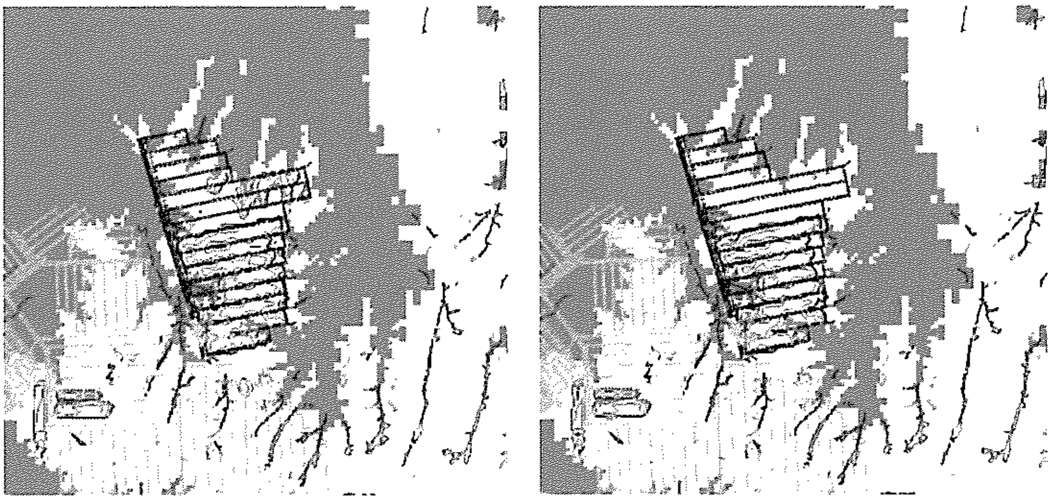
It may be the case that Run 1, for the sake of argument, leads to the 90th percentile difference between the Proposed Case and Null Case, for the early part of the model simulation, however, it may be Run 17 that has a higher 90th percentile difference in the latter part of the model simulation. i.e. results from a single run may not be responsible for the 90th percentile difference etc. To compound this issue, the 90th percentile difference may not occur when heads are at maximum or when heads are at minimum, hence the difference has to be calculated for each output time-step and stress period from the pairs of Proposed and Null Case runs.

As outlined in the IESC (2018) guidance document, it was necessary to confirm that 'uncertainty analysis convergence' was achieved. In practice, this means that the number of model runs is sufficient that the 10th percentile and 90th percentile model output has stabilised. Uncertainty analysis convergence was investigated with respect to modelled dewatering rate and it was found that convergence was achieved when the number of runs exceeded about 150. For the results presented in this report, the 299 run compilation was used.

It is highlighted that relatively few model runs were needed to achieve 'uncertainty analysis convergence' because of the use of the Latin Hypercube Sampling methodology, which deliberately targets the low probability areas of the parameter distributions.

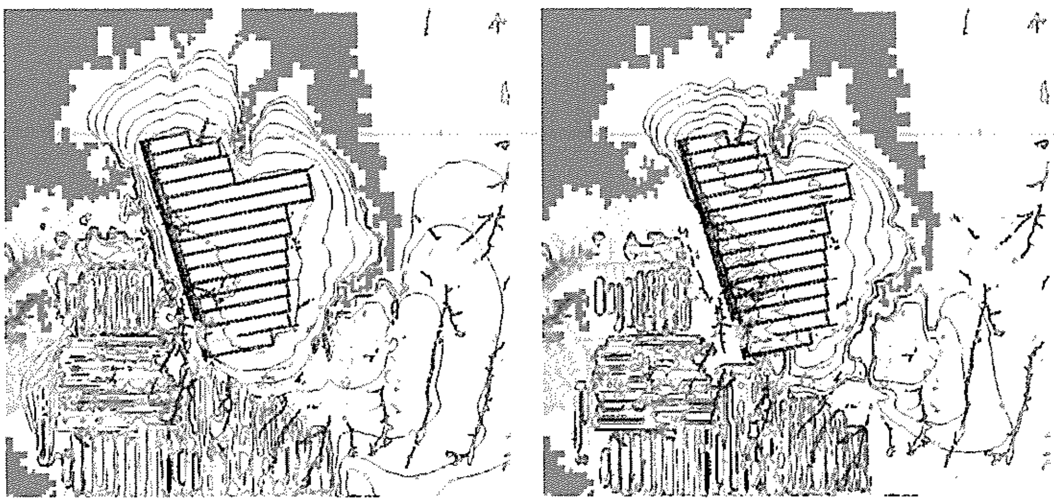
Model computation time, under load, was 30 hours for each of the 600 runs (300 pairs).

Figure 4.40 presents the 10th percentile (most negative, most drawdown) and 90th percentile difference (least negative, least drawdown) in groundwater elevation between the Proposed and Null Cases in various model layers at the end of Mine Life on 31 December 2053 (SP190). **Figure 4.41** presents the 10th percentile and 90th percentile difference in groundwater elevation between the

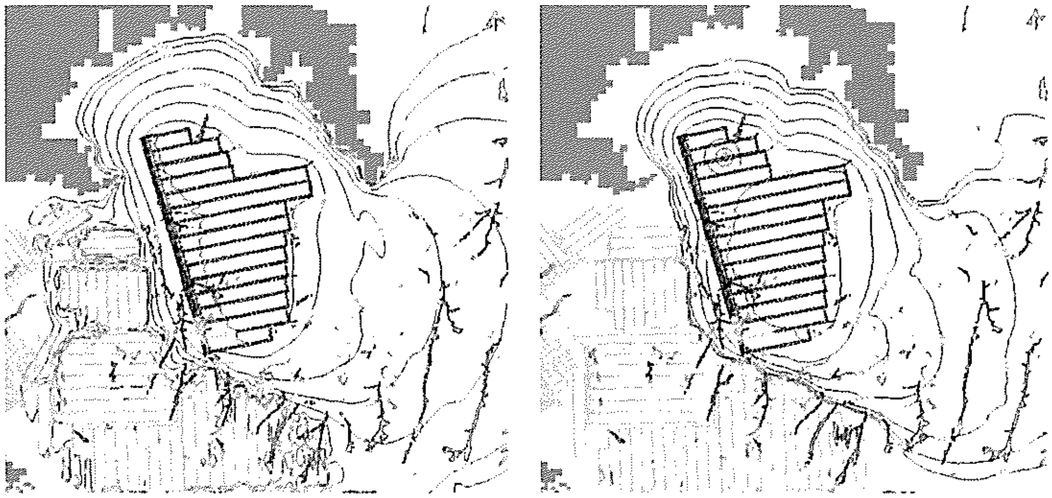


Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)

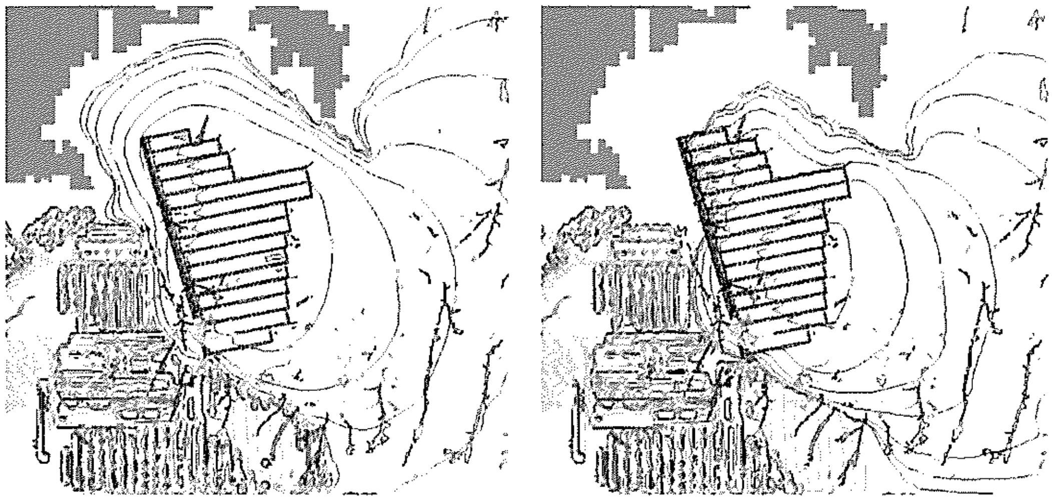
Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)



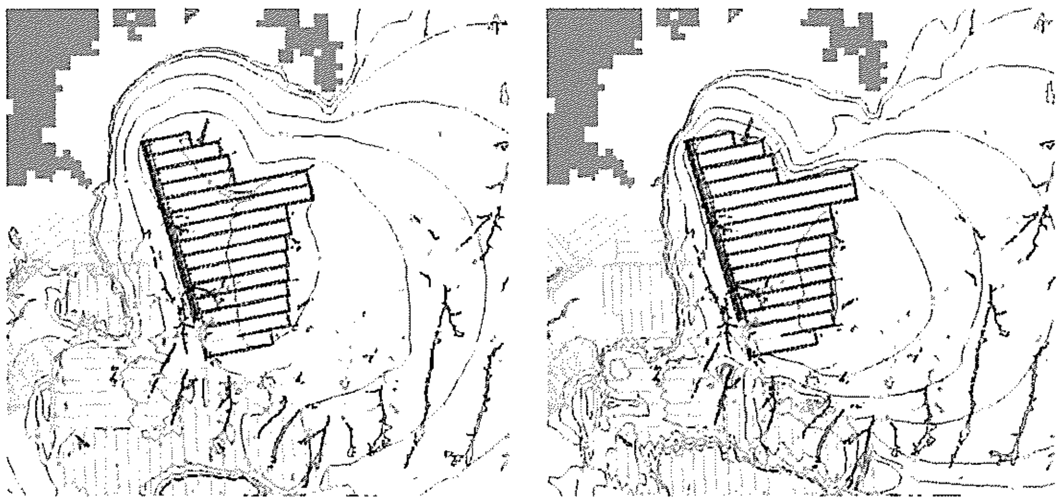
Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)



Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)



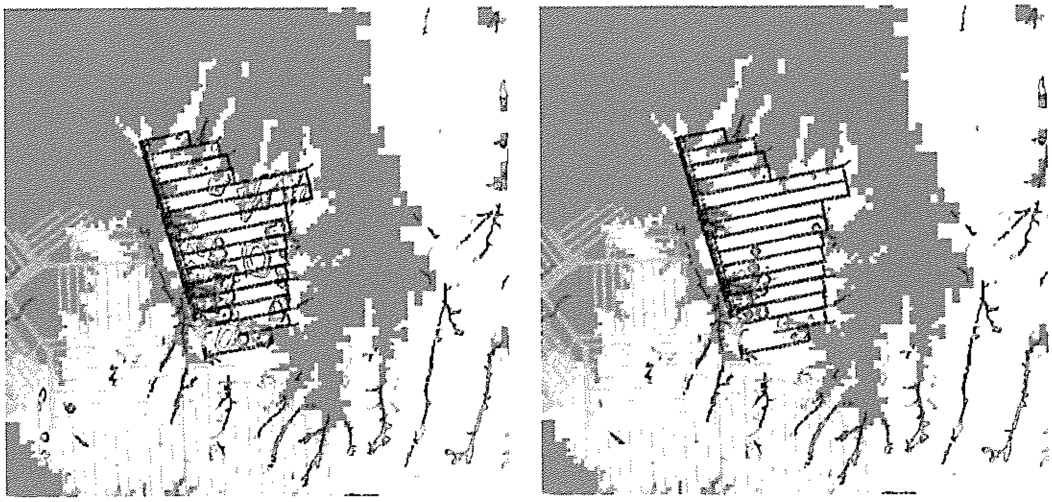
Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



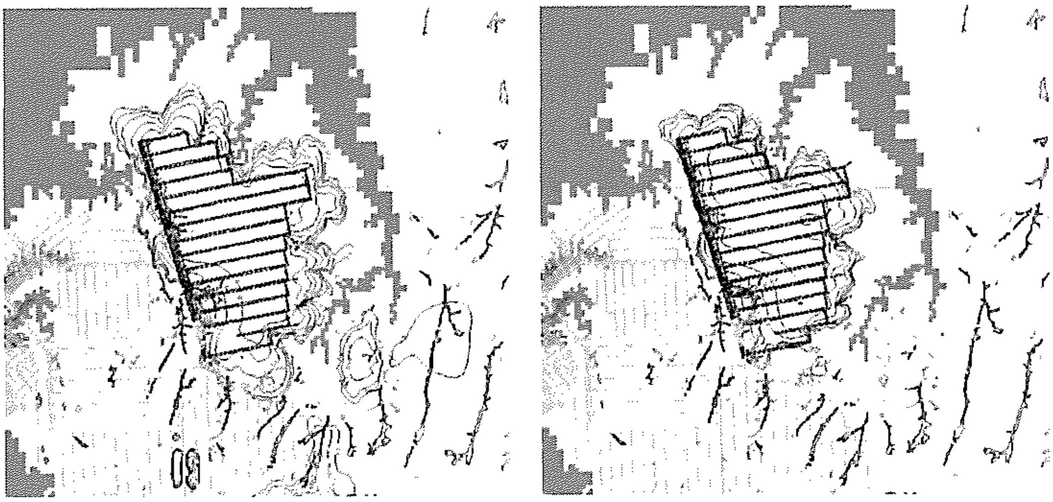
Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

▩ - 'Pinched-out' cells - Drain (DRN) cells

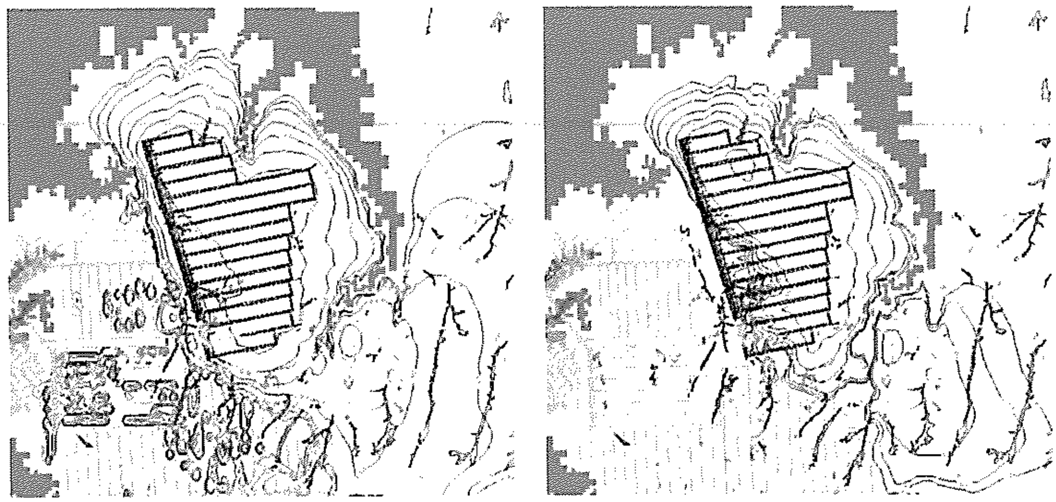
Figure 4.40: Predicted Drawdown – End of Mine Life: 31 December 2053 (SP190)



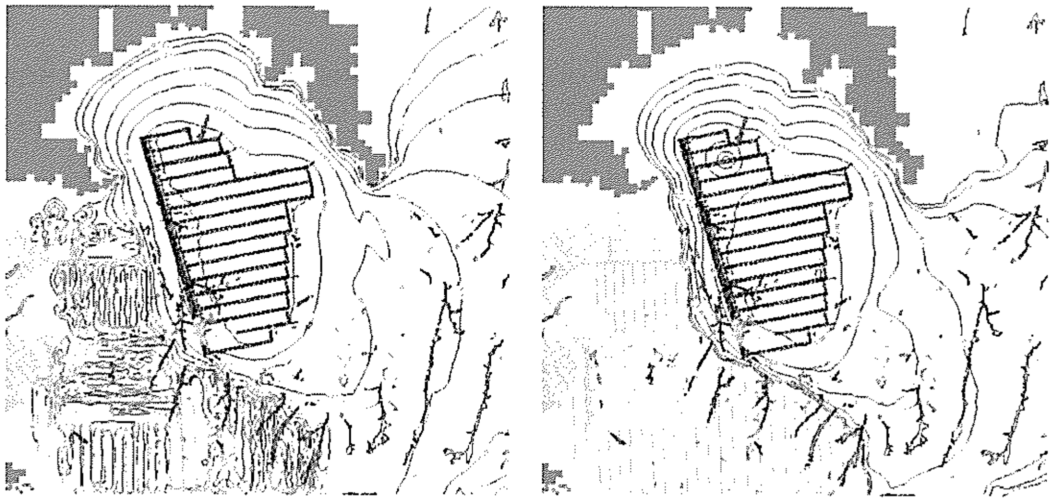
Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)



Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)

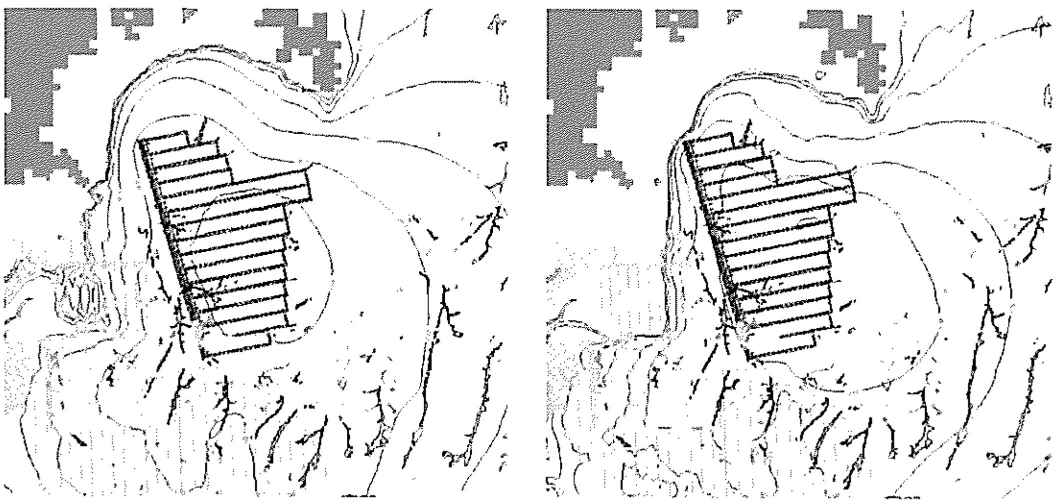


Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)



Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)

Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

- 'Pinched-out' cells - Drain (DRN) cells

Figure 4.41: Predicted Drawdown – Recovery Phase: 31 December 2091 (SP197)

Proposed and Null Cases for the 1000 Panel Area in the recovery phase, at 31 December 2091 (SP197).

From **Figure 4.40**, there is a significant drawdown in groundwater elevation beneath the 1000 Panel Area and that drawdown is still significant above the Mt York Claystone (Layer 15). From **Figure 4.40**, the top of the Stacked Drains is visible in the southern portion of the 1000 Panel Area and this is due to the 3.4m extraction height, whereas the north portion of the 1000 Panel Area has an extraction height of 2.5m.

From **Figure 4.41**, 40 years after cessation of mine dewatering, significant drawdown remains in Layer 13 (Banks Wall Sandstone) and in Layer 15 (Mt York Claystone), however, the drawdown in Layer 9 (Sandstone between YS4 and YS5) has dissipated.

It is highlighted that the 'full' profile of subsidence-induced change to hydraulic properties is enabled in the Stress Period following the cessation of mine dewatering, therefore the slow recovery of groundwater elevation in **Figure 4.41** does reflect this aspect as well.

4.14.3.3 Model Water Balance

The global water balance from the groundwater model, with respect to the SIM0 results (prediction simulation using calibration parameters), is presented in **Table 4.17** with respect to the end of mining in December 2053 (SP190) and during the recovery phase in December 2091 (SP197).

As was noted in **Section 4.12.3.3**, model output in the Listing file was available in four decimal places and was therefore presented in four decimal places in **Table 4.17** and **Table 4.18**. i.e. the concept of significant figures was ignored.

Table 4.17: Model Water Balance – End of Mine Life – December 2053 (SP190)

Component	Groundwater Inflow (m3/d)	Groundwater Outflow (m3/d)
Storage	30484.3101	20342.3580
Constant Head	0.0000	0.0000
Drains	-	211272.8949
River Leakage	10028.8730	2335.9265
Evapotranspiration	-	152919.6406
Head Dependent Boundary Conditions	-	1318.8617
Recharge	347677.0938	-
Total	388190.2769	388189.6818
	Inflow – Outflow	0.5951
	Percent Discrepancy	0.00%

Table 4.18: Model Water Balance – Recovery Phase – December 2091 (SP197)

Component	Groundwater Inflow (m3/d)	Groundwater Outflow (m3/d)
Storage	14096.0228	35317.6544
Constant Head	0.0000	0.0000
Drains	-	189037.4647
River Leakage	10984.6641	2116.2488
Evapotranspiration	-	162171.5781
Head Dependent Boundary Conditions	-	1226.9935
Recharge	364789.8438	-
Total	389870.5306	389869.9395
	Inflow – Outflow	0.5911
	Percent Discrepancy	0.00%

From **Table 4.17**, inflow to the groundwater model is dominated by recharge and outflow is mostly through drains (surface watercourse and mining) and then evapotranspiration. From **Table 4.17**, the mass balance error is less than 0.1%.

From **Table 4.18**, inflow to the groundwater model during recovery phase is also dominated by recharge. From **Table 4.18**, outflow from groundwater model comprises drains (surface watercourses only, as mining has ceased) and evapotranspiration. From **Table 4.18**, the mass balance error is less than 0.1%.

4.14.3.4 Gang Gang Swamp Catchment at Springvale Mine

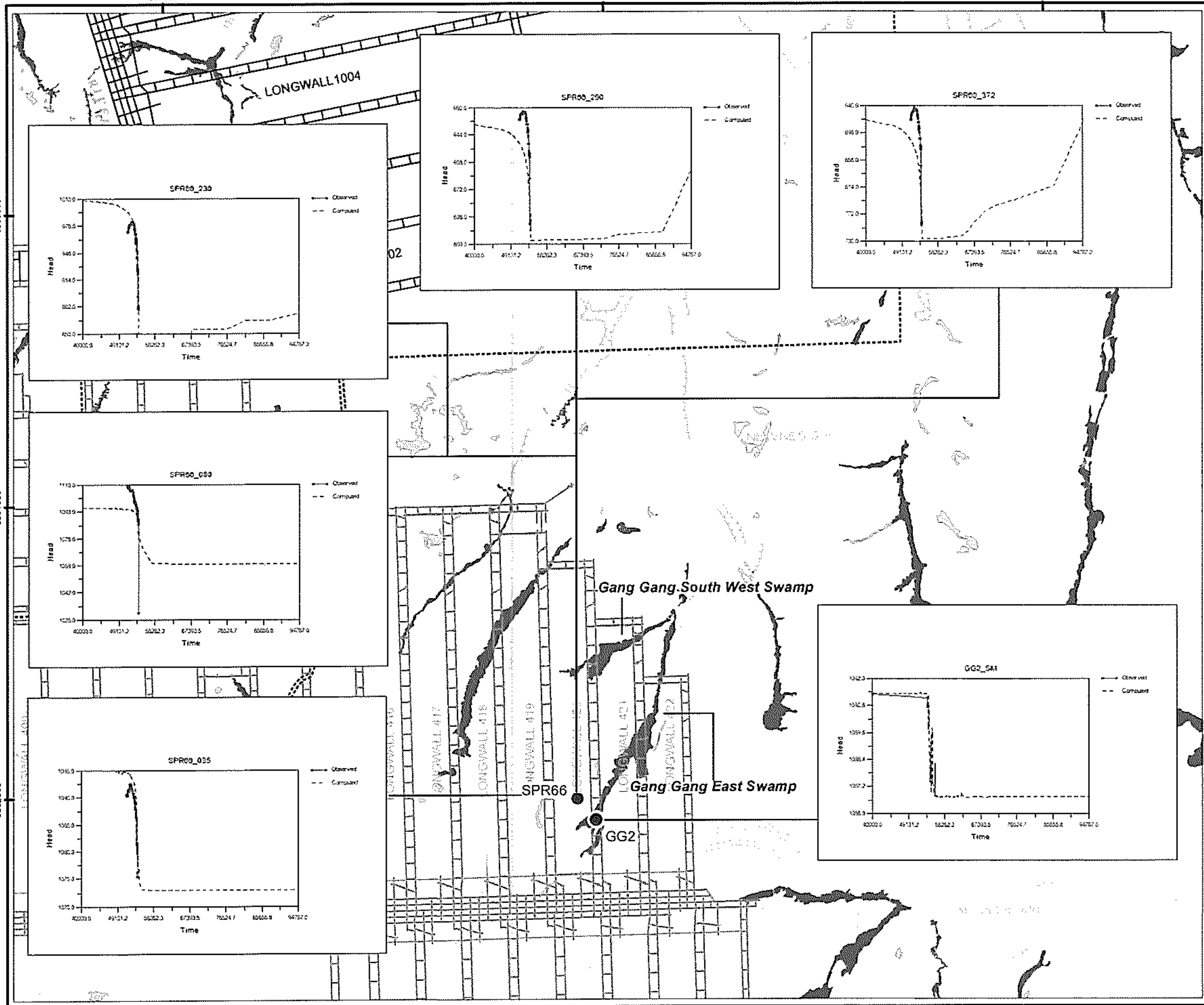
Output from the simulation model is presented in **Figure 4.42** for Gang Gang Swamp catchment with respect to Springvale Mine for the purpose of illustrating the expected effect due to mining.

From **Figure 4.42**, there is a significant decrease in groundwater elevation associated with mining and that groundwater elevation in Layer 7 (Piezometer GG2), 10 (Piezometer SPR66_035) and 12 (SPR66_080) does not recover during the prediction simulation. From **Figure 4.42**, in Layer 17 (Piezometer SPR66_230), 20 (Piezometer SPR66_290) and 23 (Piezometer SPR66_372) groundwater elevation does start to recover, although the sharp increase in **Figure 4.42** in SPR66_290 and SPR66_372 after 87000 days is considered erroneous. The results for that time and onward were erroneous due to convergence constraints in SP198 and SP199, as noted above.

Available model results imply that the recovery time for groundwater elevation in the upper part of the groundwater model will be in excess of 40 years.

Figure 4.43 presents the equivalent predicted response from the COSFLOW model (after **Figure** H8 and H9 of CSIRO (2015). Time-series water level response was not available in CSIRO (2015), therefore a change to water balance, which was available, is presented instead.

It is noted that CSIRO (2015) presented updated model simulations from CSIRO (2013), accounting for the sequential implementation of Springvale Mine followed by Angus Place East project, rather than concurrent implementation of Springvale Mine and Angus Place East as presented in CSIRO (2013). It is also noted that the nomenclature in **Figure 4.43** in regard to naming of swamps is different.



JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1 | Date: 13-Sep-2019

Drawn By: JZ | Checked By: JB

Scale 1:35,000

0 0.5 1
km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs (Gang Gang Swamp Catchment)

FIGURE: 4.42

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D024_PredictiveUncertainty_GangGang.mxd
Reference © Department of Finance, Services & Innovation 2018

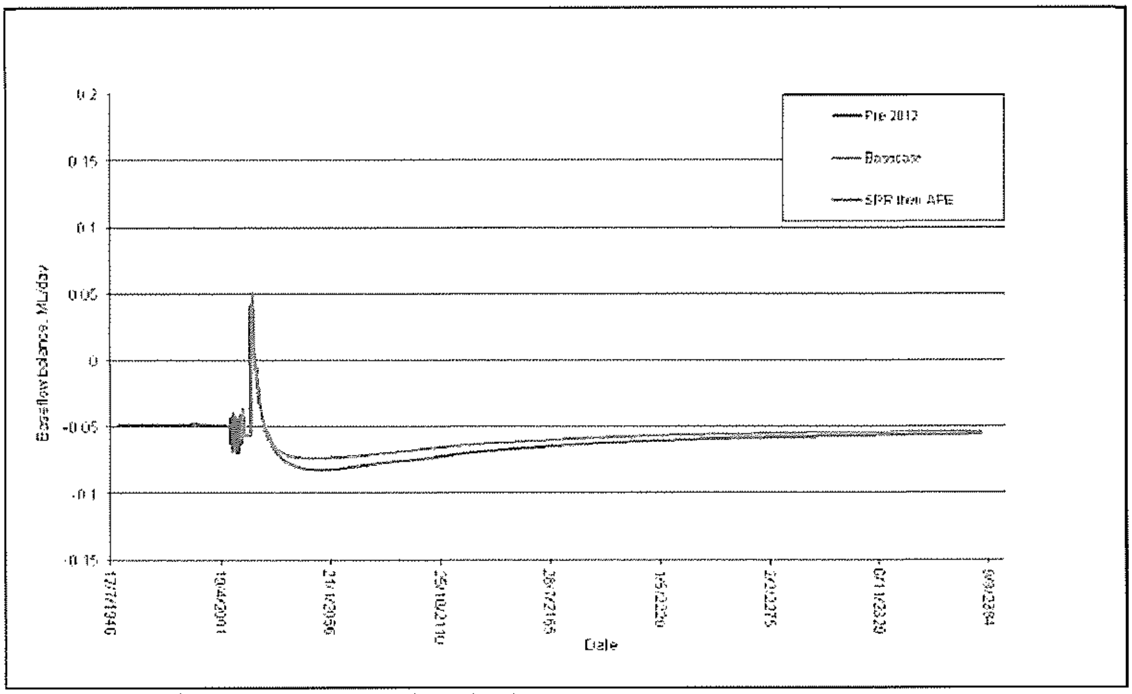


Figure H8 Estimates of baseflow balance (Gang-Gang Swamp South)

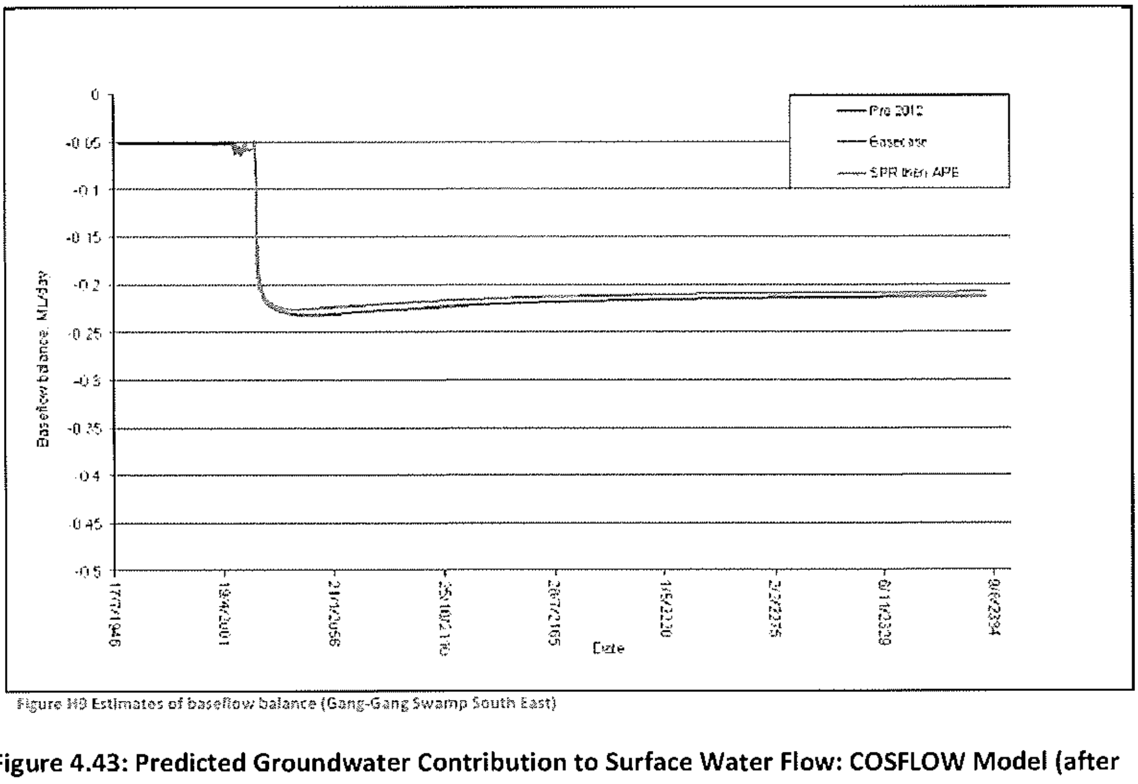


Figure H9 Estimates of baseflow balance (Gang-Gang Swamp South East)

Figure 4.43: Predicted Groundwater Contribution to Surface Water Flow: COSFLOW Model (after Figure H8 and H9 of CSIRO (2015)) – Gang Gang Swamp

4.14.3.5 Wolgan River Swamp Upper Swamp

Figure 4.44 presents the 10th percentile and 90th percentile calculated drawdown in the vicinity of Wolgan River Swamp Upper Swamp at the end of mine life on 31 December 2053 (SP190).

From **Figure 4.44**, along the Wolgan River, including the Wolgan River Swamp Upper Swamp, the calculated drawdown is less than 0.5m in the Banks Wall Sandstone (Layer 13), which is the highest active layer for this swamp. At depth, in the Lithgow Seam (Layer 24), the drawdown beneath the Wolgan River Swamp Upper Swamp ranges between approximately 10m and 15m.

Figure 4.45 presents the 10th percentile (most negative, most drawdown) and 90th percentile (least negative, least drawdown) calculated drawdown during the recovery phase at 31 December 2091 (SP197).

From **Figure 4.45**, the calculated drawdown is less than 0.5m in the Banks Wall Sandstone (Layer 13). At depth, drawdown in the Lithgow Seam (Layer 24) ranges between 20m and 30m.

Model results presented in **Figure 4.44** and **Figure 4.45** suggest that the synthetic monitoring piezometers included in the model for Wolgan River Swamp Upper Swamp should experience negligible drawdown in the Proposed Case compared to the Null Case.

Figure 4.46 presents some hydrographs in the vicinity of Wolgan River Swamp Upper Swamp. It is noted that swamp monitoring piezometers are not installed in Wolgan River Swamp Upper Swamp. To obtain output from the model, for the purpose of discussion, two synthetic monitoring piezometers were created. The first is called WOLGAN04 and the second is called WOLGAN03.

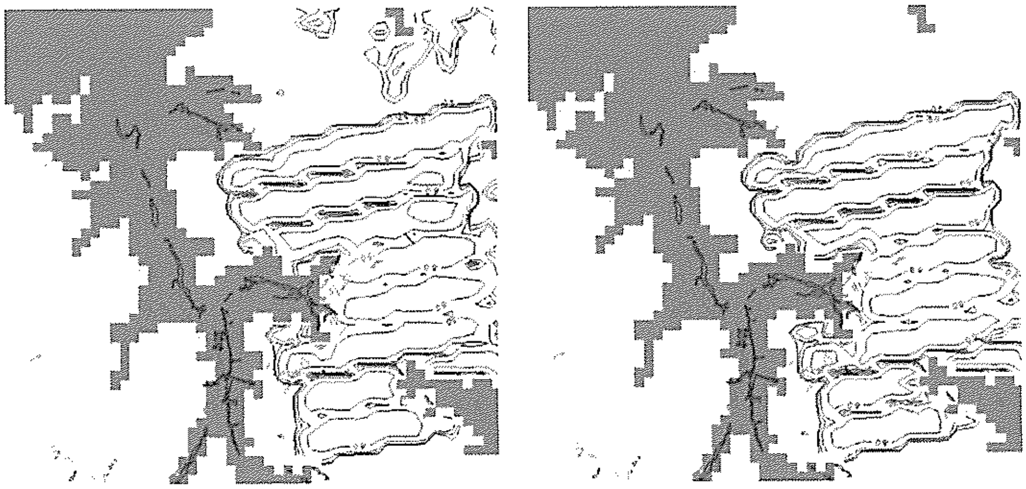
The results presented in **Figure 4.46** were obtained from the Proposed and Null Case simulations associated with the 10th percentile and 90th percentile drawdown. As indicated above, the 10th percentile and 90th percentile drawdown were calculated via an 'envelope' methodology and where a particular drawdown was ranked to be the 10th percentile at a particular node at a particular Stress Period and Time Step, the Proposed and Null Case head values were also recorded.

From **Figure 4.46**, there is negligible difference in the modelled swamp water level in Wolgan River Swamp Upper Swamp between the Proposed Case and Null Case. This is indicated in **Figure 4.46** by the grey (Null Case) and black (Proposed Case) set, representing least drawdown, being essentially the same. Similarly, in **Figure 4.46**, the peach (Null Case) and orange (Proposed Case) set, representing the most drawdown, is also the same.

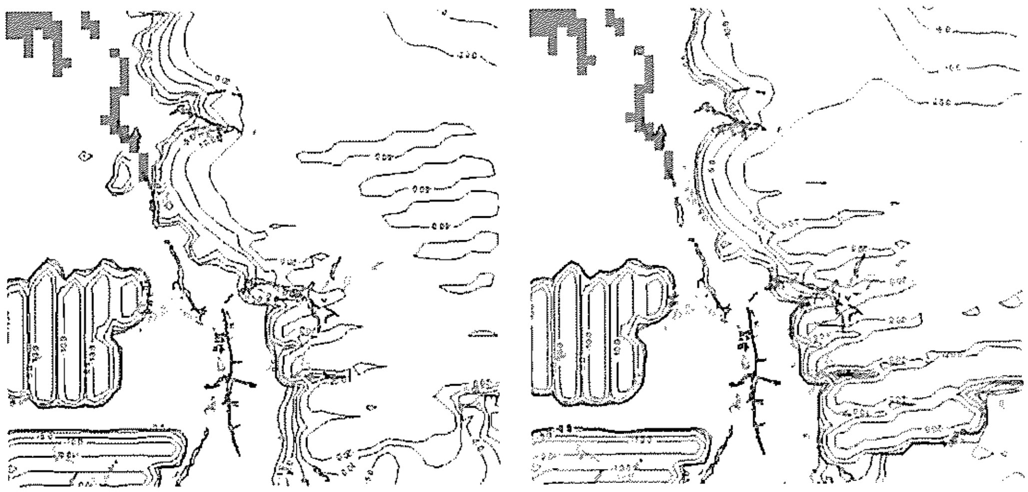
To investigate the potential change to surface water flow in Wolgan River Swamp Upper Swamp, probabilistic output from the groundwater model was used as input to the Swamp Water Balance Model (JBS&G, 2019). It is noted that groundwater model output (groundwater/surface water interaction along the thalweg of surface watercourses and outflow from seepage faces within each sub-catchment) used a loss factor to account for evaporative loss between point of discharge and point of accumulated flow. The loss factor was calibrated using available streamflow gauging, as discussed in JBS&G (2019), and was found to be 80%. i.e. groundwater model output was multiplied by 0.20 before being added to rainfall-runoff based surface water flow in the SAPSWBM.

Figure 4.47 presents the modelled change in surface water flow in Wolgan River Swamp Upper Swamp due to mining of the 1000 Panel Area at Angus Place Colliery for the 10th percentile (most negative) and 90th percentile results (least negative). The modelled change in surface water flow from the simulation prediction (based on calibrated parameter) is also presented in **Figure 4.47**. That simulation prediction is referred to as SIM0 in **Figure 4.47**.

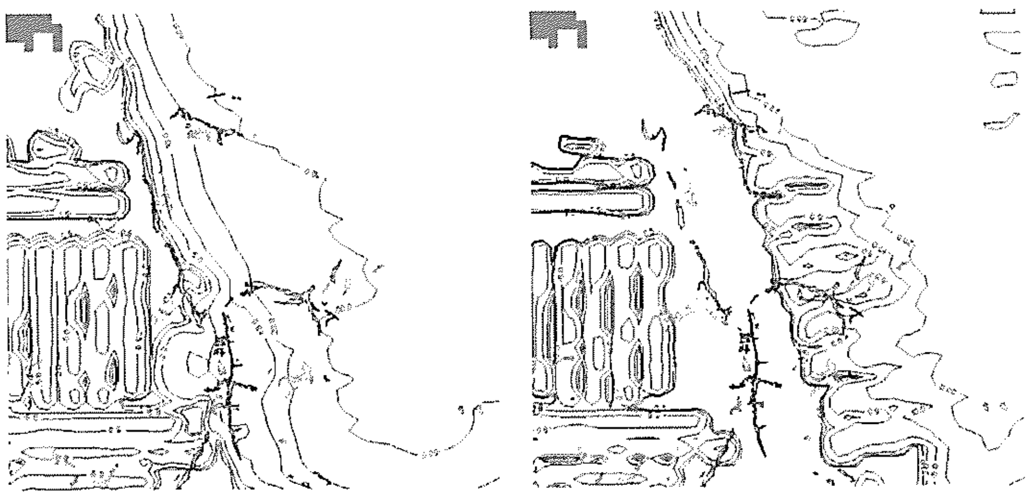
From **Figure 4.47**, modelling indicates that the change in surface water flow ranges from a decline of between 0.05 and 0.42ML/d (0.6 and 4.9L/s) initially, which quickly dissipates to a change that ranges between no change to an increase of 0.05ML/d. It is noted that the magnitude of change is evaluated in the Swamp Water Balance Report in context of modelled daily flow (JBS&G, 2019).



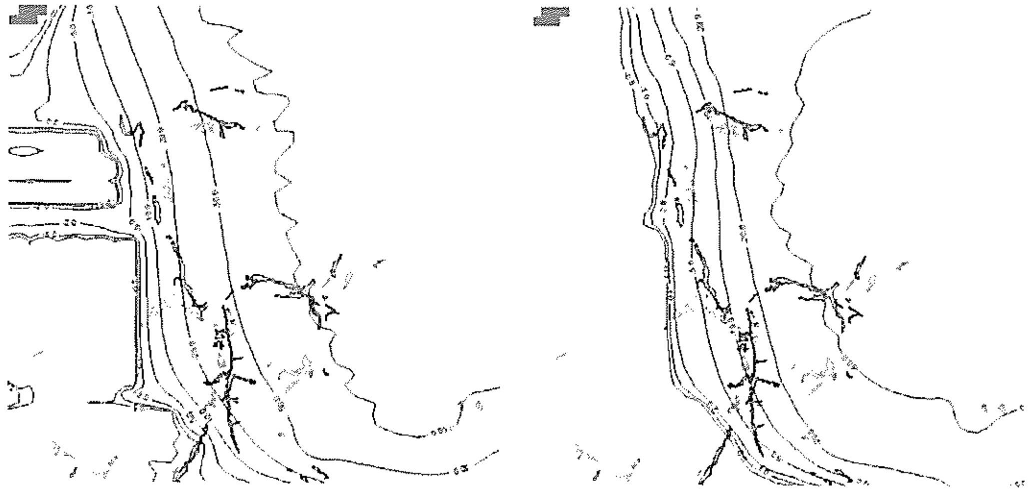
Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)



Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)

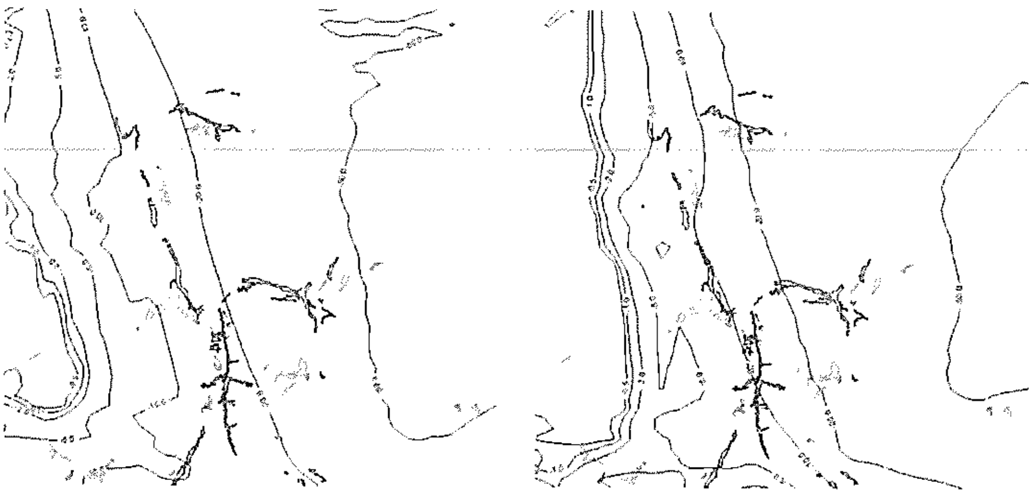


Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)



Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)

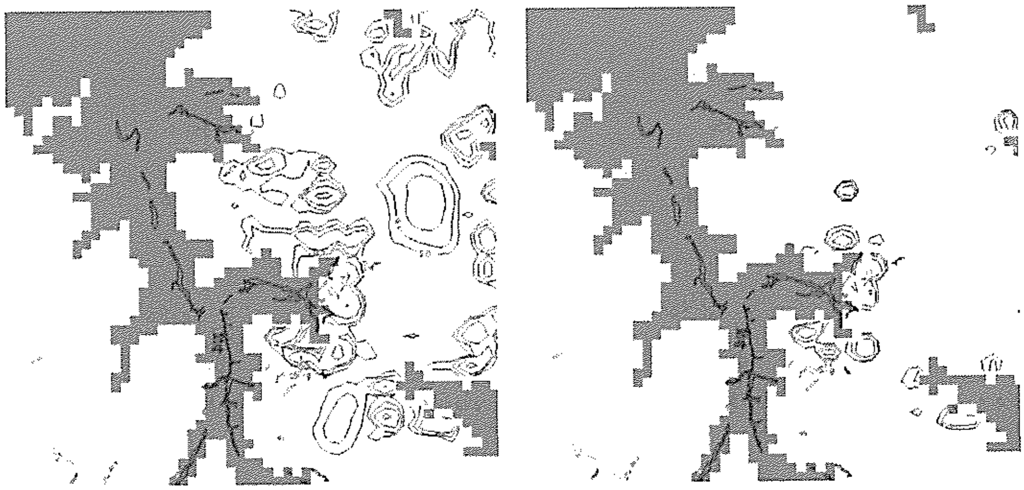
Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



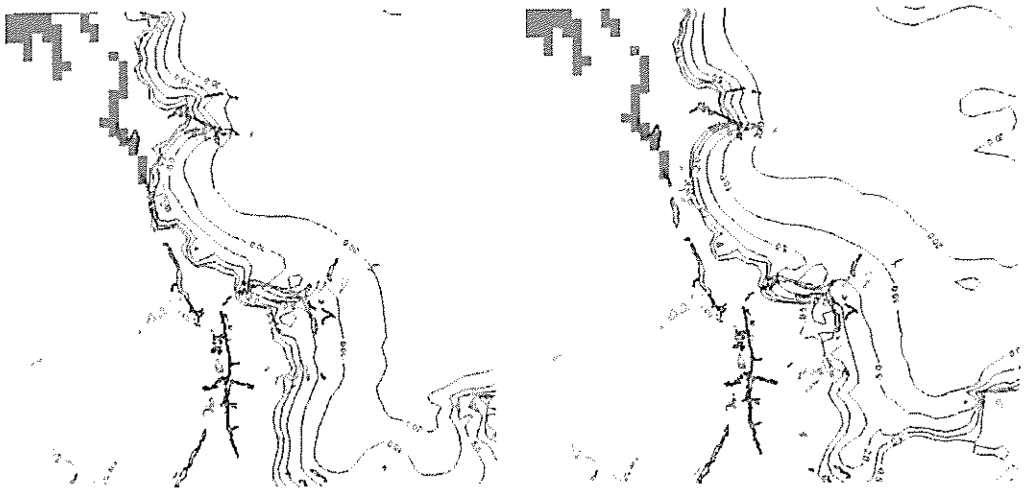
Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

▩ - 'Pinched-out' cells   - Drain (DRN) cells

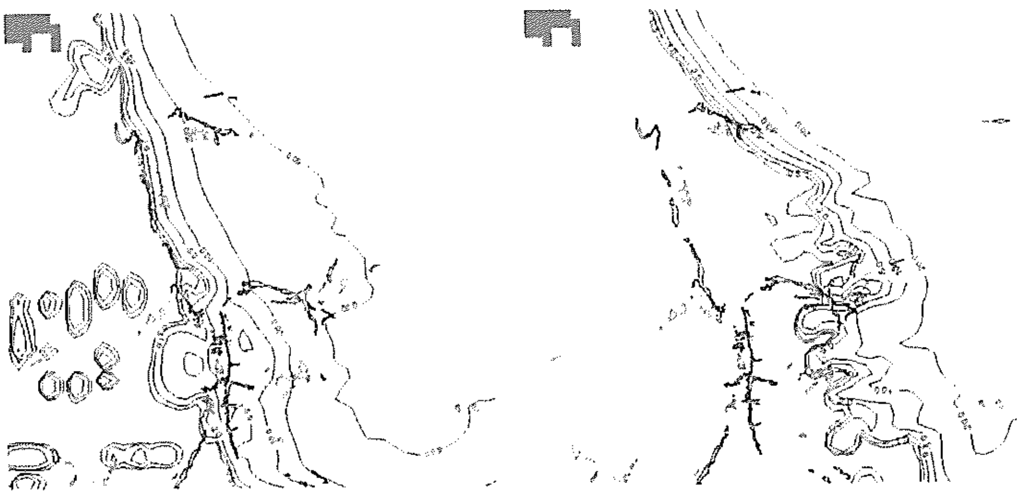
Figure 4.44: Predicted Drawdown – End of Mine Life: 31 December 2053 (SP190) – Wolgan River Swamp Upper Swamp, Tri-Star Swamp, Wolgan River Swamp and Twin Gully Swamp



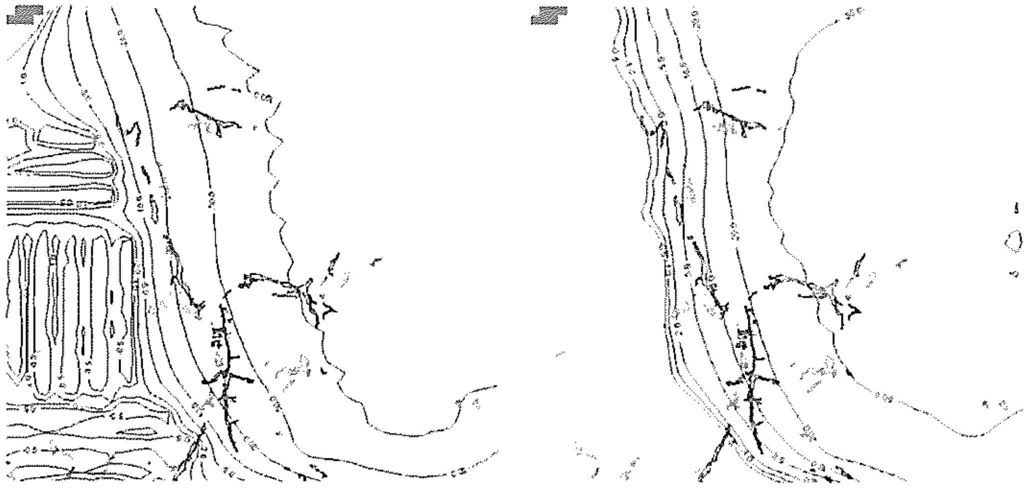
Layer 9 (Sandstone between YS4 and YS5) (L – 10th% Difference; R – 90th% Difference)



Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)



Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)



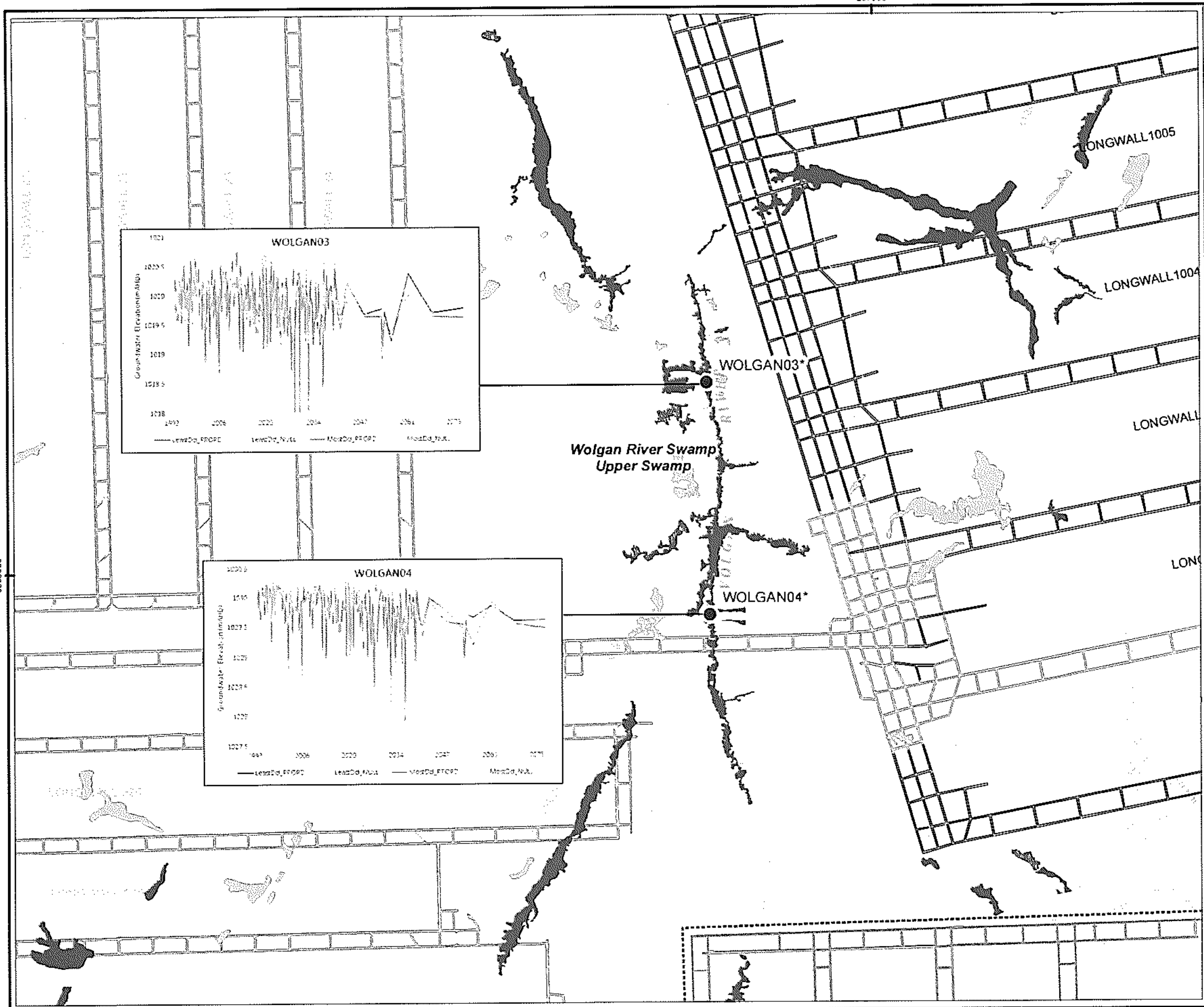
Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)

Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)

Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

- 'Pinched-out' cells - Drain (DRN) cells

Figure 4.45: Predicted Drawdown – Recovery Phase: 31 December 2091 (SP197) – Wolgan River Swamp Upper Swamp, Tri-Star Swamp, Wolgan River Swamp and Twin Gully Swamp



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

* Synthetic monitoring location, which doesn't exist.

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 13-Sep-2019
Drawn By: JZ	Checked By: JB
Scale 1:15,000	

0 0.25 0.5
km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs (Wolgan River Swamp Upper Swamp)

FIGURE: 4.46

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D042_PredictiveUncertainty_WR_Upper.mxd
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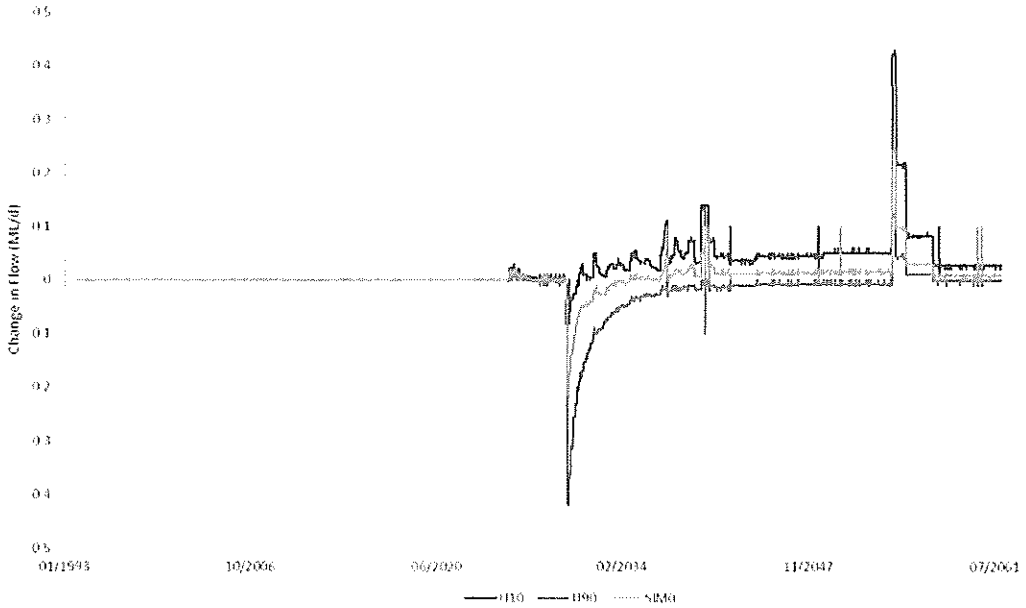


Figure 4.47: Predicted Change to Surface Water Flow (Wolgan River Swamp Upper Swamp)

4.14.3.6 Tri-Star Swamp Catchment

Figure 4.44 presents the 10th percentile and 90th percentile calculated drawdown in the vicinity of Tri-Star Swamp at the end of mine life on 31 December 2053 (SP190).

From **Figure 4.44**, the calculated drawdown ranges is between 20m and 50m in the Banks Walls Sandstone (Layer 13) surrounding Tri-Star Swamp and is at least 5m in the Burralow Formation (Layer 9).

Figure 4.45 presents the 10th percentile (most negative, most drawdown) and 90th percentile (least negative, least drawdown) calculated drawdown during the recovery phase at 31 December 2091 (SP197).

From **Figure 4.45**, the calculated drawdown had recovered to a 10m to 20m residual drawdown in the Banks Wall Sandstone (Layer 13) adjacent Tri-Star Swamp and is at least 1 to 2m residual drawdown in the Burralow Formation (Layer 9) at the same location.

Model results presented in **Figure 4.44** and **Figure 4.45** suggest that monitoring piezometers in the vicinity of Tri-Star Swamp should also experience moderate to large drawdown in the Proposed Case compared to the Null Case.

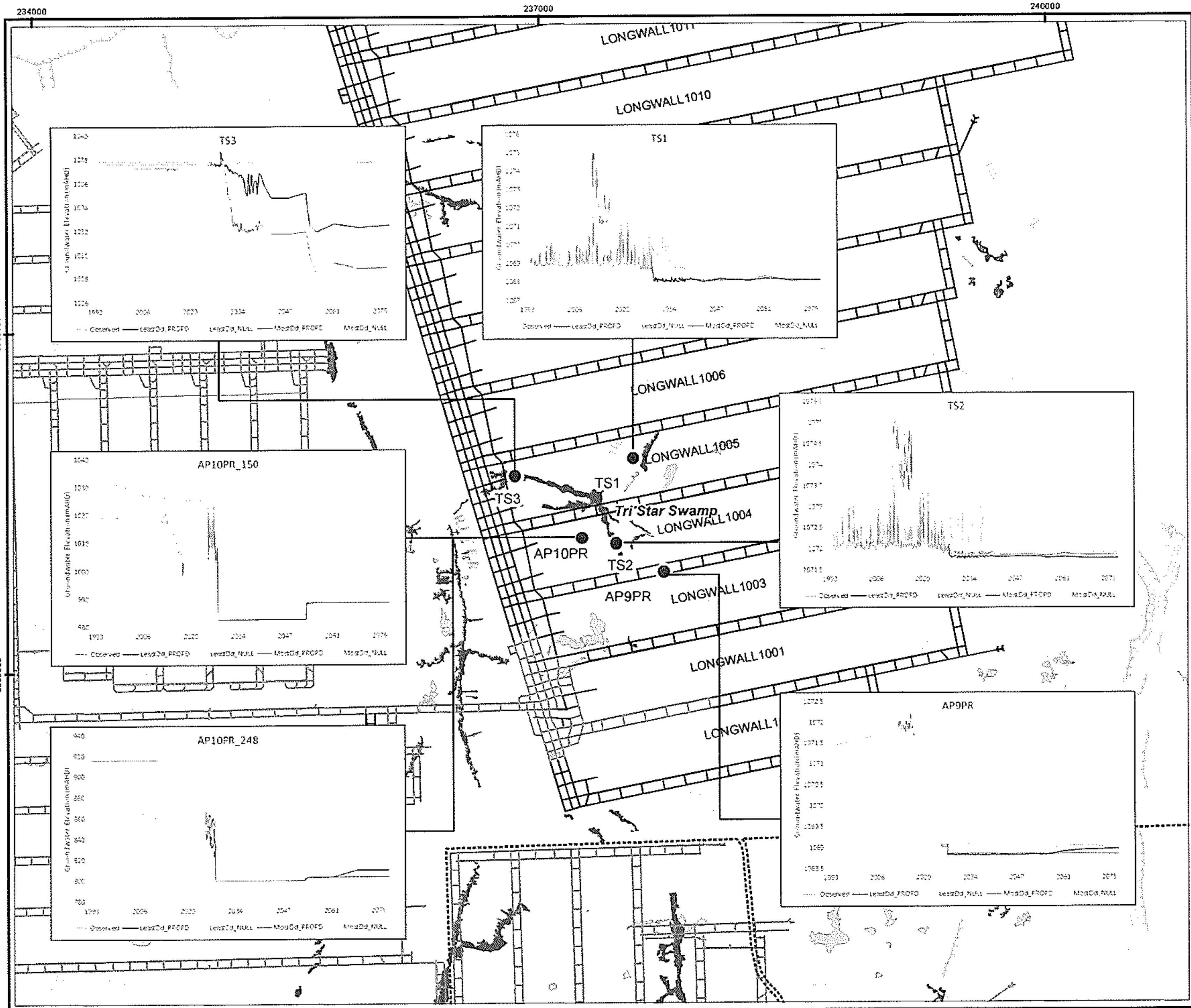
Figure 4.48 presents selected hydrographs in the vicinity of Tri-Star Swamp.

From **Figure 4.48**, modelling indicates that a decline of more than 1 metre in groundwater elevation is expected in Tri-Star Swamp piezometers, TS1, TS2 and TS3 due to mining.

From **Figure 4.48**, there is no variability in the expected change to groundwater elevation with respect to APR10PR_150 and APR10PR_248, with both experiencing a significant and sharp drop.

Analysis implies there will be adverse impact to groundwater elevation in Tri-Star Swamp due to mining.

Figure 4.49 presents the modelled change in surface water flow in Tri-Star Swamp due to mining of the 1000 Panel Area at Angus Place Colliery. The modelled change in surface water flow from the simulation prediction (based on calibrated parameter) is also presented in **Figure 4.49**.



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 13-Sep-2019
Drawn By: JZ	Checked By: JB

Scale 1:30,000

0 0.5 1
km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs (Tri-Star Swamp)

FIGURE: 4.48

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D025_PredictiveUncertainty_TriStar.mxd
Reference © Department of Finance Services & Innovation 2018

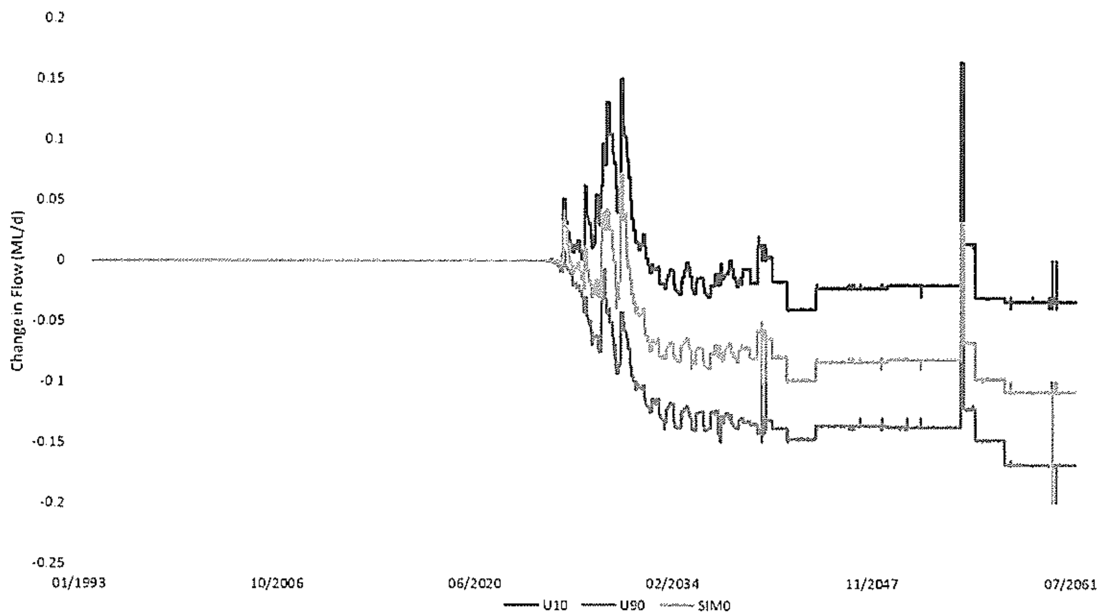


Figure 4.49: Predicted Change to Surface Water Flow (Tri-Star Swamp)

From **Figure 4.49**, the modelled change in surface water flow is minor, initially being an increase of 0.15ML/d (1.7L/s) in the 10th percentile model results and a decrease of 0.1ML/d (1.1L/s) in the 90th percentile results. The increase in flow is due to the changes to hydraulic properties in the uppermost cell above the Stacked Drains. The change to hydraulic properties, because the subsidence profile is truncated due to the depth of cover, is reasonably large. From **Figure 4.49**, at later time, the modelled change to surface water flow is a decrease of 0.04ML/d in the 10th percentile model results and is a decrease of 0.15ML/d in the 90th percentile model results.

It is noted that the 'spike' in **Figure 4.49** in 2053 is due to the cessation of dewatering via the Stacked Drain cells and application of the 'full' profile of changes to hydraulic properties, rather than just near-surface changes. The increase in hydraulic conductivity (noting that changes to storage were not considered due to model instability) with the 'full' profile leads to a brief increase in surface water flow, however, this is dissipated quickly.

Tri-Star Swamp is expected to experience a significant decline in groundwater level and whilst a brief increase in surface water flow is predicted initially, surface water flow is expected to decline in the medium and long-term.

Figure 4.50 presents the results from the COSFLOW model for the Tri-Star Swamp and are similar in nature to that presented in **Figure 4.49**.

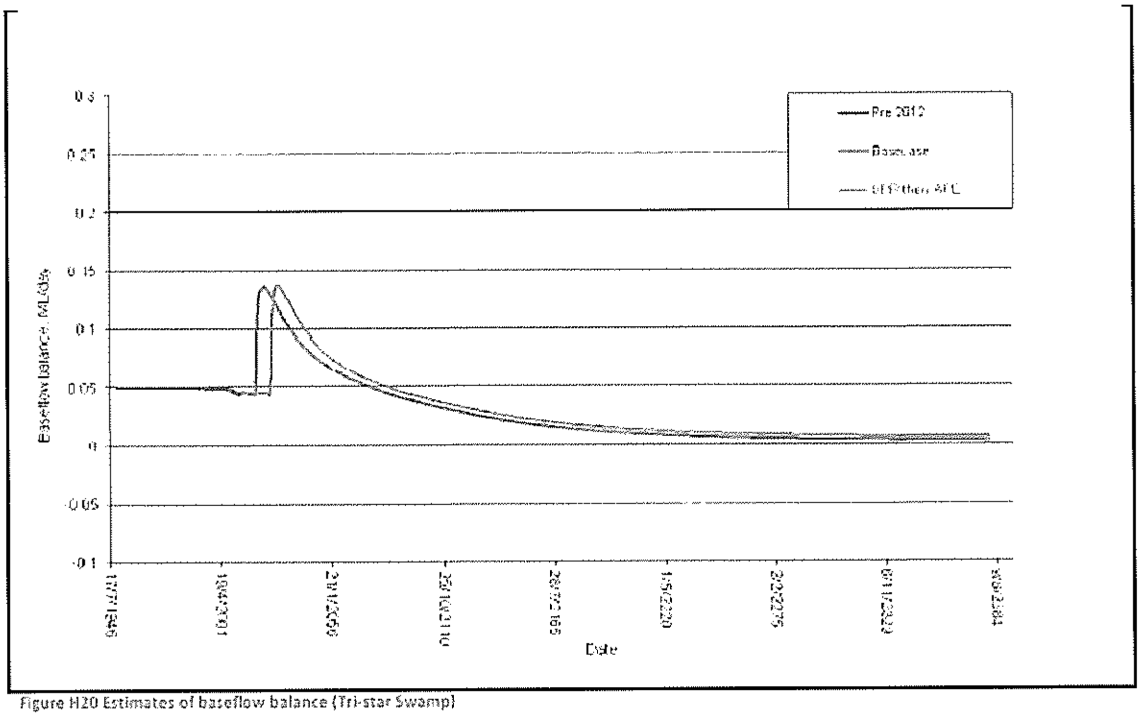


Figure 4.50: **Predicted Groundwater Contribution to Surface Water Flow: COSFLOW Model (after Figure H20 of CSIRO (2015)) – Tri-Star Swamp**

4.14.3.7 Wolgan River Swamp

The modelled change to groundwater elevation is presented in **Figure 4.44** and **Figure 4.45** at the end of mining in December 2053 (SP190) and during the recovery phase in December 2019 (SP197).

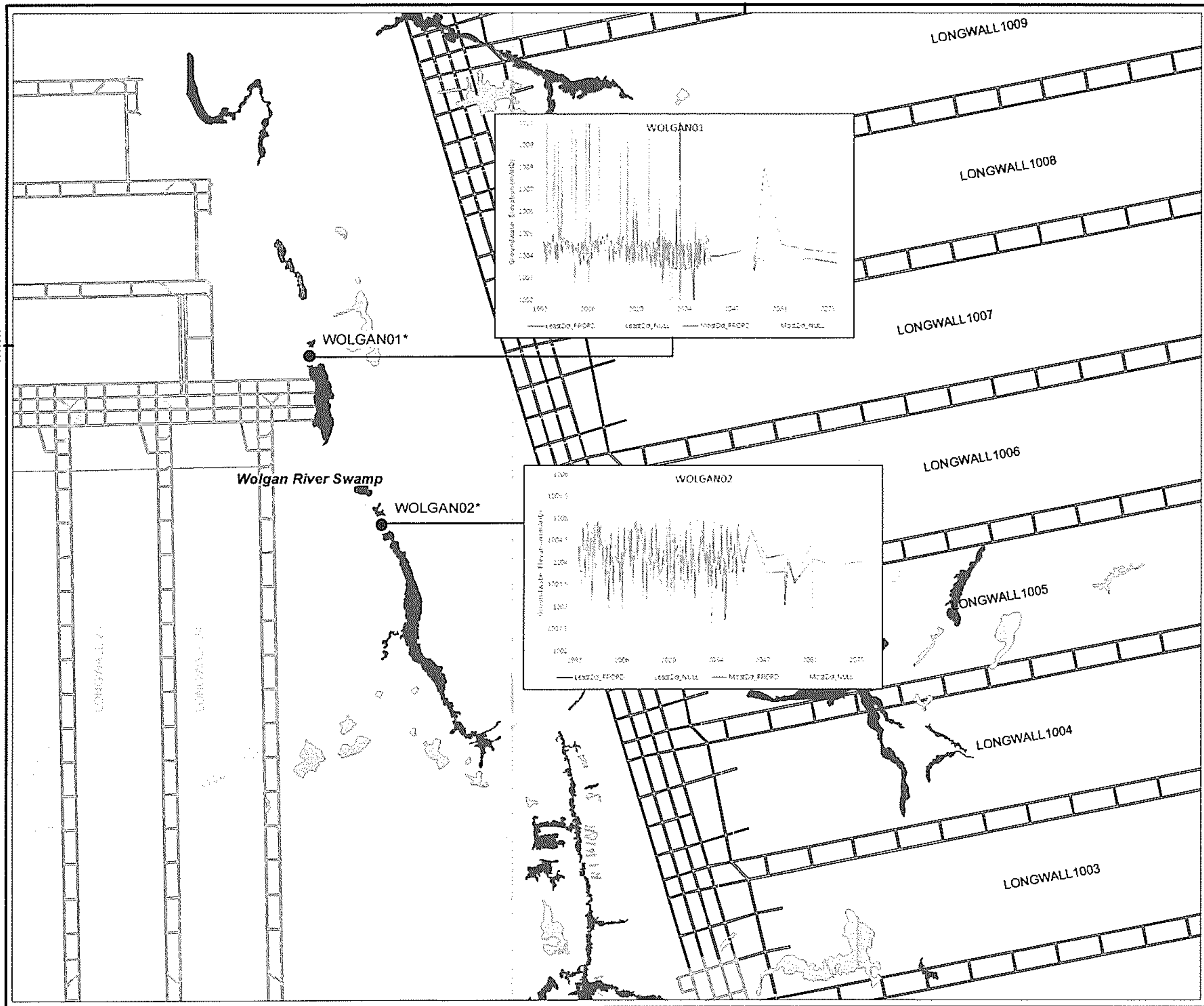
From **Figure 4.44** and **Figure 4.45**, there is minimal drawdown indicated in the Banks Wall Sandstone (Layer 13).

Figure 4.51 presents synthetic hydrographs from the Wolgan River Swamp.

From **Figure 4.S1**, the predicted change in groundwater elevation is negligible and both the least drawdown and most drawdown model output sets lie, essentially, on top of each other.

Figure 4.S2 presents the modelled change to surface water flow in Wolgan River Swamp.

From **Figure 4.52**, the modelled change to groundwater contribution to surface water flow ranges between a 0.1ML/d (1.1L/s) increase to a decrease of 0.6ML/d (7L/s) initially and then, at later time, ranges between a 0.1ML/d (1.1L/s) increase and a 0.2ML/d (2.3L/s) decrease.



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

* Synthetic monitoring location, which doesn't exist.

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Scale 1:15,000	

0 0.25 0.5
km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs (Wolgan River Swamp)

FIGURE: 4.51

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D043_PredictiveUncertainty_WRS.mxd
Reference © Department of Finance Services & Innovation 2018

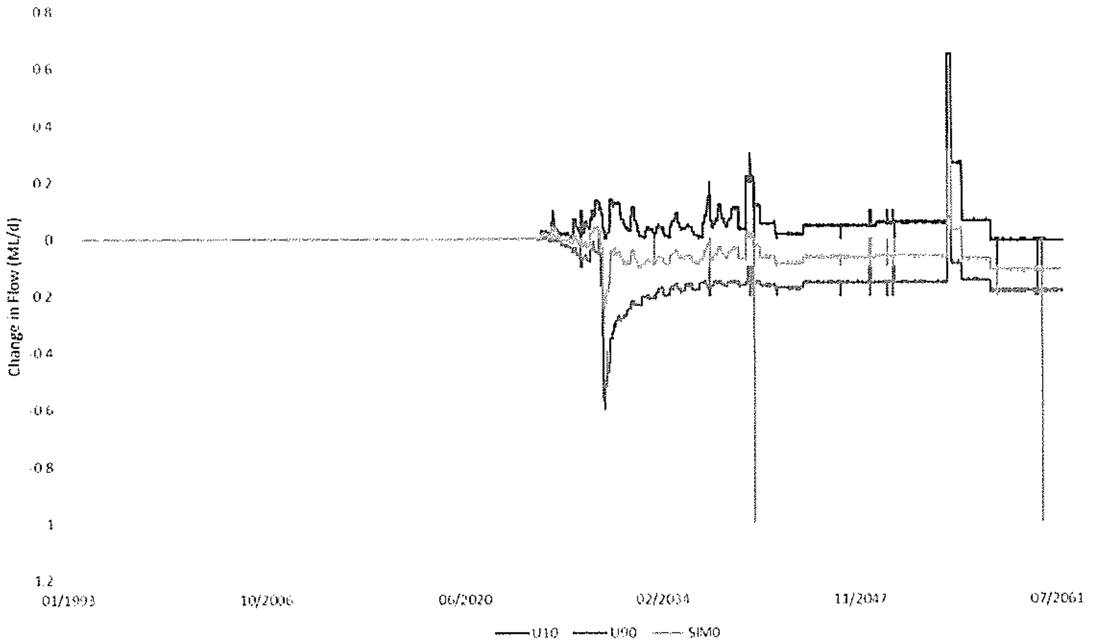


Figure 4.52: Predicted Change to Surface Water Flow (Wolgan River Swamp)

4.14.3.8 Twin Gully Swamp Catchment

Figure 4.53 presents selected hydrographs in the vicinity of Twin Gully Swamp.

From **Figure 4.53**, modelling indicates that a decline of up to 4m is expected in Twin Gully Swamp piezometers, TG1 and TG2 due to mining.

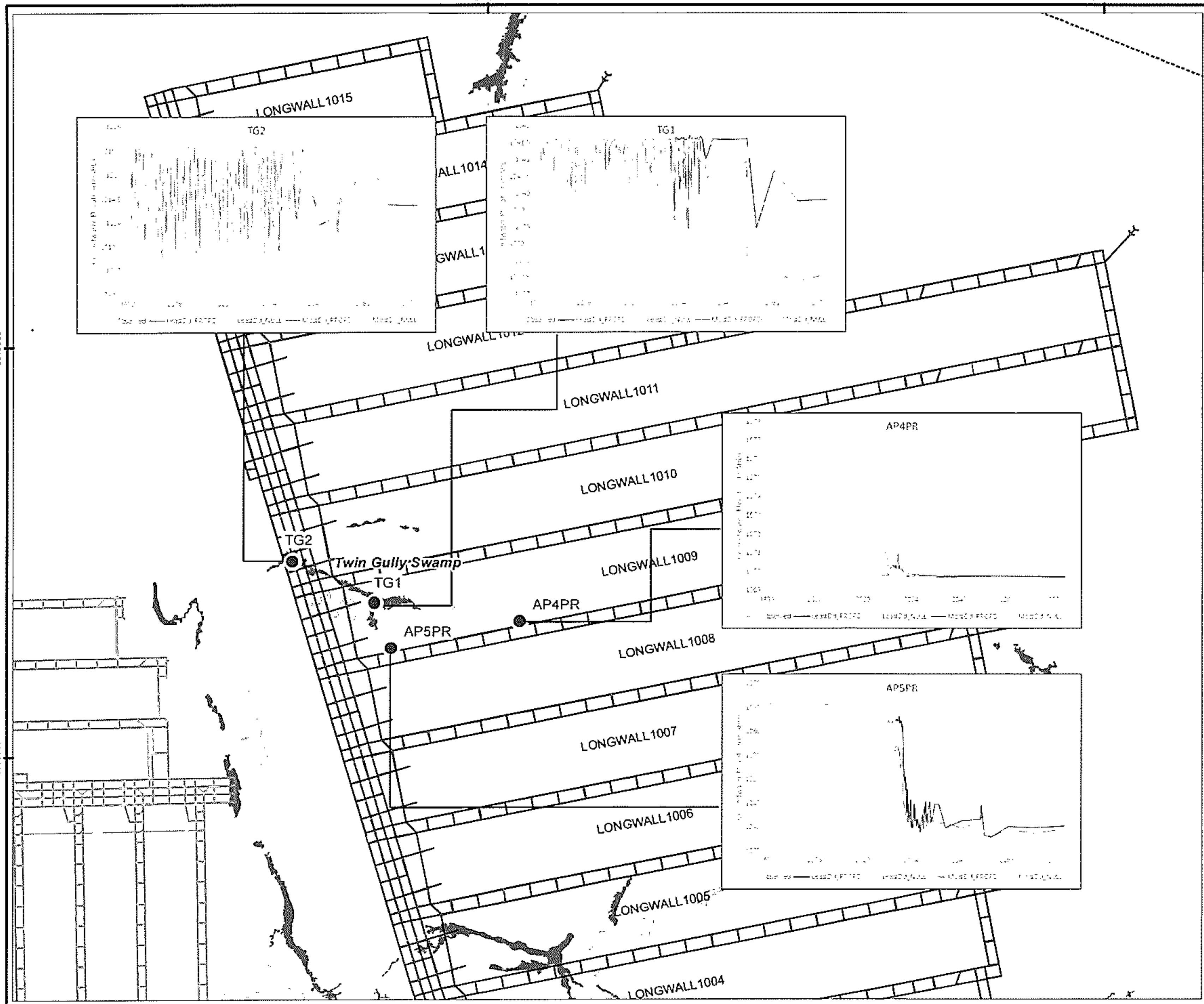
From **Figure 4.53**, both the 10th percentile and 90th percentile model results indicate a significant decline in groundwater elevation in piezometer AP5PR. The predicted change in piezometer AP4PR is also a decline. It is noted that the observed increase in groundwater elevation in AP4PR (blue line) is difficult to reconcile and may be erroneous.

Figure 4.54 presents the modelled change in surface water flow in Twin Gully Swamp due to the 1000 Panel Area. In **Figure 4.54**, the 10th percentile (most negative) and 90th percentile results (least negative) are both presented, as well as the simulation prediction based on the calibration parameter set (referred to as SIM0 in **Figure 4.54**).

From **Figure 4.54**, the modelled change in surface water flow is minor, being an increase initially of up to 0.1ML/d (1.2L/s) in the 10th percentile model results and a decrease of 0.02ML/d (0.2L/s) in the 90th percentile model results. From **Figure 4.54**, at later time, the change to surface water flow in the 10th percentile results is an increase of 0.01ML/d, which is negligible, and the change in flow in the 90th percentile results is a decrease of 0.05ML/d (0.6L/s).

As discussed above, the 'spike' in 2053 in **Figure 4.54**, is due to the transition from Stacked Drain cells being active to the 'full' profile of changes to hydraulic properties being applied.

Figure 4.55 presents the results from the COSFLOW model for the Twin Gully Swamp and are, again, similar in nature to that presented in **Figure 4.54**.



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1 | Date: 13-Sep-2019

Drawn By: JZ | Checked By: JB

Scale 1:25,000

0 0.5 1
km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs (Twin Gully Swamp)

FIGURE: 4.53

File Name N:\Projects\Centennial\Coal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_0026_PredictiveUncertainty_TwinGully.mxd
Reference © Department of Finance Services & Innovation 2018

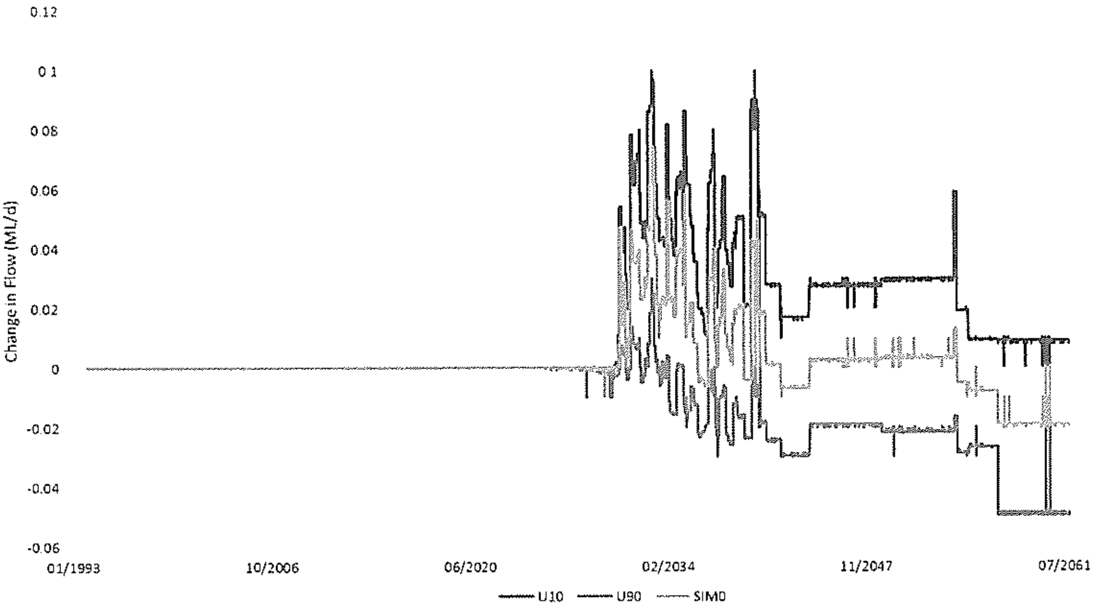


Figure 4.54: Predicted Change to Surface Water Flow (Twin Gully Swamp)

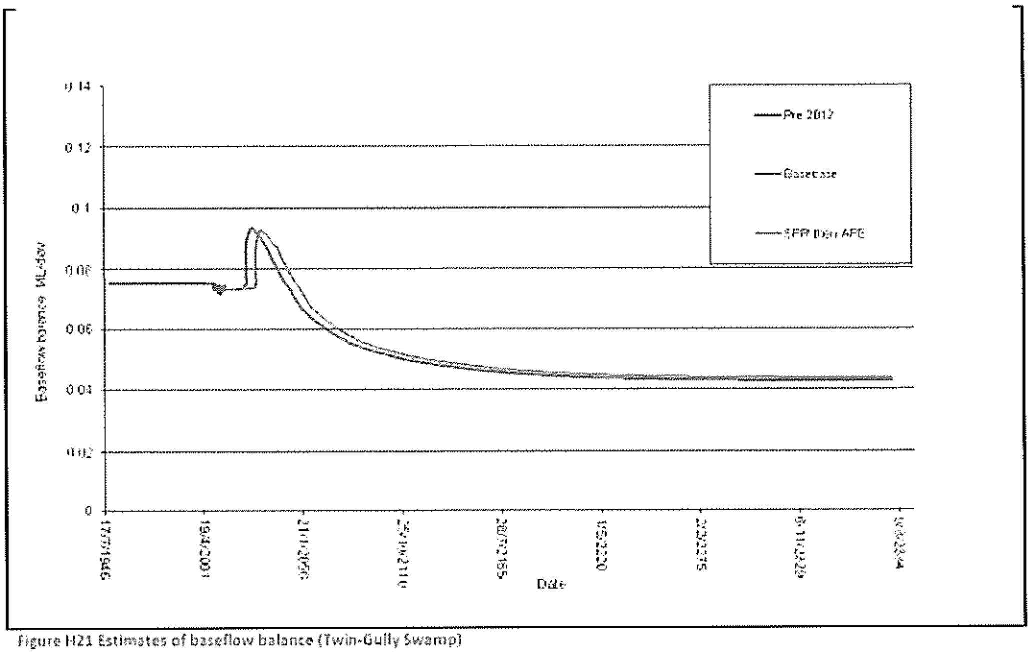


Figure H21 Estimates of baseflow balance (Twin-Gully Swamp)

Figure 4.55: Predicted Groundwater Contribution to Surface Water Flow: COSFLOW Model (after Figure H21 of CSIRO (2015)) – Twin Gully Swamp

4.14.3.9 Crocodile Swamp Catchment

Figure 4.56 presents the predicted change in groundwater elevation due to the Angus Place Mine Extension Project: Amended Project at the end of mine life in December 2053 (SP190). **Figure 4.57** presents the predicted change in groundwater elevation during the recovery phase in December 2091 (SP197).

From **Figure 4.56**, there is significant drawdown in hydrogeologic layers underlying Crocodile Swamp. There is also significant drawdown remaining by December 2091, as indicated in **Figure 4.57**.

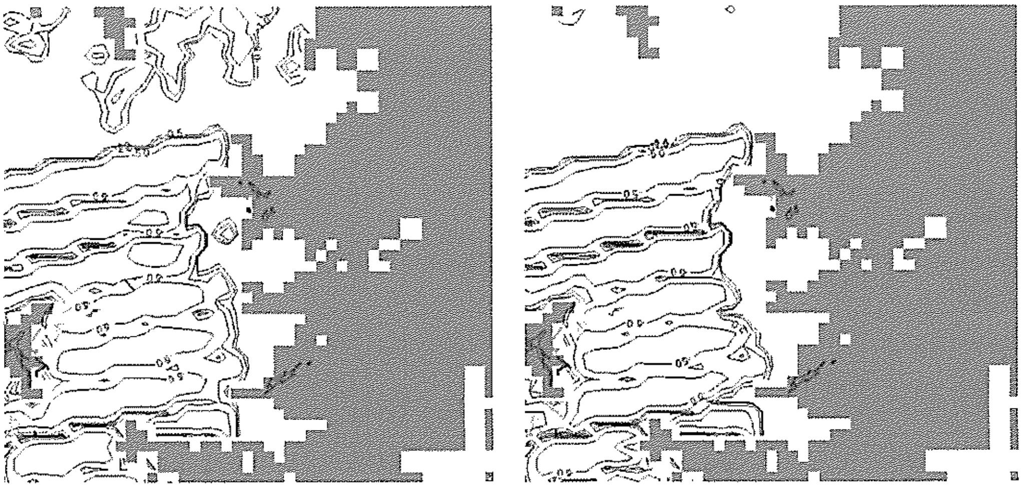
Figure 4.58 presents output hydrographs from vibrating wire piezometer AP1104 and standpipe piezometer AP1104, as well as output hydrographs from a synthetic swamp monitoring piezometer called CROC01.

From **Figure 4.58**, there is complete depressurisation indicated in vibrating wire piezometer AP1104 (to 170mBGL). From **Figure 4.58**, standpipe piezometer AP1104 is predicted to decline about 0.3m.

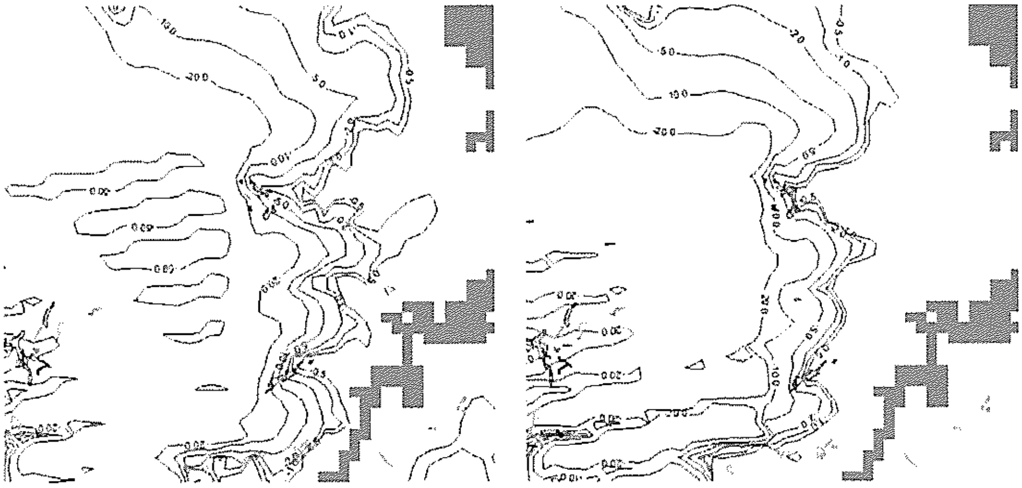
From **Figure 4.58**, the predicted change in the synthetic swamp monitoring piezometer CROC01 ranges between a decline of 0.5m and no change.

Figure 4.59 presents the modelled change in surface water flow due to the Proposal.

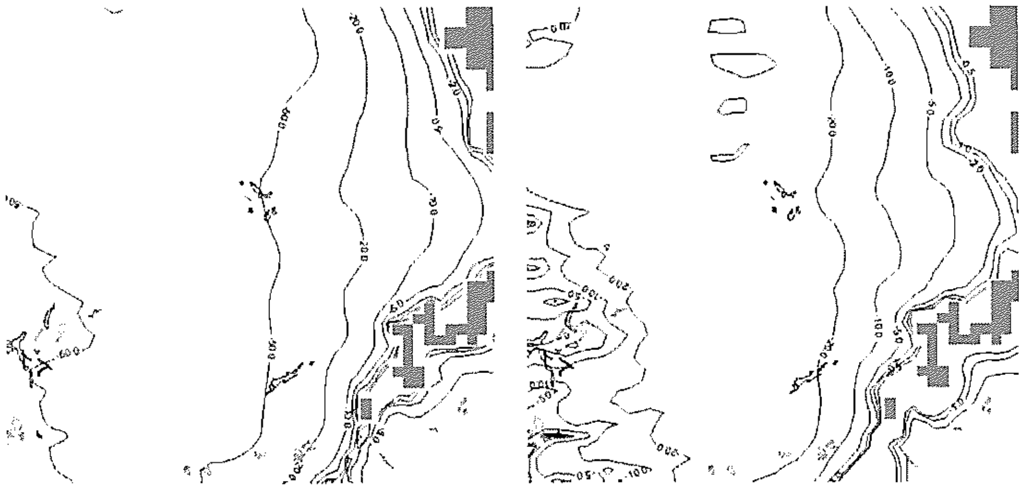
From **Figure 4.59**, the modelled change in surface water flow ranges between an increase of 0.01ML/d (0.1L/s) and a decrease of 0.002ML/d (0.02L/s) and is considered a negligible change.



Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)

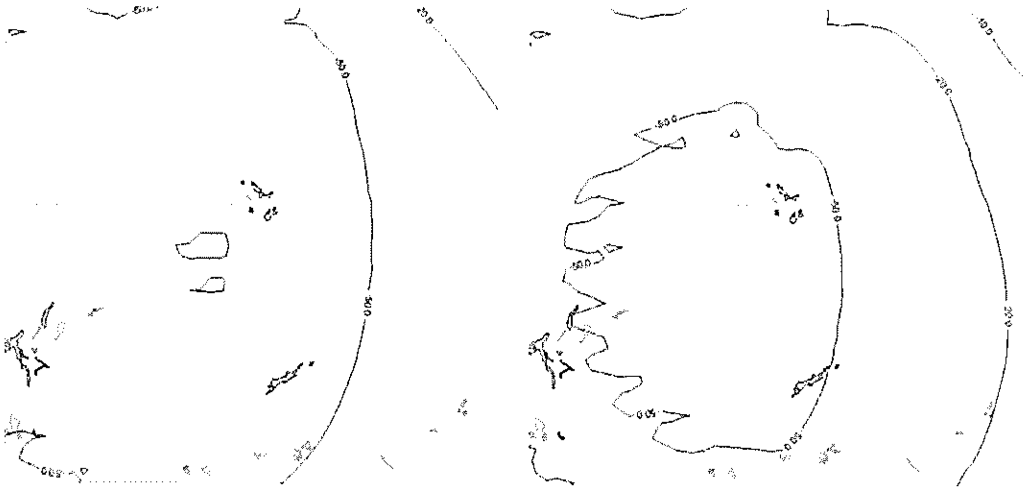


Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)

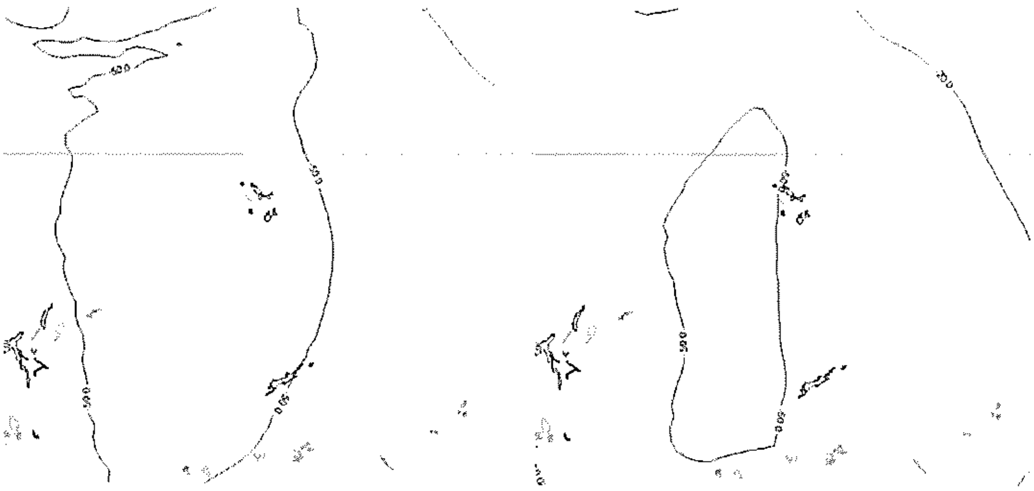


Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)

Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)



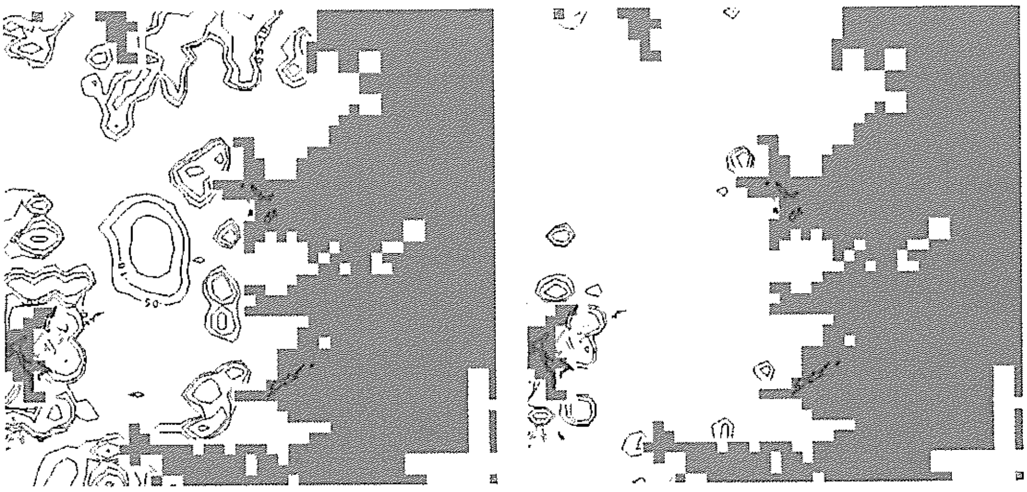
Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

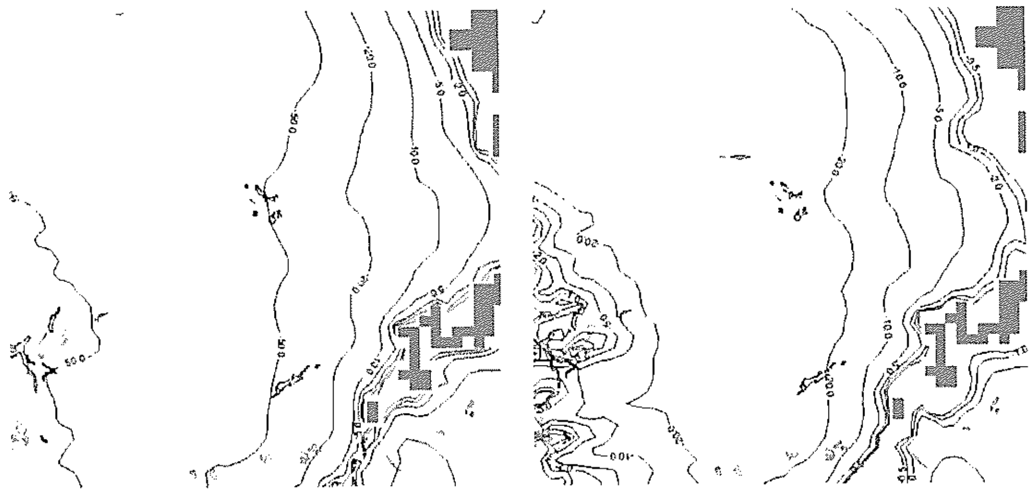
▩ - 'Pinched-out' cells - Drain (DRN) cells

Figure 4.56: Predicted Drawdown – End of Mine Life: 31 December 2053 (SP190) – Crocodile Swamp and Birds Rock Swamp



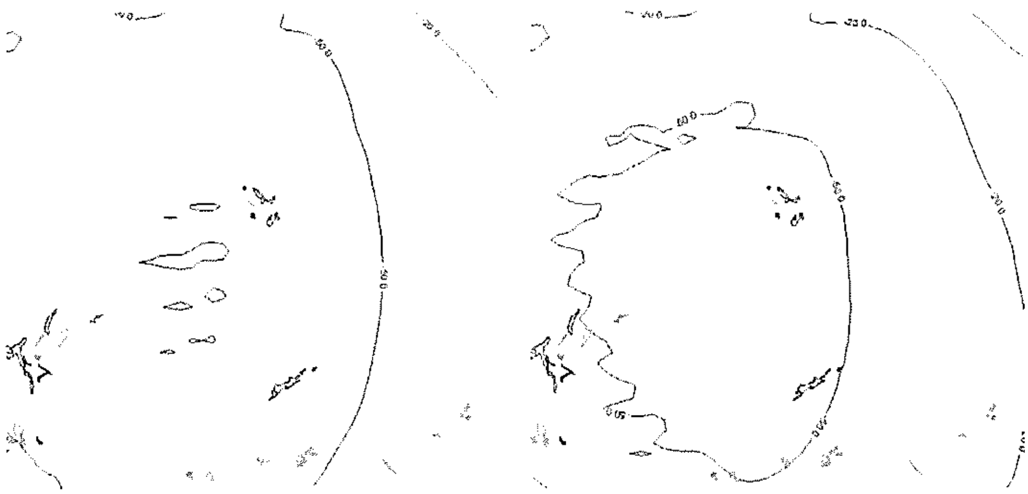
Layer 9 (Sandstone between YS4 and YS5) (L – 10th% Difference; R – 90th% Difference)

Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)

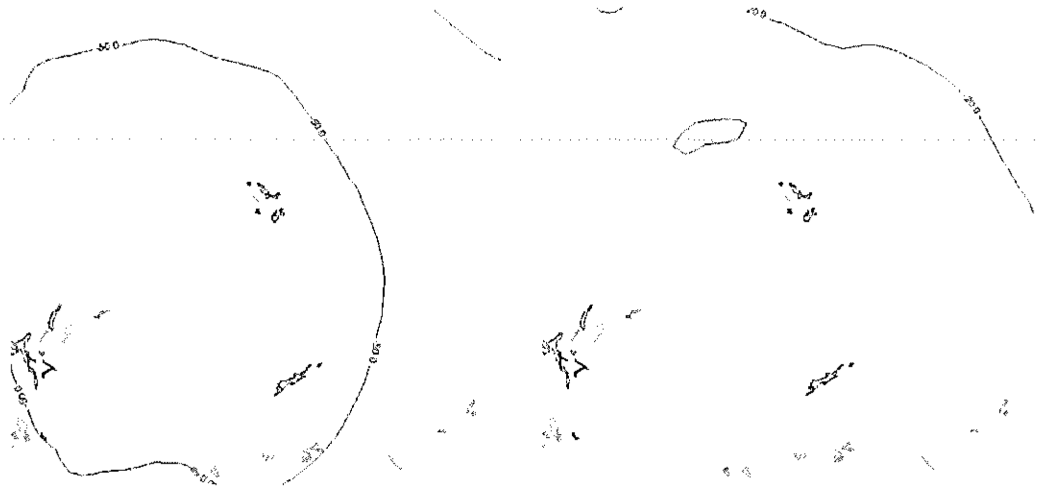


Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)

Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)



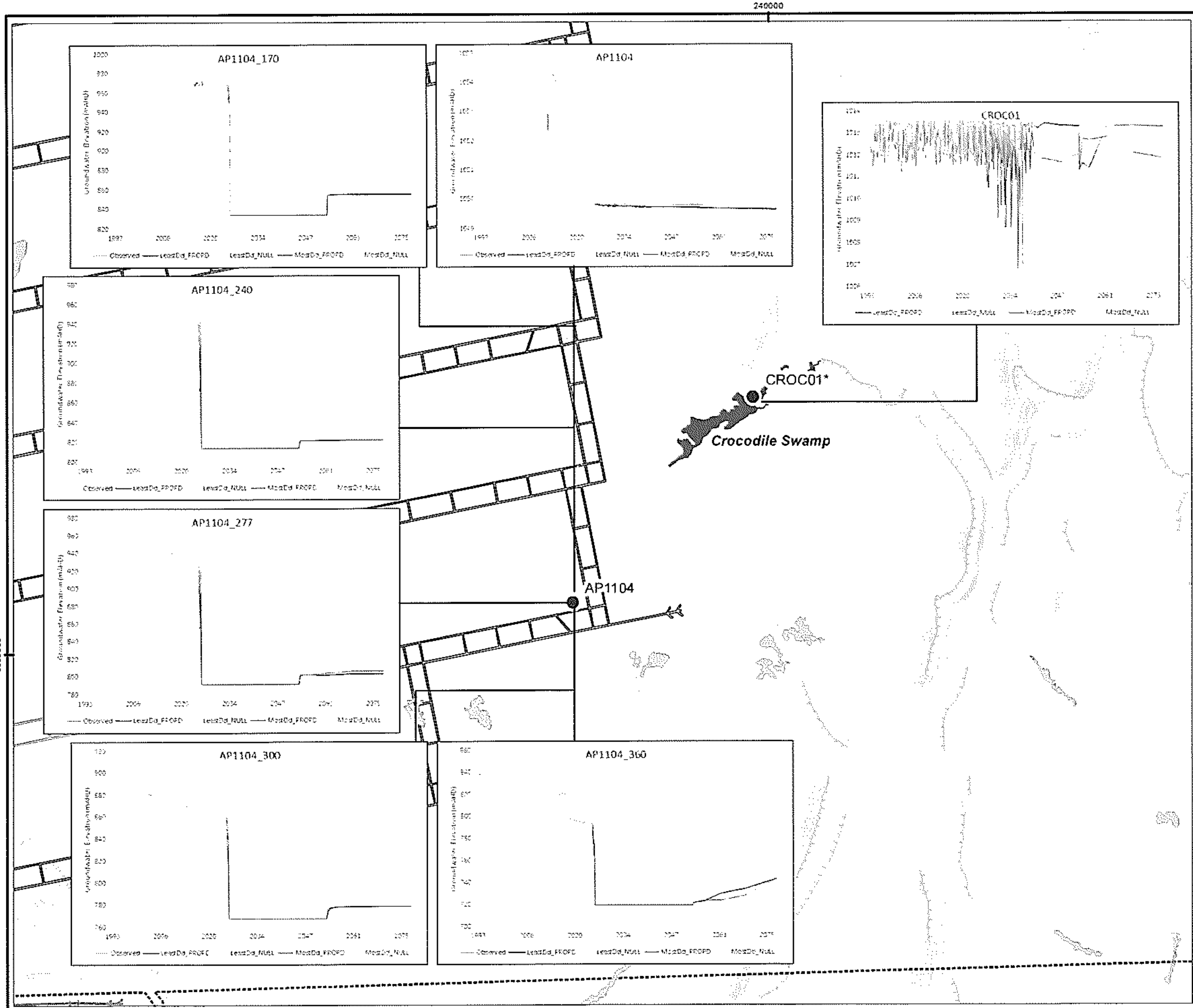
Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

- 'Pinched-out' cells - Drain (DRN) cells

Figure 4.57: Predicted Drawdown – Recovery Phase: 31 December 2091 (SP197) – Crocodile Swamp and Birds Rock Swamp



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

* Synthetic monitoring location, which doesn't exist.

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1 | Date: 13-Sep-2019

Drawn By: JZ | Checked By: JB

Scale 1:15,000

0 0.25 0.5 km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs (Crocodile Swamp)

FIGURE: 4.58

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GWR02Rev1_D044_PredictiveUncertainty_Crocodile.mxd
Reference © Department of Finance Services & Innovation 2018

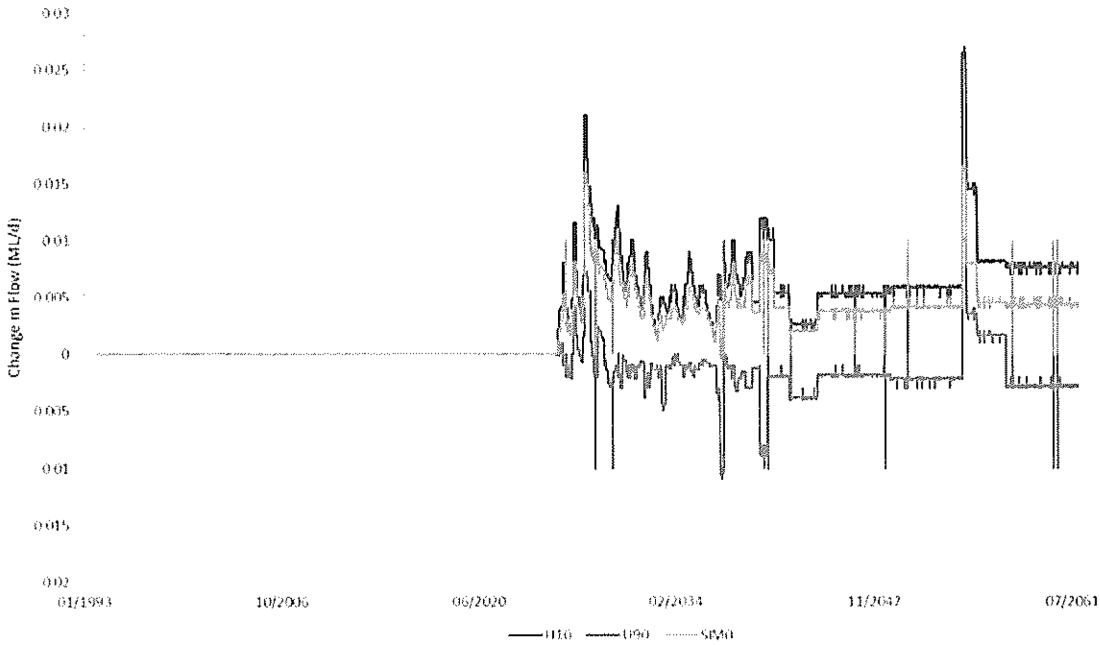


Figure 4.59: Predicted Change to Surface Water Flow (Crocodile Swamp)

4.14.3.10 Birds Rock Swamp Catchment

Figure 4.56 presents the predicted change in groundwater elevation in the vicinity of Birds Rock Swamp at the end of mine life in December 2053 (SP190). **Figure 4.57** presents the predicted change in groundwater elevation during the recovery phase in December 2091 (SP197).

From **Figure 4.56**, there is significant drawdown in hydrogeologic layers underlying Birds Rock Swamp as well as its catchment. **Figure 4.57** indicates that there is still a significant drawdown remaining by December 2091.

Figure 4.60 presents groundwater hydrographs in the vicinity of Birds Rock Swamp, including a synthetic swamp monitoring location called BIRDS01.

From **Figure 4.60**, there is a significant drawdown predicted in vibrating wire piezometer AP1102 as well as standpipe piezometer AP1102. Modelling indicates that the predicted drawdown in synthetic swamp monitoring location BIRDS01 ranges between 0.1m and 1.2m.

Figure 4.61 presents the modelled change in surface water flow due to the Proposal.

From **Figure 4.61**, the modelled change ranges between a decrease of 0.005ML/d (0.06L/s) and a decrease of 0.05ML/d (0.6L/s).

Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

* Synthetic monitoring location, which doesn't exist.

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Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 13-Sep-2019
Drawn By: JZ	Checked By: JB

Scale 1:15,000

0 0.25 0.5 km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs (Birds Rock Swamp)

FIGURE: 4.60

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_0045_PredictiveUncertainty_BirdsRock.mxd
Reference © Department of Finance Services & Innovation 2018

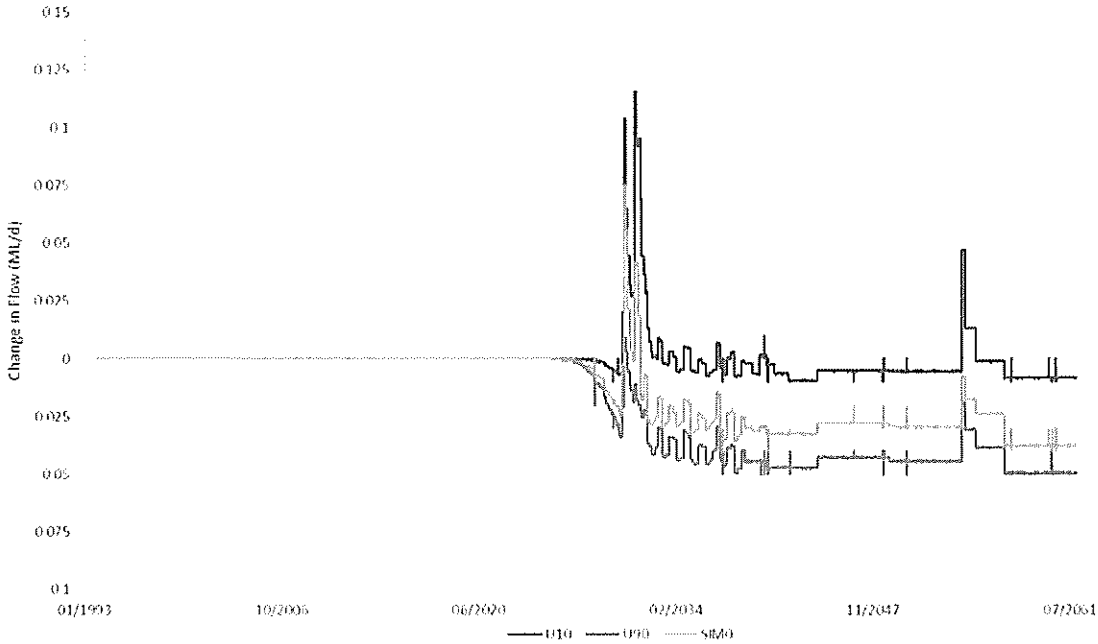


Figure 4.61: Predicted Change to Surface Water Flow (Birds Rock Swamp)

4.14.3.11 Trail Six Swamp Catchment

Figure 4.62 presents the 10th percentile (most negative) drawdown and 90th percentile (least negative) drawdown in groundwater elevation at the end of mine life at 31 December 2053 (SP190) and **Figure 4.63** presents the equivalent results during the recovery phase at 31 December 2091 (SP197).

From **Figure 4.62**, there is drawdown of 10m to 20m in the Banks Wall Sandstone (Layer 13) in the 10th percentile model results on either side of the Trail Six Swamp. In the 90th percentile model results the 'drawdown' is 2m to 10m. From **Figure 4.63** modelled 'drawdown' remains at 10m to 20m and 2m to 10m residual drawdown respectively after 40 years of recovery.

Model results imply that a large decrease in groundwater level within Trail Six Swamp is expected due to mining.

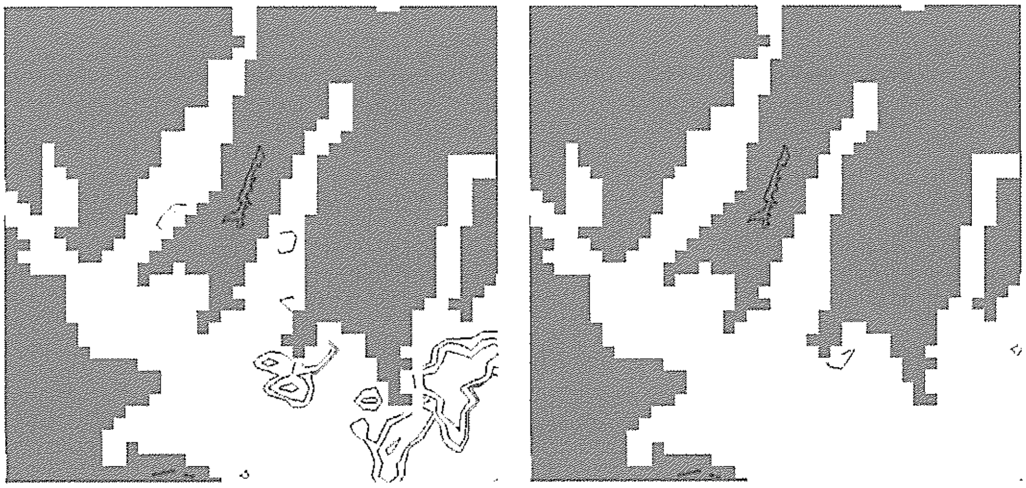
Figure 4.64 presents selected hydrographs in the vicinity of Trail Six Swamp.

From **Figure 4.64**, the modelled decline in groundwater level in piezometer XS1 is between 1m and 2m in the 90th percentile model results and is up to 10m in the 10th percentile model results.

From **Figure 4.64**, the modelled significant decline in groundwater elevation in the vibrating wire piezometer site APR1107 is consistent in the 10th percentile and 90th percentile model results.

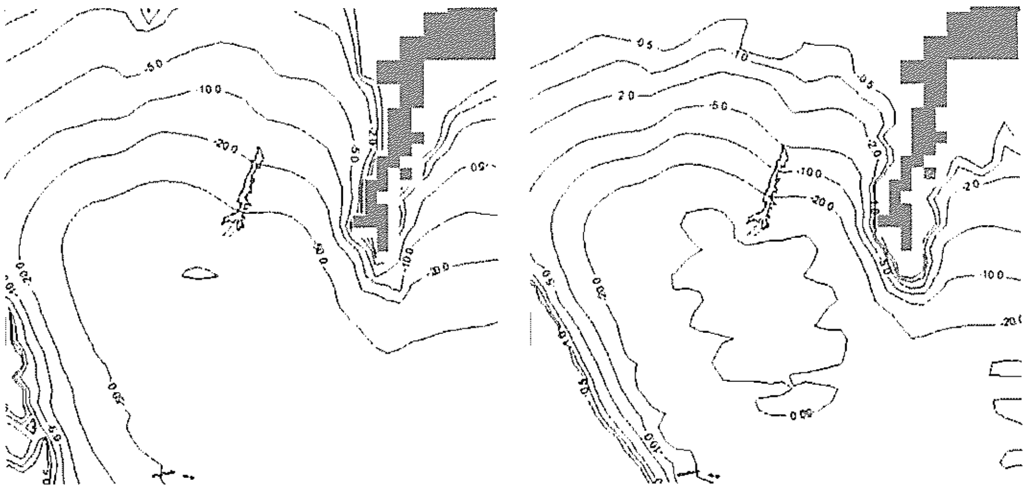
Figure 4.65 presents the modelled change in surface water flow in Trail Six Swamp due to mining of the 1000 Panel Area.

From **Figure 4.65**, the modelled change in surface water flow is minor, with an increase in flow in the 10th percentile results of up to 0.1ML/d (1.2L/s) in early time and a 0.02ML/d (0.2L/s) decrease in early time in the 90th percentile results. From **Figure 4.65**, at later time, the change in the 10th percentile results is less than 0.01ML/d, so is negligible, and is a decline of 0.06ML/d (0.7L/s) in the 90th percentile results. It is noted that there was no output from the COSFLOW model for Trail Six Swamp with which to compare the current groundwater model.

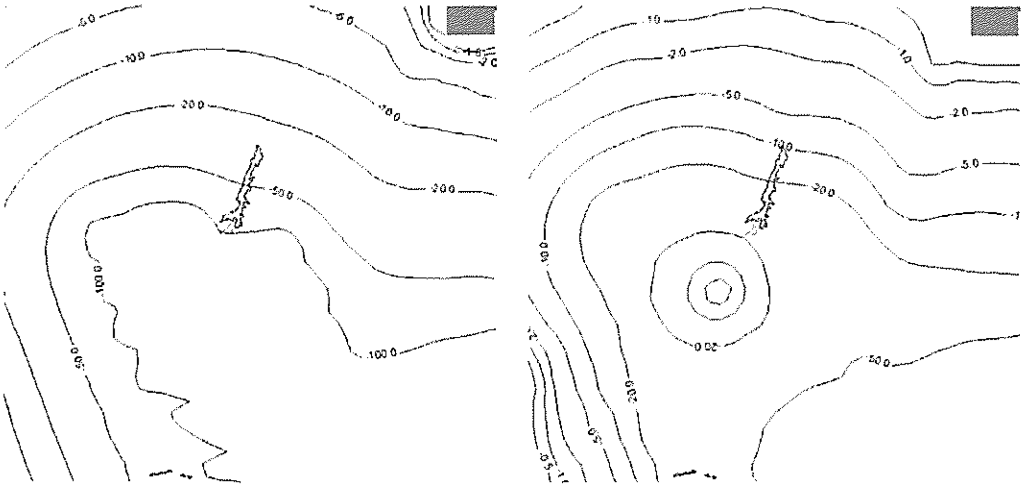


Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)

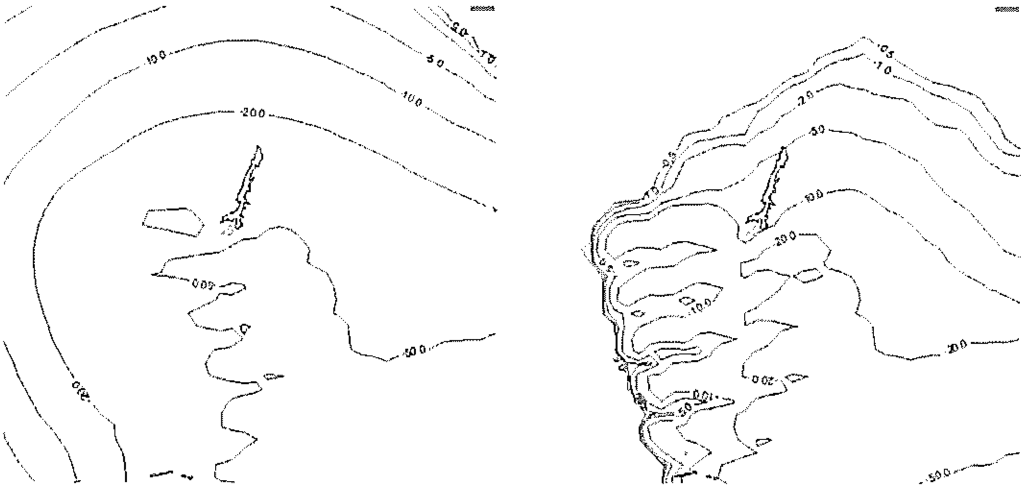
Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)



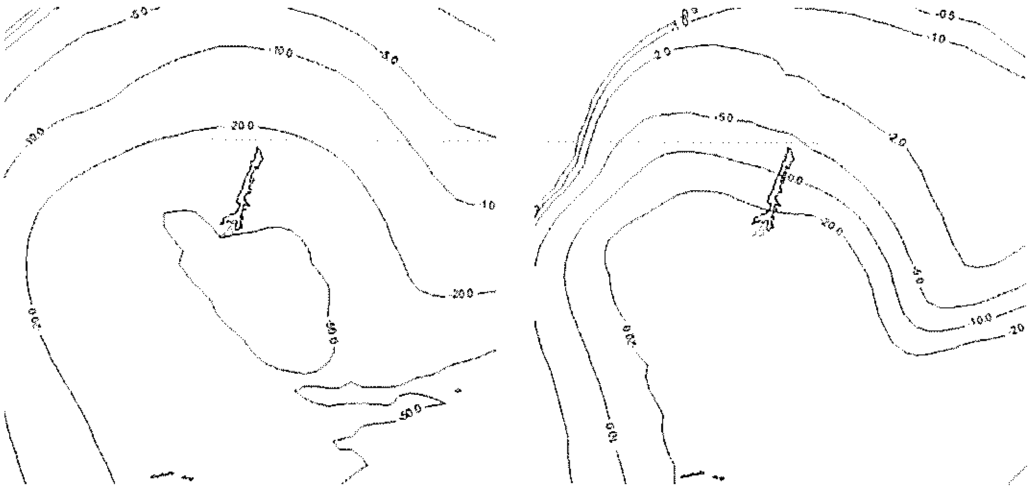
Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)



Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)



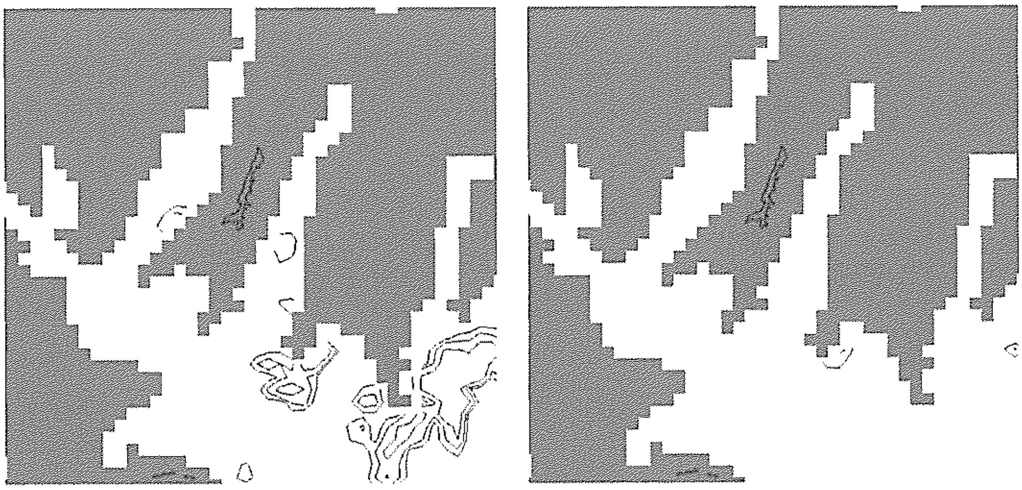
Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

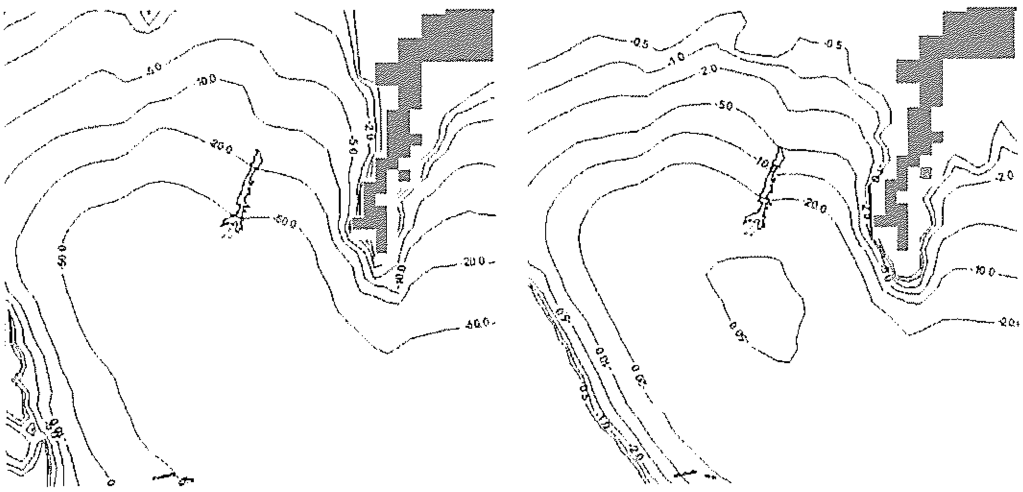
- 'Pinched-out' cells - Drain (DRN) cells

Figure 4.62: Predicted Drawdown – End of Mine Life: 31 December 2053 (SP190) – Trail Six Swamp

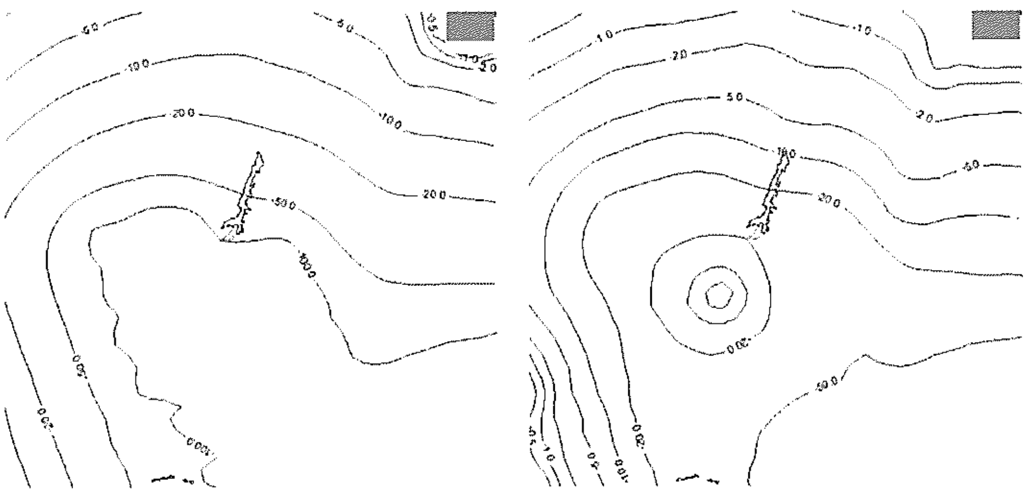


Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)

Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)

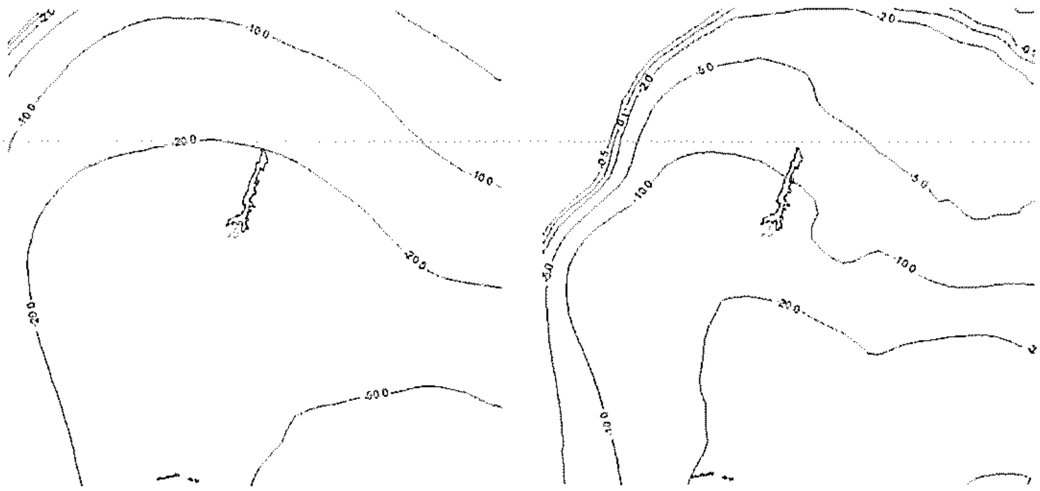


Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)



Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)

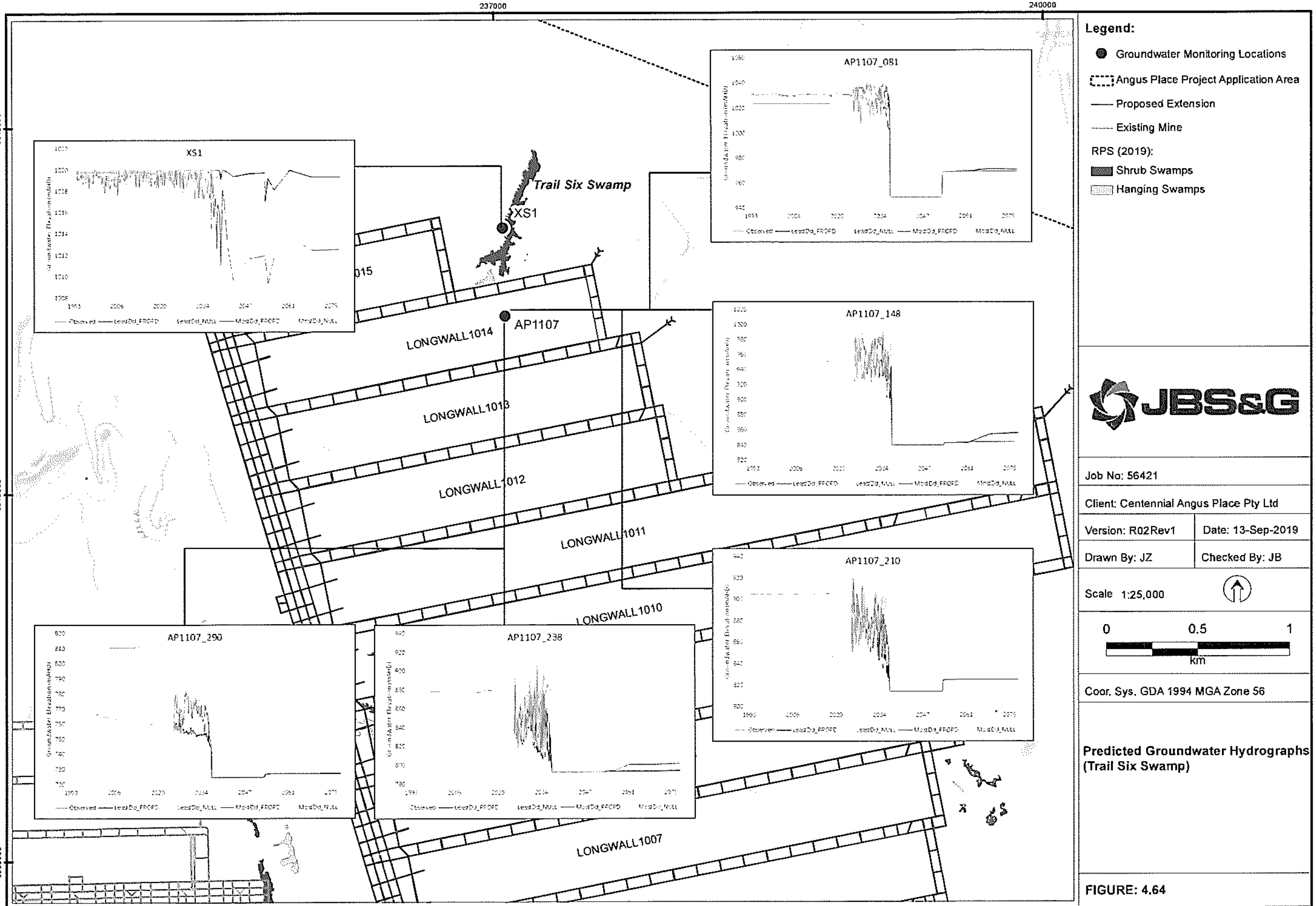
Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



Layer 24 (Lithgow Seam) (L – most Drawdown; R – Least Drawdown)

- 'Pinched-out' cells - Drain (DRN) cells

Figure 4.63: Predicted Drawdown – Recovery Phase: 31 December 2091 (SP197) – Trail Six Swamp



Predicted Groundwater Hydrographs (Trail Six Swamp)

FIGURE: 4.64

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D027_PredictiveUncertainty_TrailSix.mxd
Reference © Department of Finance Services & Innovation 2018

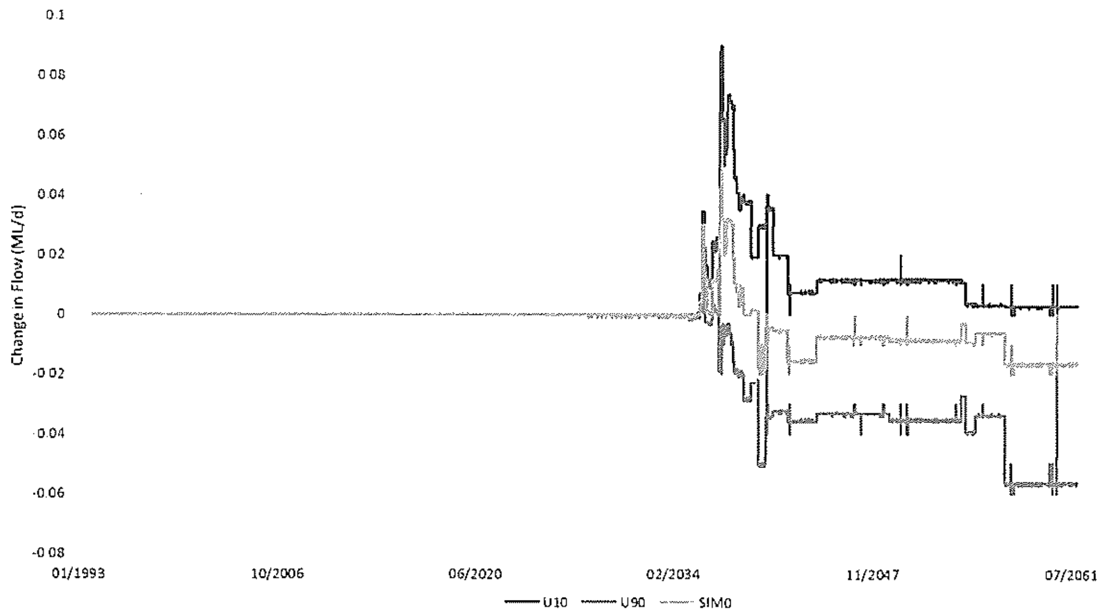


Figure 4.65: Predicted Change to Surface Water Flow (Trail Six Swamp)

4.14.3.12 Mine Dewatering Rates

Angus Place Colliery (300, 700, 800, 900 and 1000 Panel Areas)

Figure 4.66 presents the predicted mine dewatering rate at Angus Place Colliery (300, 700, 800, 900 and 1000 Panel Areas) for the Proposed Case and for the Null Case.

It is noted that predictive uncertainty results are not presented with respect to mine dewatering rates. Model output presented in **Figure 4.66** is from the Proposed and Null Case simulation using calibrated parameter values.

It is further noted that a four-point moving average was applied to model output in **Figure 4.66** during quarterly stress periods. The moving average was applied to account for the overestimation of mine dewatering rate associated with 'instantaneous' dewatering using a DRN boundary condition in MODFLOW and is considered appropriate.

The modelled mine dewatering rate from the COSFLOW model is also presented in **Figure 4.66.** It is noted that the results from the COSFLOW model will be slightly different to due minor changes in the mine plan, different model parameters and a different temporal discretisation.

From **Figure 4.66**, the predicted mine dewatering rate is expected to reach approximately 26ML/d at maximum in 2025 and stabilise at about 20ML/d. It is highlighted that the large increase in **Figure 4.66** is a conservative prediction and the approximate 20ML/d increase in mine inflow rate upon commencement of mining of the 1000 Panel Area in 2025 is without precedence in underground mining. The large, almost instantaneous, increase reflects the Stacked Drain assumption in the model becoming activated in an area where there had been limited drawdown previously. Accordingly, the magnitude and the rate of increase is expected to be overpredicted.

From **Figure 4.66**, there is a difference in predicted peak dewatering rate between the updated groundwater model and COSFLOW. In **Figure 4.66**, the updated peak rate at Angus Place Colliery (including 1000 Panel Area) is 26ML/d in 2025, whereas the predicted peak rate from COSFLOW is 36ML/d in 2032.

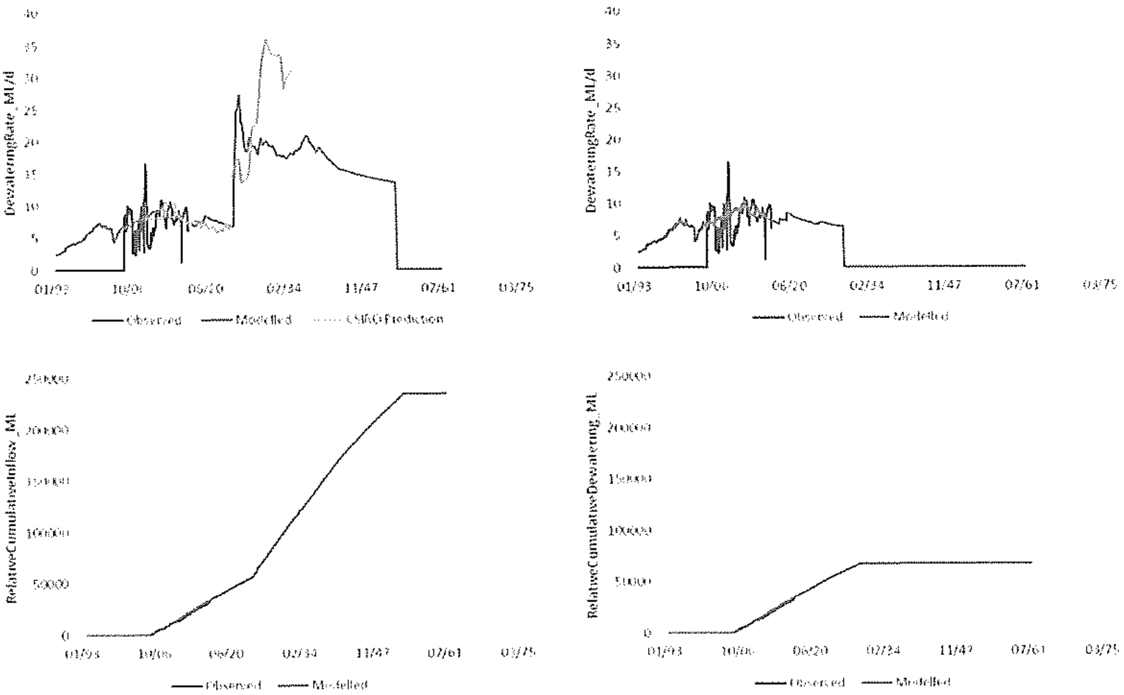


Figure 4.66: Predicted Mine Dewatering Rate – Angus Place Colliery (300, 700, 800, 900 and 1000 Panel Area) (L – Proposed Case; R – Null Case)

Springvale Mine

Figure 4.67 presents the predicted dewatering rate at Springvale Mine for the Proposed Case. The modelled dewatering rate from the COSFLOW model is also presented in **Figure 4.67**.

From **Figure 4.67**, the modelled dewatering rate at Springvale is predicted to increase to 30ML/d at the end of mining at Springvale. As noted in **Section 4.14.2**, there will be a hiatus in pumping at Springvale between April 2025 and December 2017, followed by a resumption of dewatering to maintain the groundwater elevation at 810mAHD.

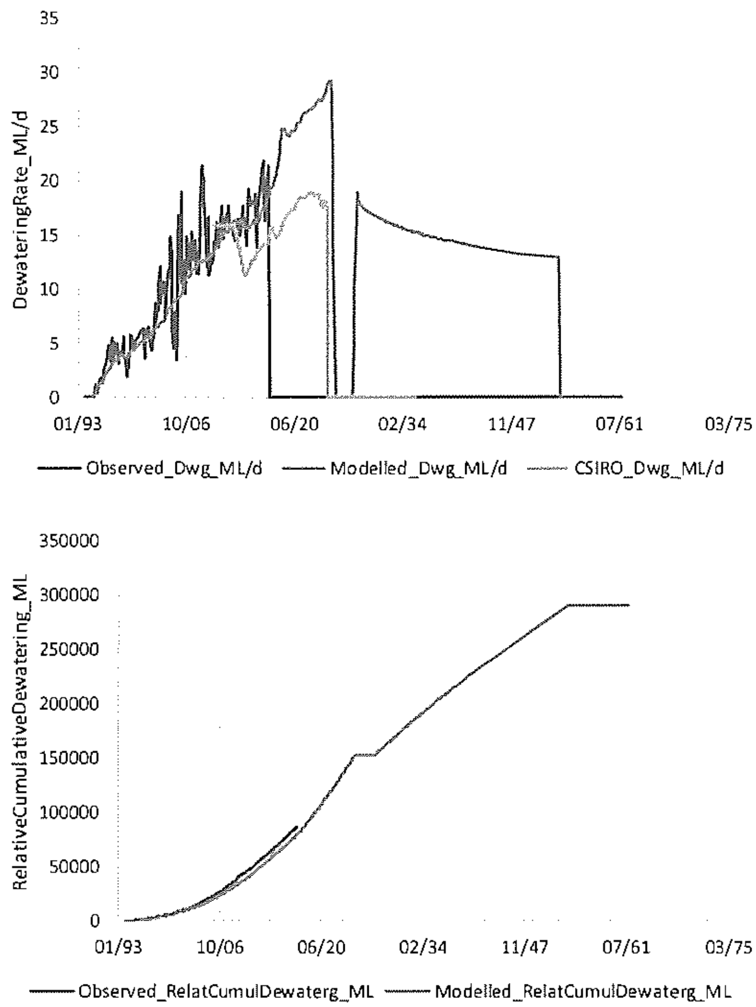


Figure 4.67: Predicted Mine Dewatering Rate – Springvale Mine (Proposed Case)

Combined Mine Dewatering Rate

The combined mine dewatering rate, including mine dewatering from Springvale Mine, is presented in **Figure 4.68**. The previous data for combined mine dewatering rate derived from COSFLOW model output is also presented in **Figure 4.68**, for the purpose of comparison.

From **Figure 4.68**, there is a difference between the previous results (COSFLOW) and the current results (UpdatedTotal), with the updated total being higher; however, the general shape is equivalent. As noted in **Section 4.14.2**, it is assumed in the groundwater model that pumping at Springvale Mine is disabled for the period April 2025 (SP128) through December 2027 (SP138).

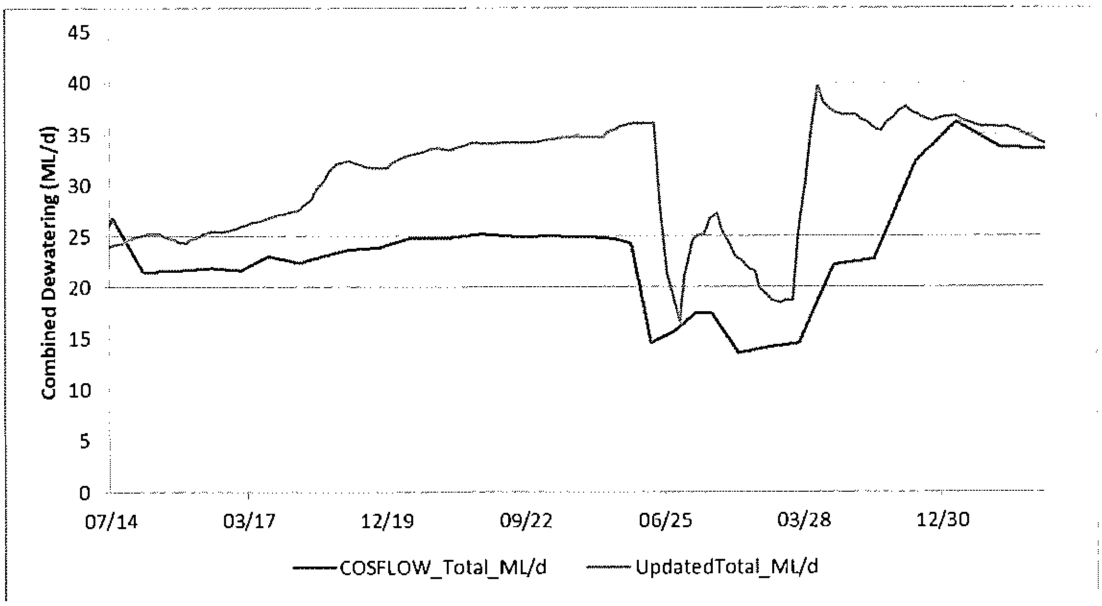


Figure 4.68: Predicted Combined Mine Dewatering Rate – Angus Place Colliery and Springvale Mine

4.15 Cumulative Impact Considerations

The approach adopted to Cumulative Impact Assessment in the numerical groundwater model has been to:

- develop a Proposed Case based on extension of existing mining operations at Angus Place Colliery into the 1000 Panel Area.
  - the Proposed Case includes the extension of operation of Springvale Mine, with respect to maintaining Springvale Mine in a dewatered state through to 2053.
- develop a Null Case based on cessation of mining at Angus Place Colliery and the adjacent operation at Springvale at the end of 2029.
  - Both Angus Place Colliery and Springvale Mine are existing and approved operations.
- incorporate the potential influence from Clarence Colliery on proposed mining at Angus Place Colliery, although at sufficient distance from Angus Place Colliery to not be significant.

Whilst complicated, the adopted approach takes into account the potential changes to groundwater contribution to surface water and exchange between groundwater sources due to surrounding existing and approved operations before assessing the proposed changes due to the extension of mining at Angus Place Colliery into the 1000 Panel Area.

It is highlighted that the adopted approach assumes all changes to groundwater contribution to surface water and changes to exchange between groundwater sources are due to the Amended Project, inclusive of changes associated with the extension of duration of dewatering at Springvale Mine.

4.16 Climate Change Scenarios

4.16.1 Approach to Predictive Uncertainty

The approach to predictive uncertainty for the Climate Change scenarios is consistent with the approach for the median rainfall/evapotranspiration presented in **Section 4.14.1**.

The same parameter files, .PAR, that we used for the median rainfall/evapotranspiration simulations were adopted for the Climate Change scenarios.

4.16.2 Model Setup

The Proposed Case and Null Case assumptions presented in **Section 4.14.2** were not altered for the Climate Change scenarios. The only change to Proposed Case and Null Case simulations was that the rainfall and evapotranspiration datasets were updated with a High Rainfall and Low Rainfall version in place of the median version.

4.16.3 Prediction Results

4.16.3.1 High Rainfall Scenario

The model control file associated with the High Rainfall prediction scenario is:

- R02RevB_UNC210_01a.gwv

<u>Wolgan River Swamp Upper Swamp</u>

Figure 4.69 presents the 10th percentile (most negative) and 90th percentile (least negative) calculated drawdown in the vicinity of Wolgan River Swamp Upper Swamp at 31 December 20S3 (SP190), which is the end of mine life.

Figure 4.70 presents the 10th percentile (most negative) and 90th percentile (least negative) calculated drawdown during the recovery phase at 31 December 2091 (SP197).

From **Figure 4.69** and **Figure 4.70**, the modelled drawdown in the vicinity of Wolgan River Swamp Upper Swamp is less than 0.Sm in the Banks Wall Sandstone, which underlies the swamp.

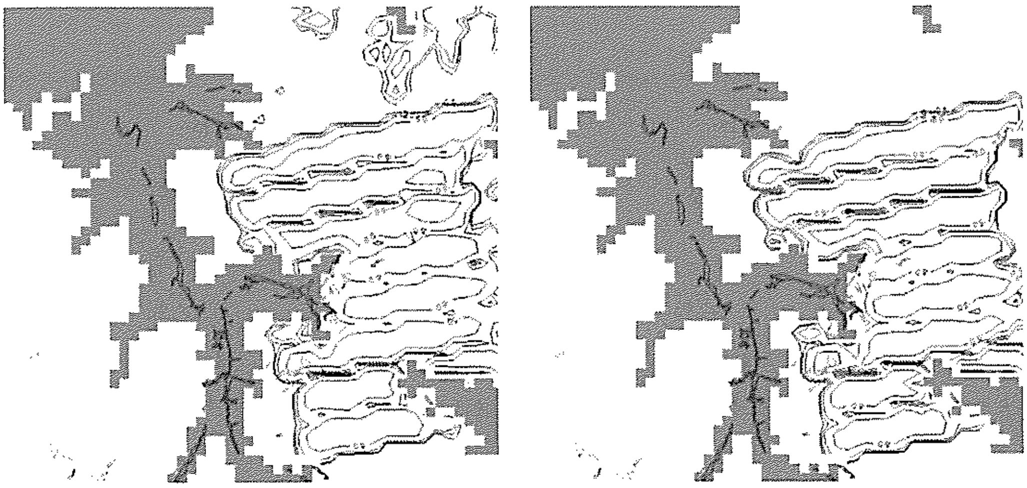
From **Figure 4.69** and **Figure 4.70**, the calculated drawdown contours in the High Rainfall scenario are very similar to that presented for the median rainfall conditions in **Figure 4.44** and **Figure 4.45**.

Figure 4.71 presents groundwater hydrographs in the vicinity of Wolgan River Swamp Upper Swamp. As noted in **Section 4.14.3.5**, a swamp monitoring piezometer in Wolgan River Swamp Upper Swamp is not currently installed, therefore a synthetic location was introduced instead.

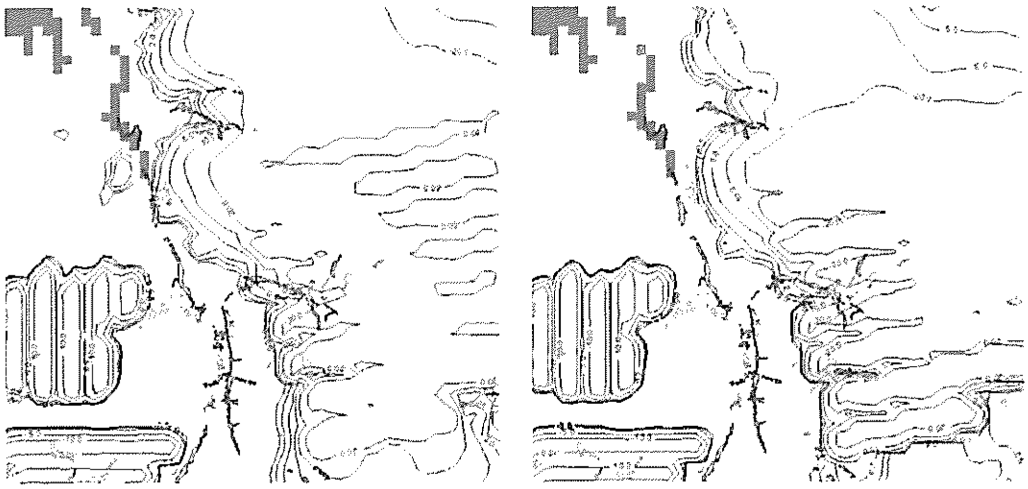
From **Figure 4.71**, as per the findings presented in **Section 4.14.3.5**, there is negligible difference between the Proposed and Null Case modelled groundwater elevation in Wolgan River Swamp Upper Swamp.

Figure 4.72 presents the change to modelled groundwater contribution to surface water flow in Wolgan River Swamp Upper Swamp.

From **Figure 4.72**, the modelled change ranges from a decline of 0.1ML/d to a decline of 0.45ML/d initially, which transitions rapidly to an increase 0.05ML/d and a negligible decline. It is noted that the resultants presented in **Figure 4.72** are very similar to the results presented in **Section 4.14.3.5** with respect to median rainfall conditions.

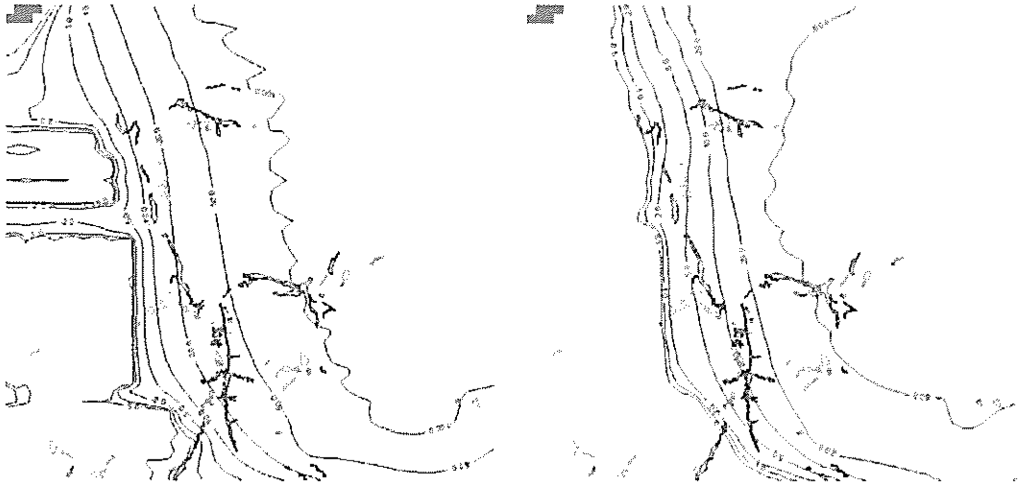


Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)



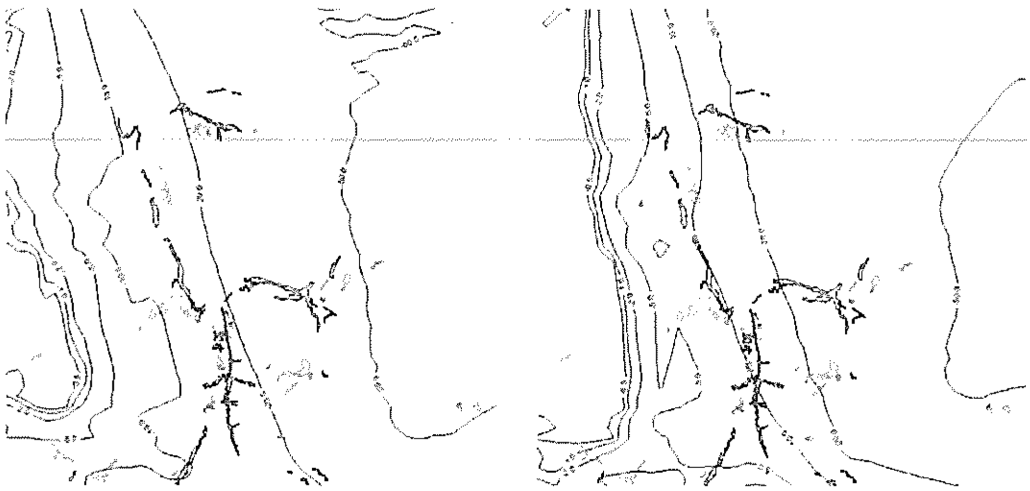
Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)

Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)



Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)

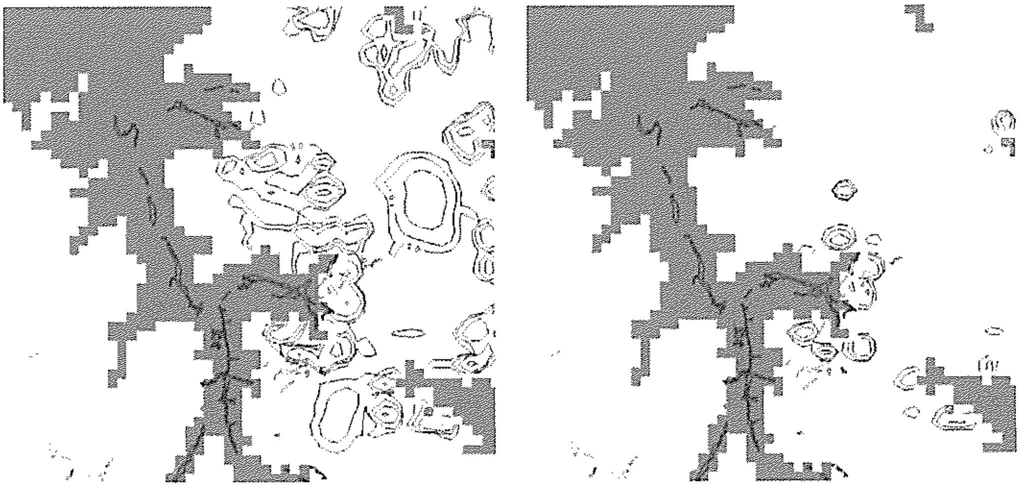
Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



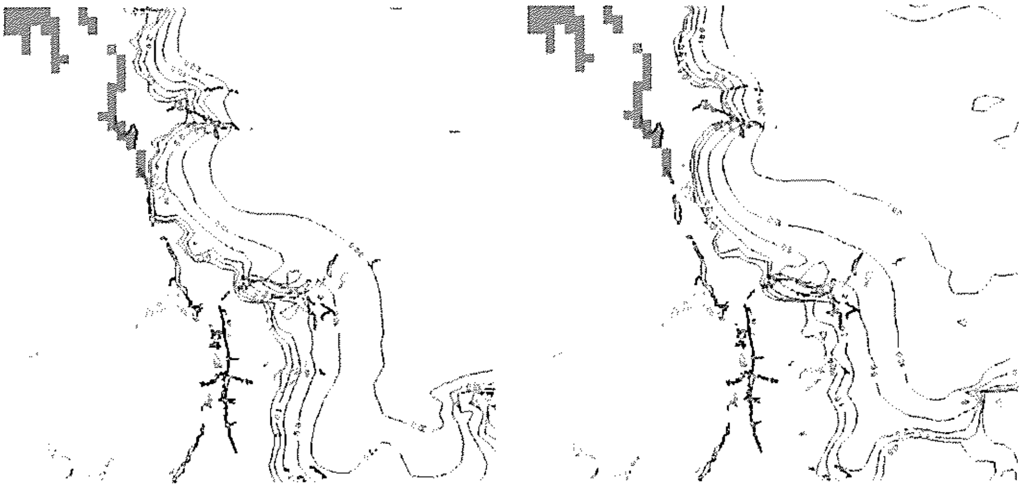
Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

- 'Pinched-out' cells - Drain (DRN) cells

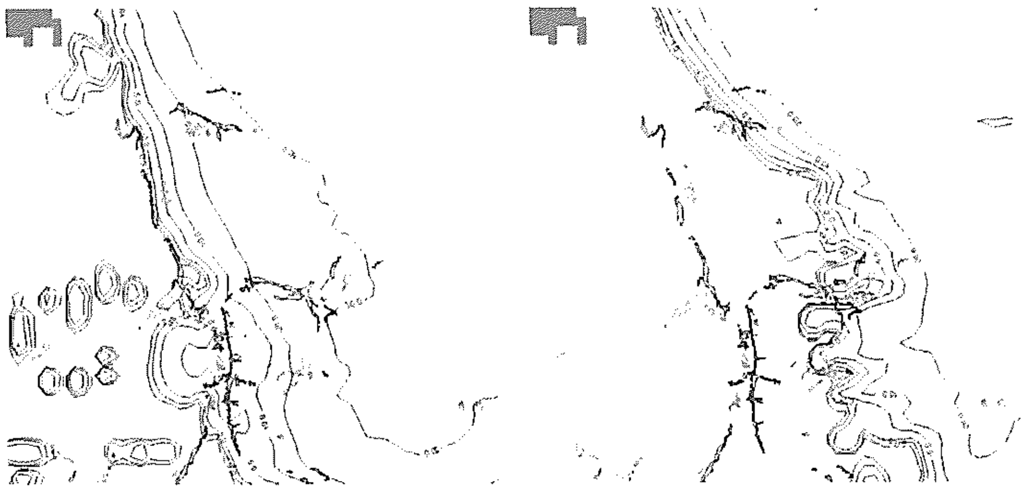
Figure 4.69: Predicted Drawdown (High Rainfall Scenario) – End of Mine Life: 31 December 2053 (SP190) – Wolgan River Swamp Upper, Tri-Star, Wolgan River and Twin Gully Swamps



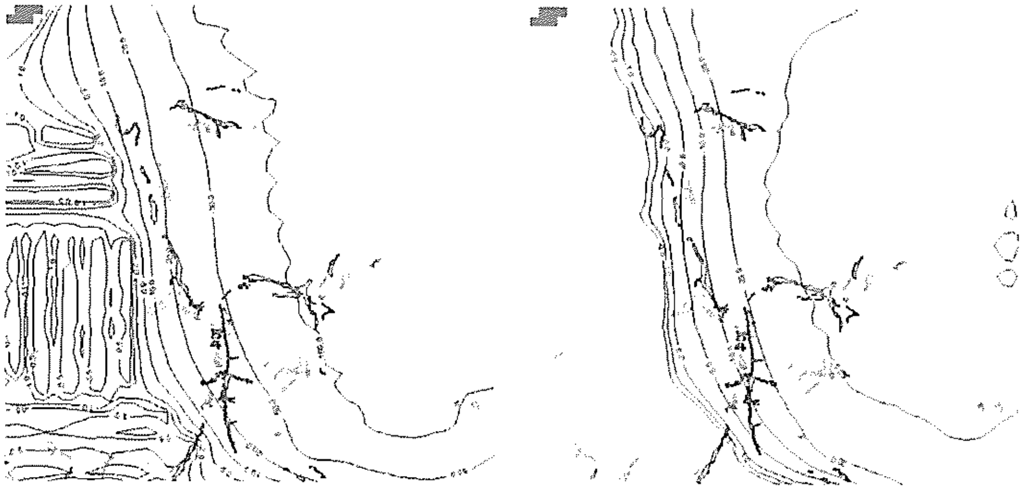
Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)



Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)

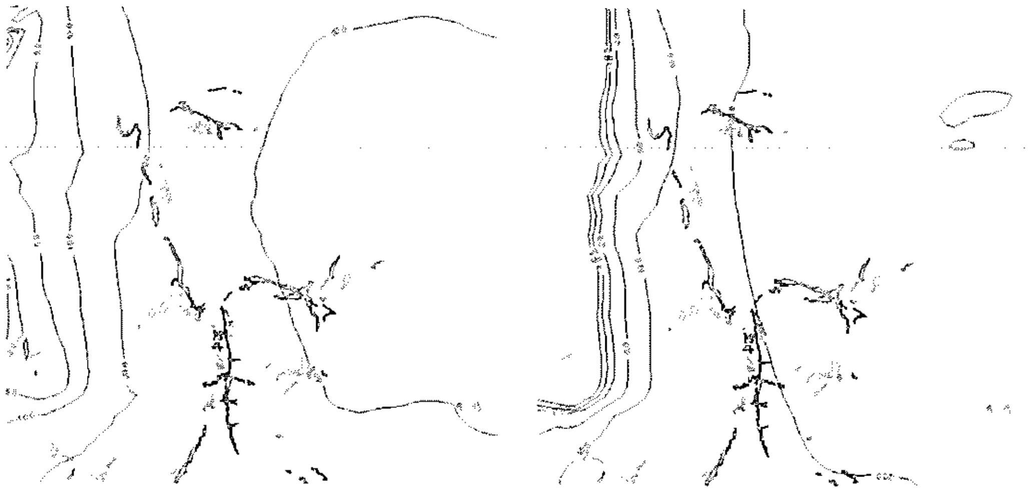


Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)



Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)

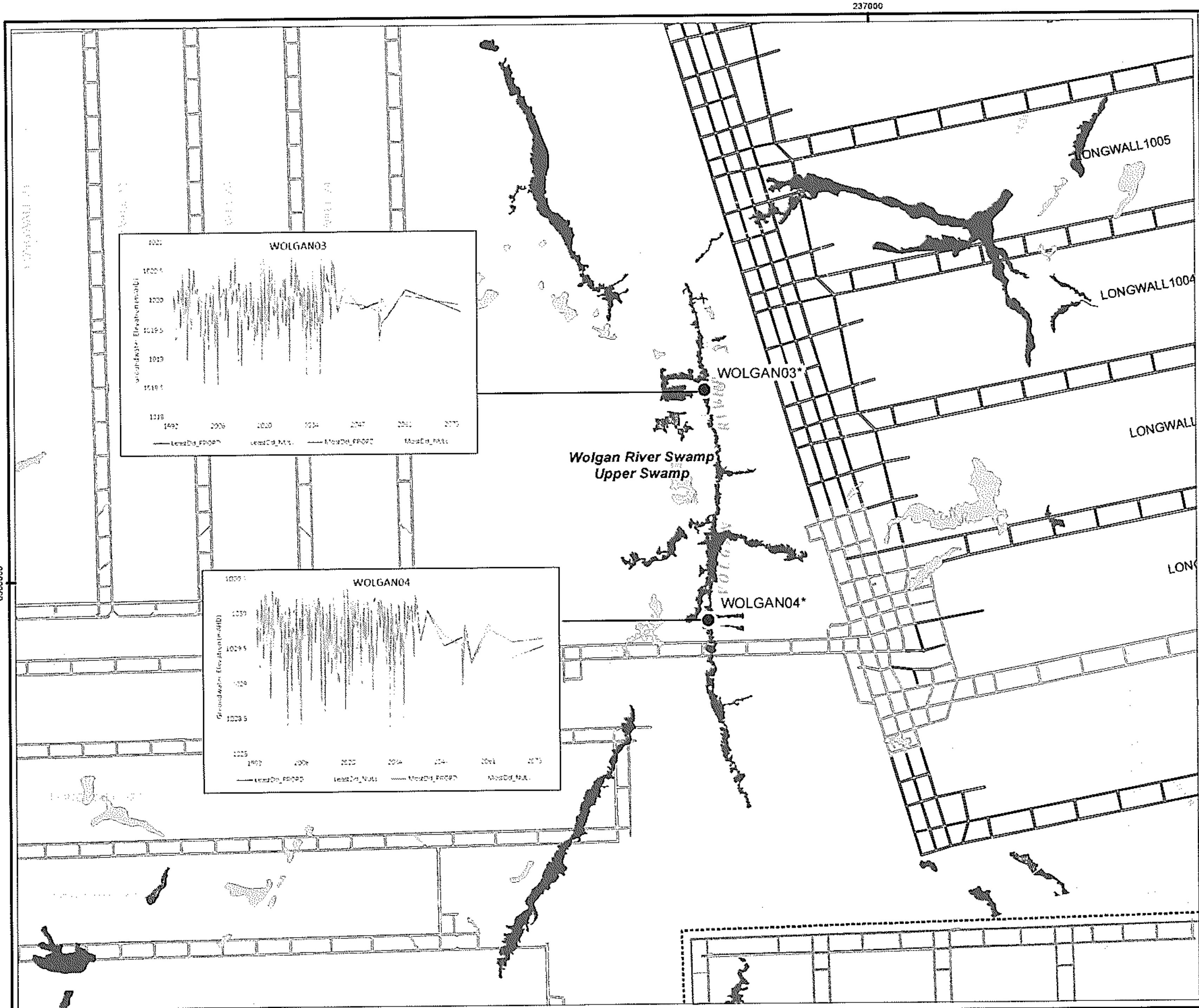
Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

- 'Pinched-out' cells - Drain (DRN) cells

Figure 4.70: Predicted Drawdown (High Rainfall Scenario) – Recovery Phase: 31 December 2091 (SP197) – Wolgan River Swamp Upper, Tri-Star, Wolgan River and Twin Gully Swamps



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

* Synthetic monitoring location, which doesn't exist.

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 13-Sep-2019
Drawn By: JZ	Checked By: JB
Scale 1:15,000	

0 0.25 0.5
km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs - High Rainfall Scenario (Wolgan River Swamp Upper Swamp)

FIGURE: 4.71

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D045_PredictiveUncertainty_WR_Upper_U210.mxd
Reference © Department of Finance Services & Innovation 2018

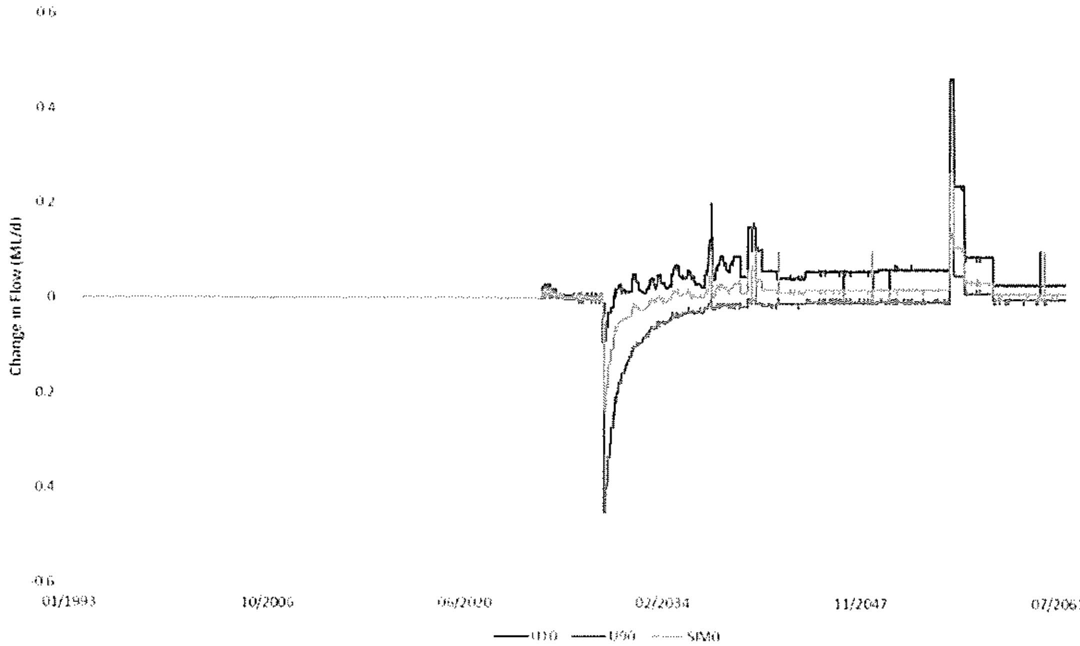


Figure 4.72: Predicted Change to Surface Water Flow – High Rainfall Scenario (Wolgan River Swamp Upper Swamp)

<u>Tri-Star Swamp</u>

Figure 4.69 presents the range of calculated drawdown in the vicinity of Tri-Star Swamp at the end of mine life on 31 December 2053 (SP190).

Figure 4.70 presents the range of calculated drawdown during the recovery phase at 31 December 2091 (SP197).

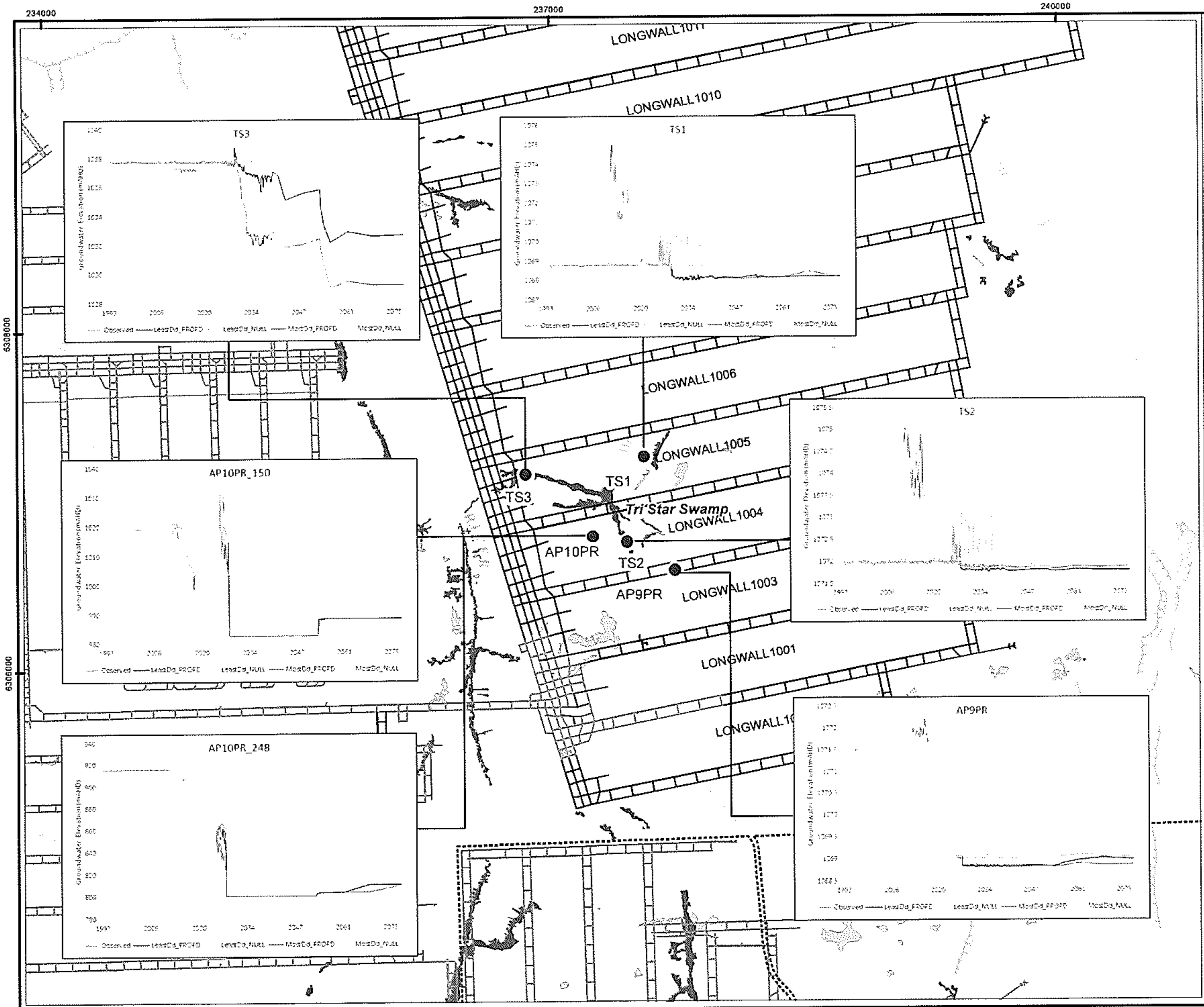
Figure 4.73 presents selected hydrographs in the vicinity of Tri-Star Swamp. These hydrographs are the same locations as presented for the median rainfall scenario (refer **Figure 4.48**).

From **Figure 4.73**, the modelled drawdown in piezometer TS1 ranges between 1m and 2m. For piezometer TS2, the modelled drawdown ranges between 0.2m and 0.7m. For piezometer TS3, the modelled drawdown is more pronounced and reaches between 5.5m in the least drawdown compilation and is 9m in the most drawdown compilation. Modelling does not indicate that the water table level recovers after cessation of mining in December 2053 (SP190). The outcomes presented in **Figure 4.73** are similar to that presented in **Figure 4.48**.

From **Figure 4.73**, a significant change in piezometer AP9PR is not predicted. For APR10PR_150 and APR10PR_248, a large change in groundwater elevation is predicted and is due to the application of the Stacked Drain cells. The outcomes presented in **Figure 4.73** are similar to that presented in **Figure 4.48**.

Figure 4.74 presents the modelled change in surface water flow due to the Proposal in Tri-Star Swamp in the High Rainfall Scenario.

From **Figure 4.74**, the shape of the response is, essentially, the same as that presented in **Figure 4.49**. From **Figure 4.74**, during early time, there is a predicted increase in surface water flow up to 0.15ML/d (1.7L/s) in the 10th percentile results and a predicted decrease in flow 0.1ML/d (1.2L/s) in the 90th percentile results. At later time in **Figure 4.74**, there is a decrease in modelled flow of 0.04ML/d (0.5L/s) in the 10th percentile model results and a decrease in modelled flow of 0.18ML/d (2.1L/s) in the 90th percentile results.



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

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Scale 1:30,000

0 0.5 1
km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs - High Rainfall Scenario (Tri-Star Swamp)

FIGURE: 4.73

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Reference: © Department of Finance, Services & Innovation 2018

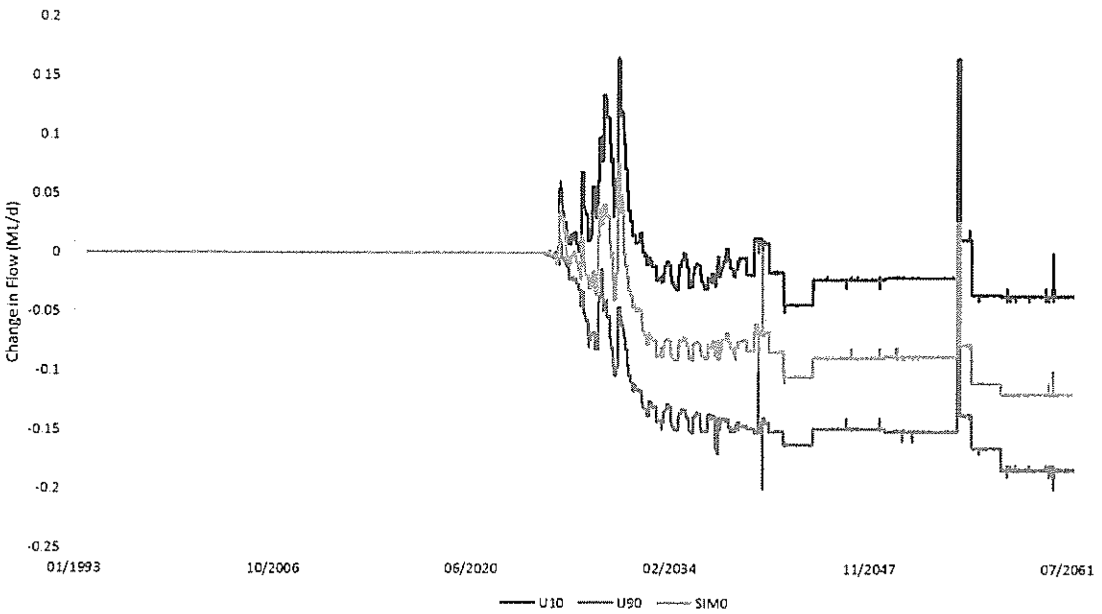


Figure 4.74: Predicted Change to Surface Water Flow – High Rainfall Scenario (Tri-Star Swamp)

Wolgan River Swamp

Figure 4.69 presents the range of calculated drawdown in the vicinity of Wolgan River Swamp at the end of mine life on 31 December 2053 (SP190).

Figure 4.70 presents the range of calculated drawdown during the recovery phase at 31 December 2091 (SP197).

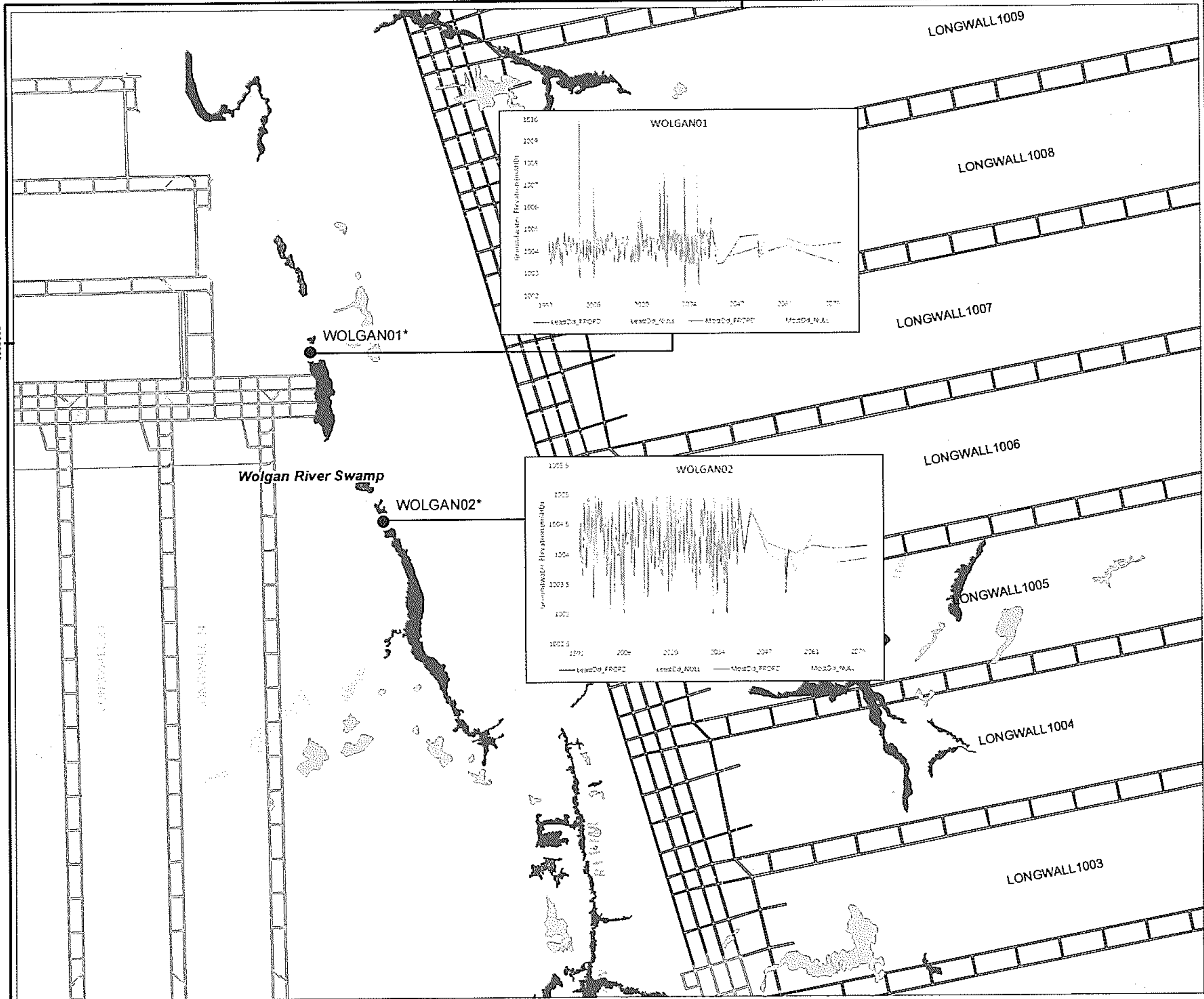
From **Figure 4.69** and **Figure 4.70**, the modelled drawdown is less than 0.5m in the Banks Wall Sandstone that underlies Wolgan River Swamp.

Figure 4.75 presents the predicted groundwater hydrograph response in the vicinity of Wolgan River Swamp in the High Rainfall Scenario.

From **Figure 4.75**, there is negligible difference between Proposed and Null Case groundwater elevations for either the most drawdown or least drawdown output results. The results presented in **Figure 4.75** are very similar to that presented in **Figure 4.51** with respect to Median Rainfall conditions.

Figure 4.76 presents the modelled change to groundwater contribution to surface water flow in Wolgan River Swamp.

From **Figure 4.76**, the modelled change ranges between an increase of 0.1ML/d (1.1L/s) and a decline of 0.6ML/d (7L/s) initially, which transitions to a change that ranges between an increase of 0.05ML/d (0.6L/s) and a decline of 0.2ML/d (2.3L/s).



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

* Synthetic monitoring location, which doesn't exist.

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Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 13-Sep-2019
Drawn By: JZ	Checked By: JB

Scale 1:15,000

0 0.25 0.5 km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs - High Rainfall Scenario (Wolgan River Swamp)

FIGURE: 4.75

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D046_PredictiveUncertainty_WRS_U210.mxd
Reference © Department of Finance Services & Innovation 2018

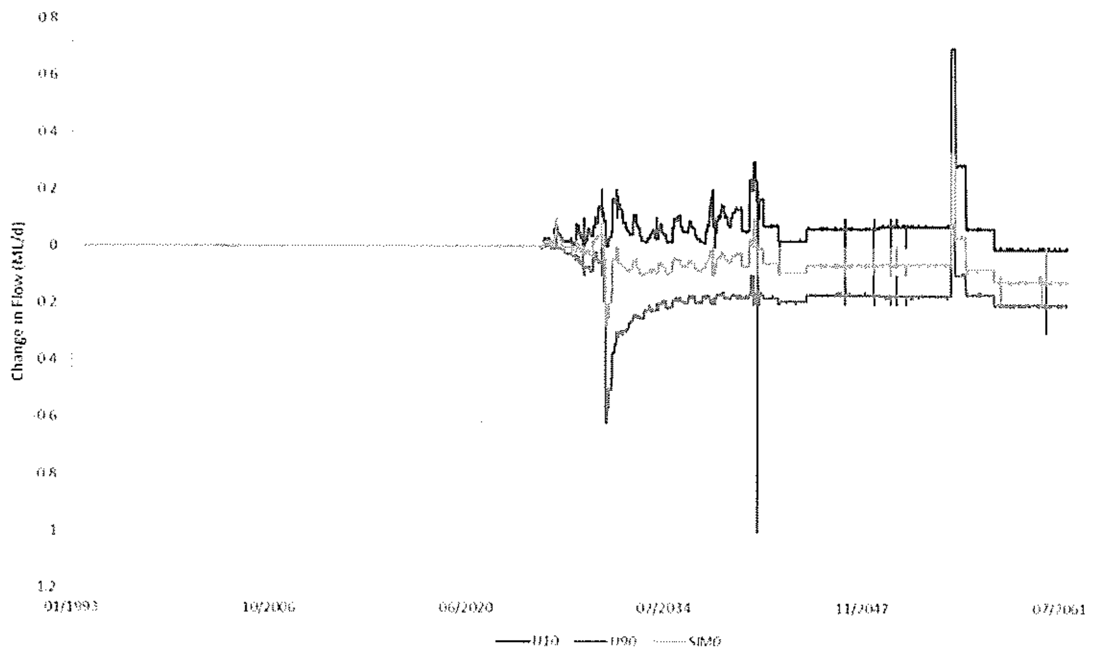


Figure 4.76: Predicted Change to Surface Water Flow – High Rainfall Scenario (Wolgan River Swamp)

Twin Gully Swamp

Figure 4.69 presents the modelled 10th percentile and 90th percentile drawdown for the High Rainfall scenario at the end of mine life in December 2053 (SP190). **Figure 4.69** presents the results for both Tri-Star and Twin Gully Swamps.

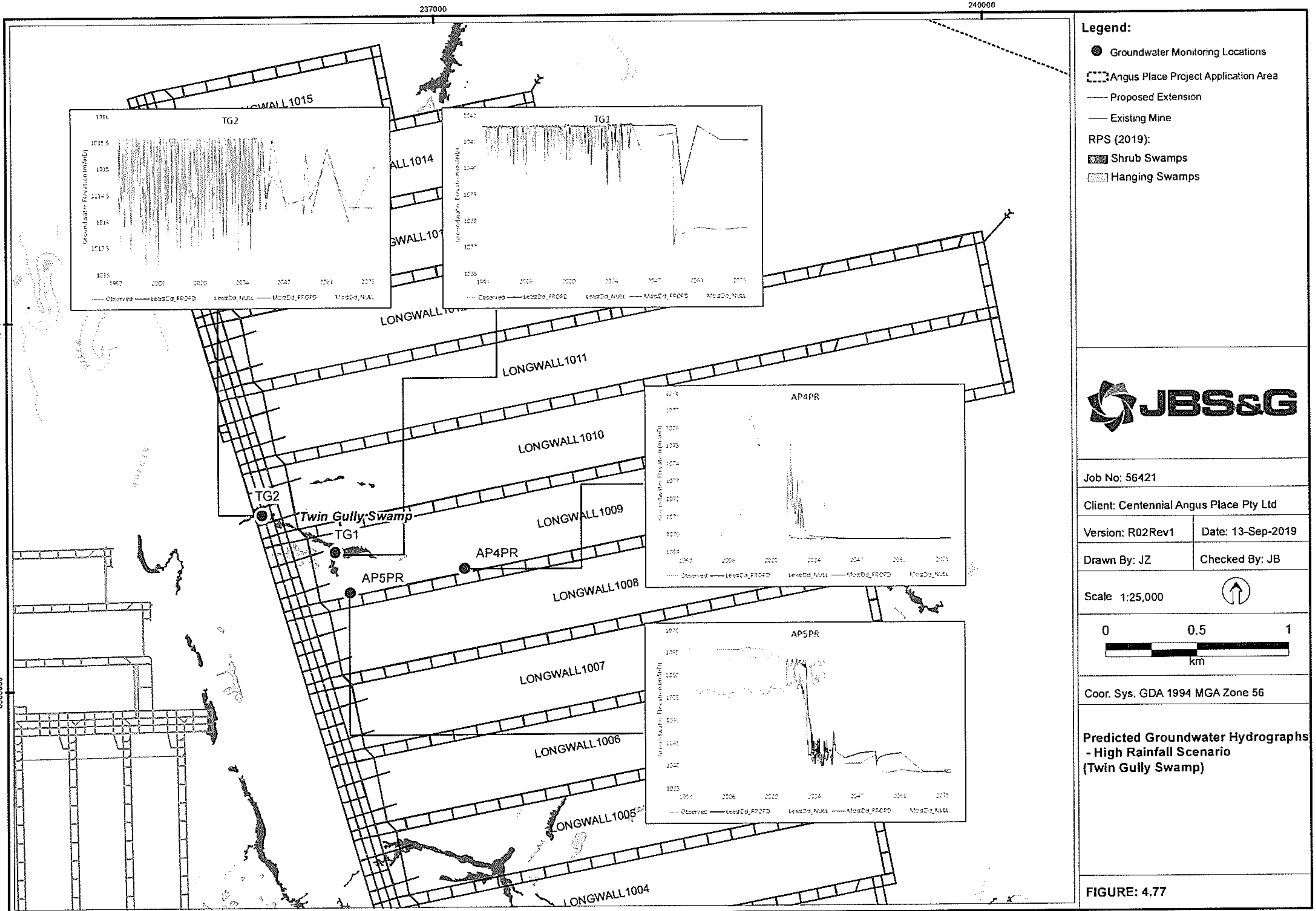
Figure 4.70 presents the modelled 10th and 90th percentile drawdown during the recovery phase at 31 December 2091 (SP197). **Figure 4.70** presents the results for both Tri-Star and Twin Gully Swamps.

Figure 4.77 presents selected hydrographs in the vicinity of Twin Gully Swamp. The locations identified in **Figure 4.77** are at the same locations as that presented in **Figure 4.53**.

From **Figure 4.77**, there is only minor change predicted at piezometer TG2, which is consistent with the results presented in **Figure 4.53**. In piezometer TG1, drawdown reaches a maximum of 4m in late time. From **Figure 4.77**, in piezometer APR4PR, predicted drawdown ranges between 0m and 2m. In piezometer APR5PR, the predicted drawdown ranges between 20m and 25m. From **Figure 4.77**, the modelled groundwater elevation does not appear to recover.

Figure 4.78 presents the modelled change to surface water flow in Twin Gully Swamp associated with the High Rainfall Scenario.

From **Figure 4.78**, the results are quite similar to that presented in **Figure 4.54**, which are the median rainfall uncertainty analysis predictions. From **Figure 4.78**, the predicted increase in 10th percentile results in early time is up to 0.1ML/d (1.2L/s) and a decrease of 0.02ML/d (0.2L/s) in the 90th percentile results. At late time, the predicted change is a negligible increase in the 10th percentile results and a 0.06ML/d (0.7L/s) decrease in the 90th percentile results.



File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D029_PredictiveUncertainty_TwinGully_UNC210.mxd
Reference © Department of Finance Services & Innovation 2018

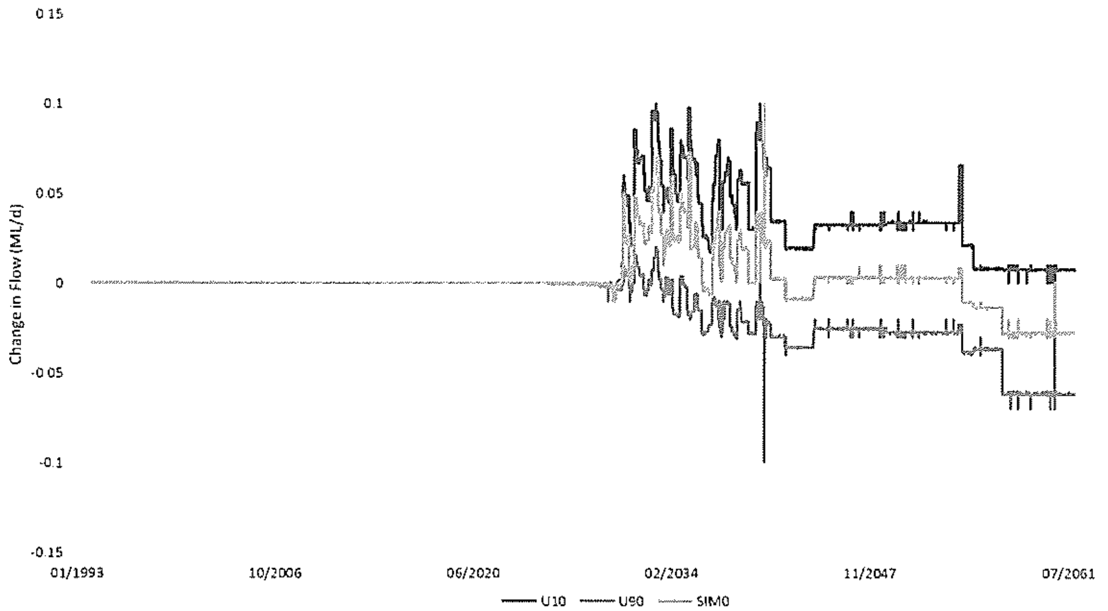


Figure 4.78: Predicted Change to Surface Water Flow – High Rainfall Scenario (Twin Gully Swamp)

Crocodile Swamp

Figure 4.79 presents the range of calculated drawdown in the vicinity of Crocodile Swamp in December 2053 (SP190).

Figure 4.80 presents the range of calculated drawdown during the recovery phase in December 2091 (SP197).

From **Figure 4.79**, there is significant drawdown in the Banks Wall Sandstone that underlies Crocodile Swamp at the end of mining in 2053. From **Figure 4.80**, the drawdown in the Banks Walls Sandstone is still significant beneath Crocodile Swamp in 2091.

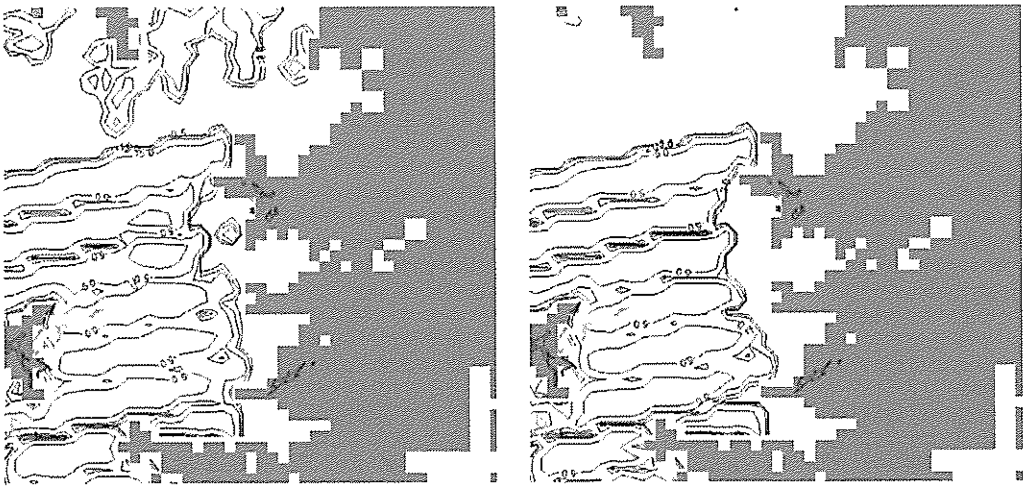
Figure 4.81 presents modelled groundwater hydrographs in the vicinity of Crocodile Swamp.

From **Figure 4.81**, the modelled drawdown in synthetic piezometer CROC01 ranges between no drawdown up to 0.5m. From **Figure 4.81**, the drawdown in standpipe piezometer AP1104 ranges between 0.2 and 0.4m. From **Figure 4.81**, vibrating wire piezometer AP1104 indicates complete depressurisation of those units below 170mBGL.

The results presented in **Figure 4.81** are very similar to that presented in **Figure 4.58** which presents prediction results considering median rainfall conditions.

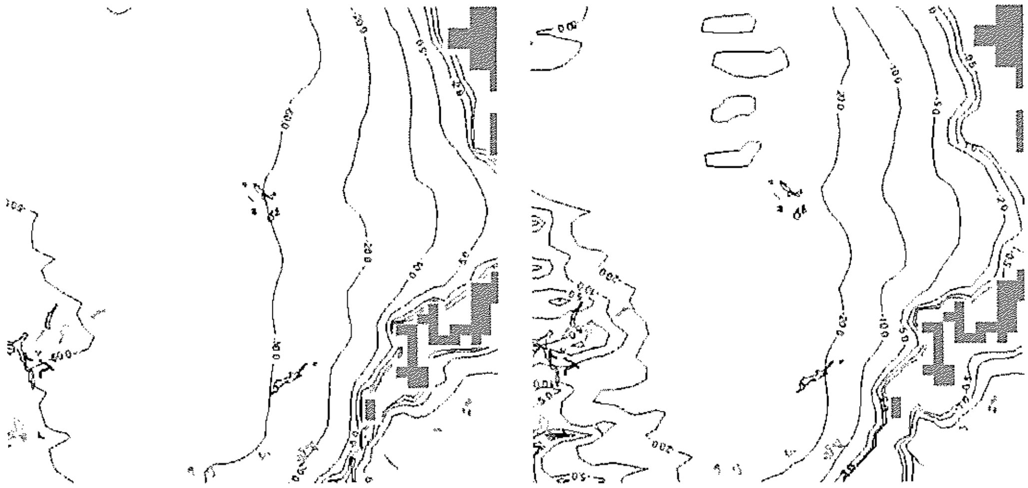
Figure 4.82 presents the modelled change in groundwater contribution to surface water flow due to the Proposal.

From **Figure 4.82**, the modelled change ranges between an increase of 0.01ML/d (0.1L/s) and a decline of 0.005ML/d (0.06L/s). The magnitude of the predicted change in flow is evaluated further, in context of modelled daily flow, in the Swamp Water Balance Model Report (JBS&G, 2019).



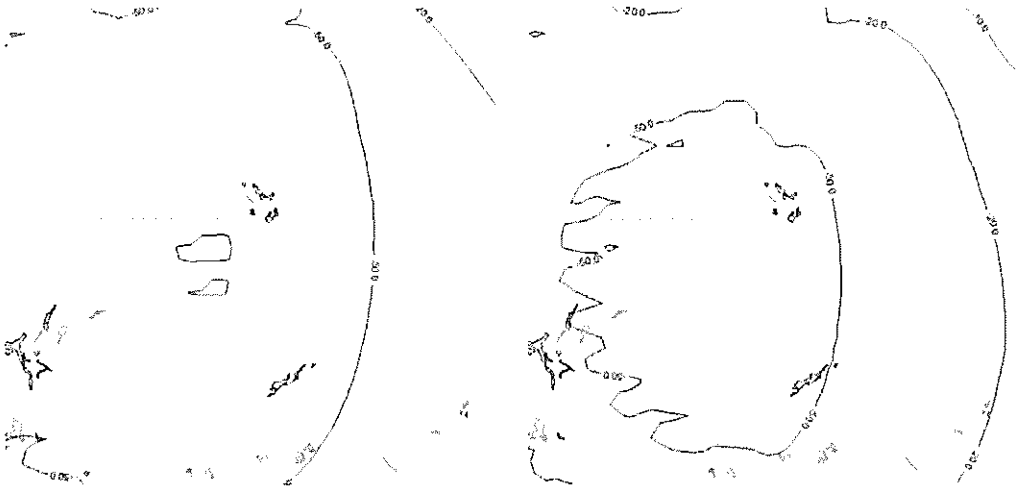
Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)

Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)

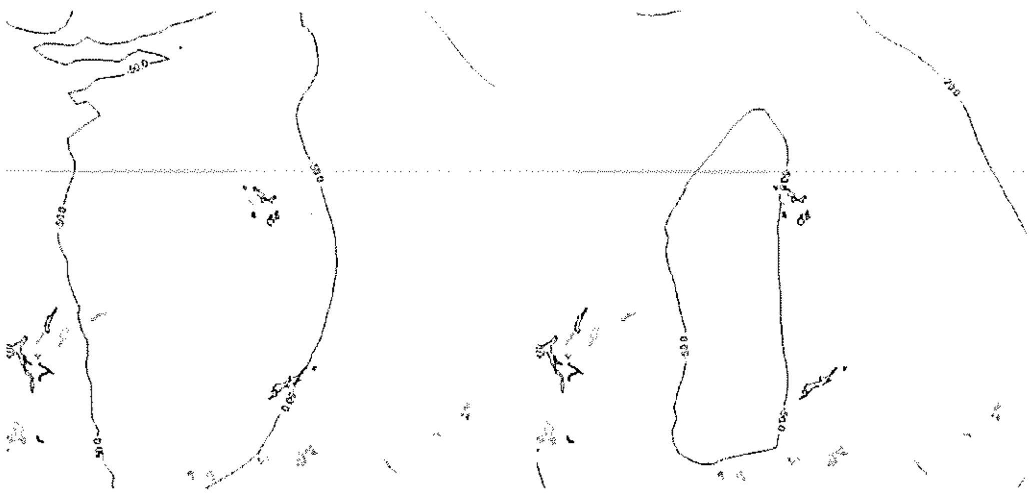


Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)

Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)



Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)

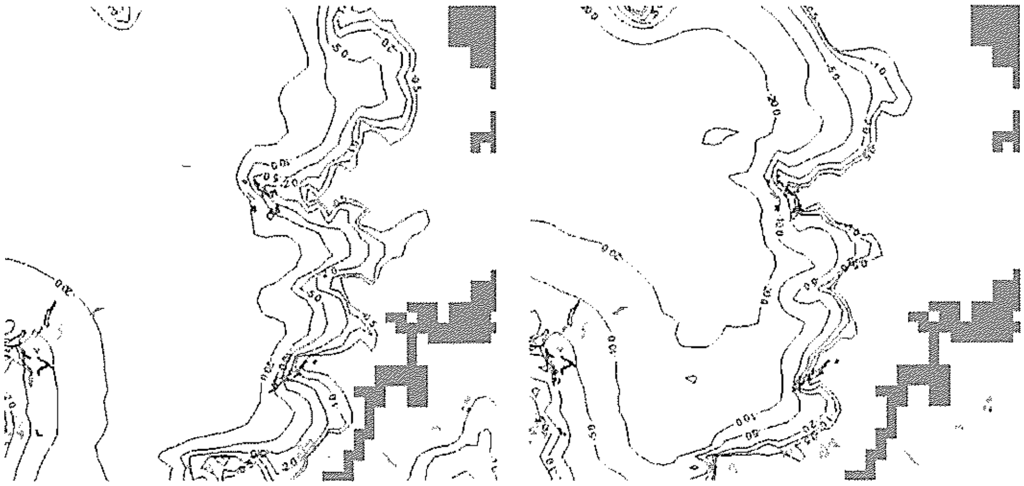


Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

▨ - 'Pinched-out' cells - Drain (DRN) cells

Figure 4.79: Predicted Drawdown (High Rainfall Scenario) – End of Mine Life: 31 December 2053 (SP190) – Crocodile Swamp and Birds Rock Swamp

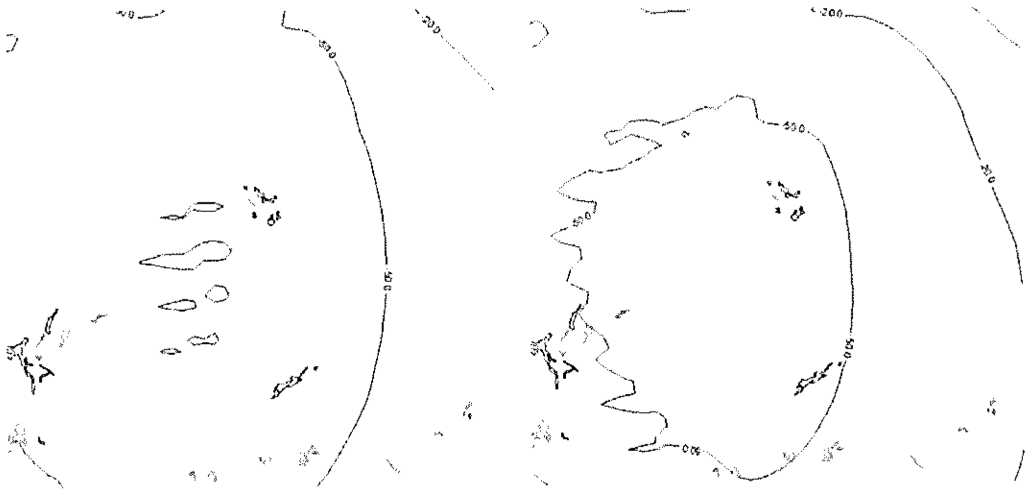
Layer 9 (Sandstone between YS4 and YS5) (L – 10th% Difference; R – 90th% Difference)



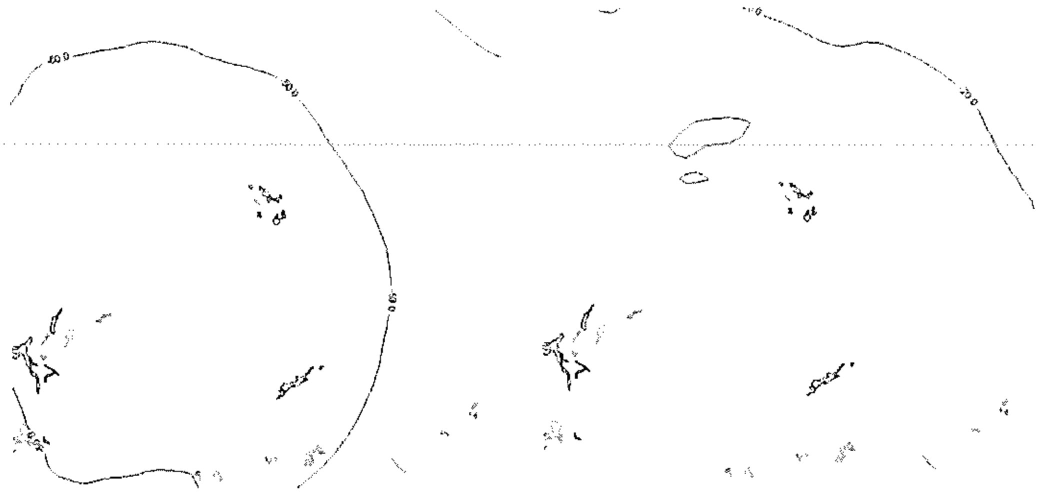
Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)

Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)

Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)



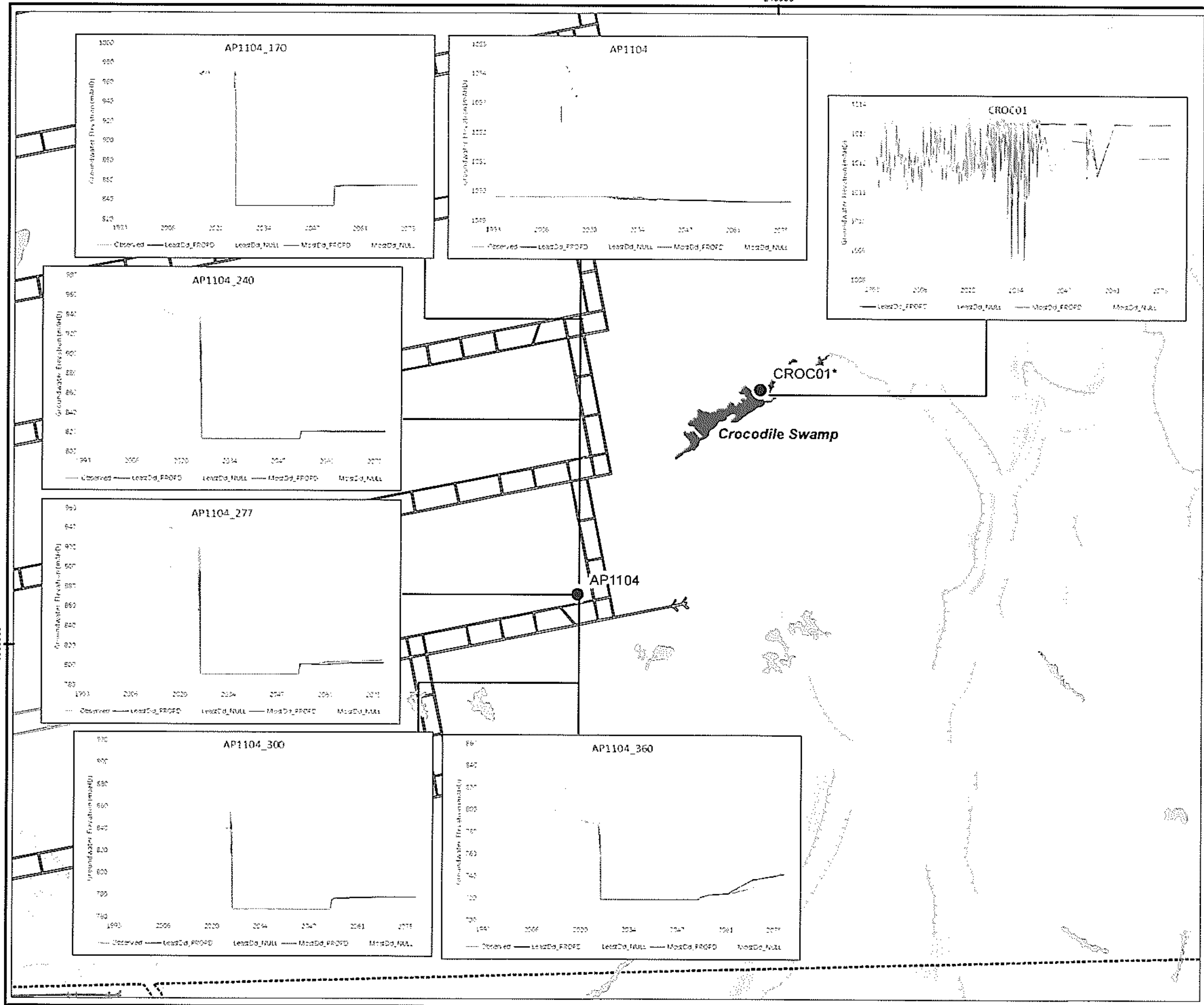
Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

- 'Pinched-out' cells - Drain (DRN) cells

Figure 4.80: Predicted Drawdown (High Rainfall Scenario) – Recovery Phase: 31 December 2091 (SP197) – Crocodile Swamp and Birds Rock Swamp



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

* Synthetic monitoring location, which doesn't exist.

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 13-Sep-2019
Drawn By: JZ	Checked By: JB

Scale 1:15,000

0 0.25 0.5 km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs - High Rainfall Scenario (Crocodile Swamp)

FIGURE: 4.81

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D047_PredictiveUncertainty_Crocodile_U210.mxd
Reference © Department of Finance Services & Innovation 2018

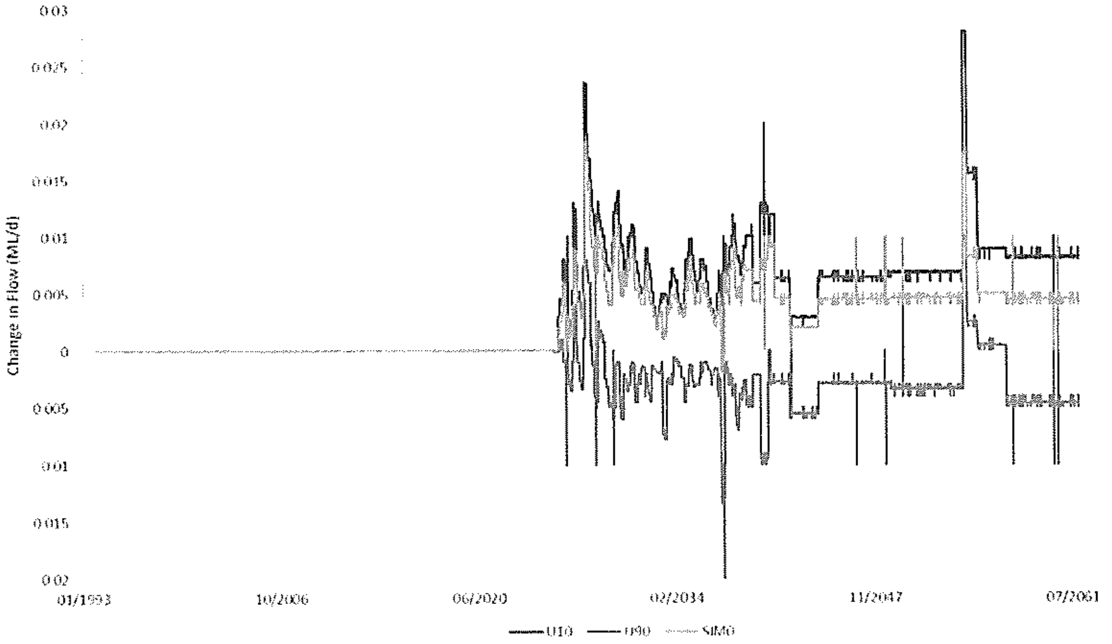


Figure 4.82: Predicted Change to Surface Water Flow – High Rainfall Scenario (Crocodile Swamp)

Birds Rock Swamp

Figure 4.79 presents the range of calculated drawdown in the vicinity of Birds Rock Swamp in December 2053 (SP190). **Figure 4.80** presents the range of calculated drawdown during the recovery phase in December 2091 (SP197).

From **Figure 4.79**, there is significant drawdown in the Banks Wall Sandstone that underlies Birds Rock Swamp at the end of mining in 2053. From **Figure 4.80**, the drawdown in the Banks Walls Sandstone is still significant beneath Birds Rock Swamp in 2091.

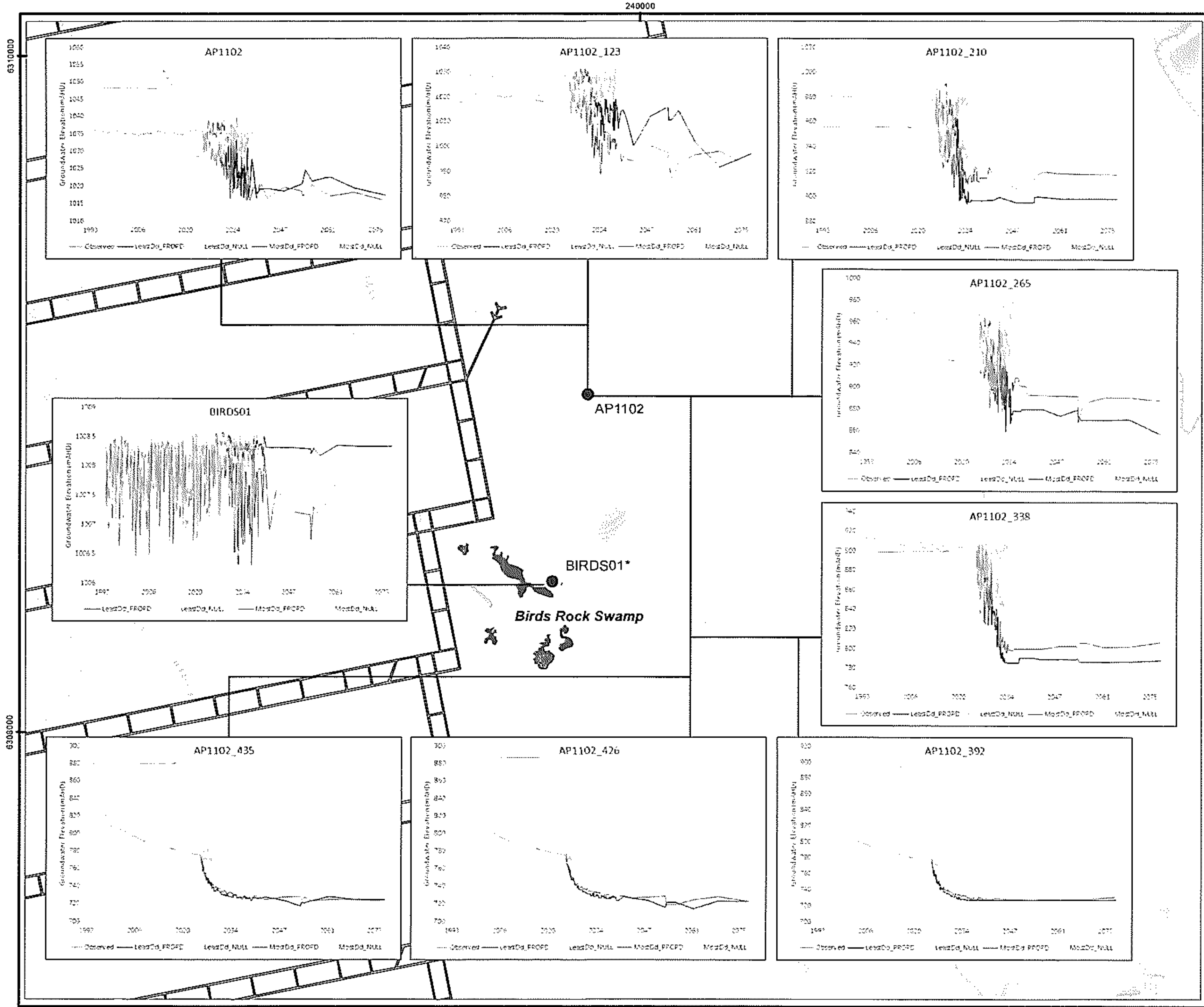
Figure 4.83 presents the modelled groundwater hydrographs in the vicinity of Birds Rock Swamp, including the synthetic swamp monitoring piezometer, BIRDS01

From **Figure 4.83**, synthetic swamp monitoring piezometer BIRDS01 is predicted to experience a drawdown of between 0.2m and 1.0m. The predicted drawdown in the High Rainfall scenario is, essentially, the same as that presented in **Figure 4.60**, with respect to simulations considering median rainfall conditions.

From **Figure 4.83**, standpipe piezometer AP1102 is predicted to experience a drawdown of 10 to 15m and vibrating wire piezometer AP1102 illustrates the effect of depressurisation of the Lithgow Seam in hydrogeologic units below 210mBGL. That depressurisation also effects the shallowest sensor in AP1102 at 123mBGL, wherein a 15 to 40m drawdown is predicted.

Figure 4.84 presents the modelled change in groundwater contribution to surface water flow in Birds Rock Swamp due to the Proposal.

From **Figure 4.84**, the modelled change ranges between an initial increase in flow between 0.13ML/d and no change. The increase in flow is considered to be due to the change to hydraulic properties of the uppermost cell. That change to the uppermost cell was implemented in an attempt to represent the potential effect of near-surface cracking. Following the initial increase in flow, the modelled change in flow ranges between negligible change and a decrease in 0.05ML/d (0.6L/s).



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

* Synthetic monitoring location, which doesn't exist.

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 13-Sep-2019
Drawn By: JZ	Checked By: JB
Scale 1:15,000	

0 0.25 0.5
km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs - High Rainfall Scenario (Birds Rock Swamp)

FIGURE: 4.83

File Name N:\Projects\Centennial\Coal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D048_PredictiveUncertainty_BirdsRock_U210.mxd
Reference © Department of Finance Services & Innovation 2018

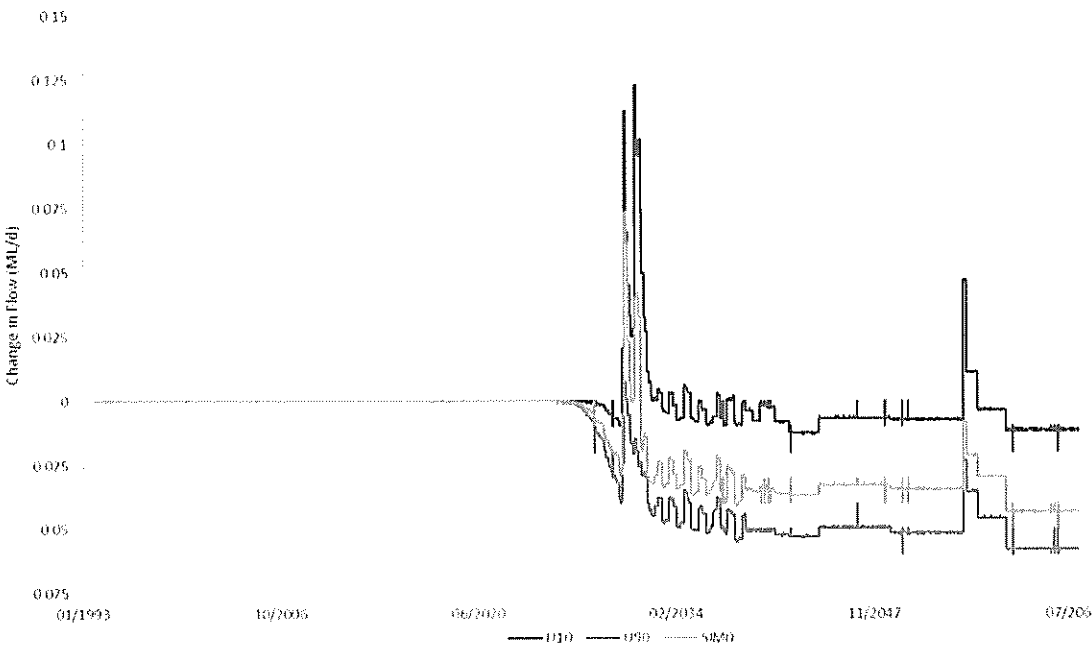


Figure 4.84: Predicted Change to Surface Water Flow – High Rainfall Scenario (Birds Rock Swamp)

<u>Trail Six</u>

Figure 4.85 presents the modelled 10th and 90th percentile drawdown for Trail Six Swamp in the High Rainfall Scenario at the end of mine life in December 2053 (SP190).

Figure 4.86 presents the modelled 10th and 90th percentile drawdown for Trail Six Swamp during the recovery phase in December 2091 (SP197).

The results presented in **Figure 4.85** and **Figure 4.86** are essentially the same as that presented in **Figure 4.62** and **Figure 4.63** respectively.

Figure 4.87 presents the selected hydrographs at Trail Six Swamp for the High Rainfall Scenario.

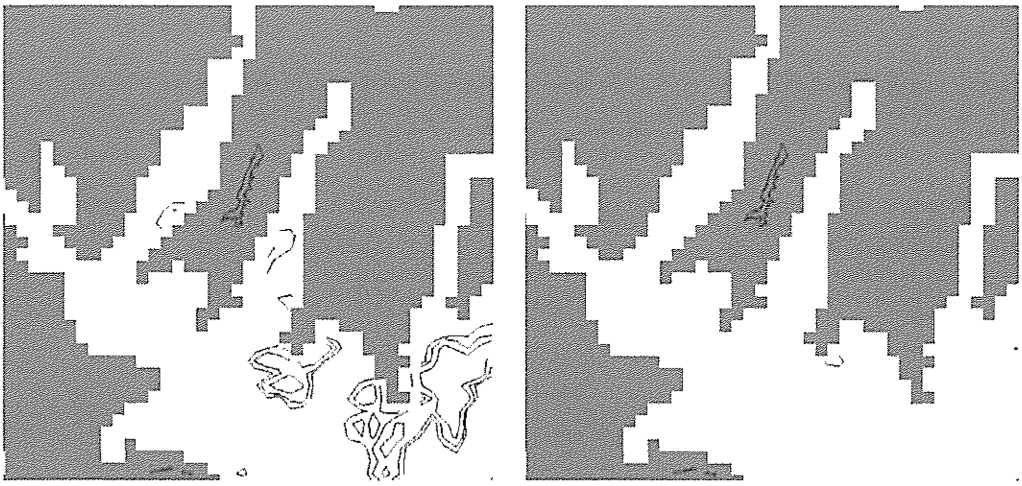
From **Figure 4.87**, the predicted drawdown in piezometer XS1 ranges between 0m and 7m. The predicted drawdown in piezometer XS1 in **Figure 4.87** is similar to that presented in **Figure 4.64**.

From **Figure 4.87**, each of the vibrating wire piezometers at site AP1107 show the influence of the Stacked Drain assumption. The drawdown at AP1107_081 ranges between 70m and 90m, for example. The results presented in **Figure 4.87** are, essentially, the same as that presented in **Figure 4.64**. The outcomes indicate that the predicted change to modelled groundwater level is not dependent on the climate scenario.

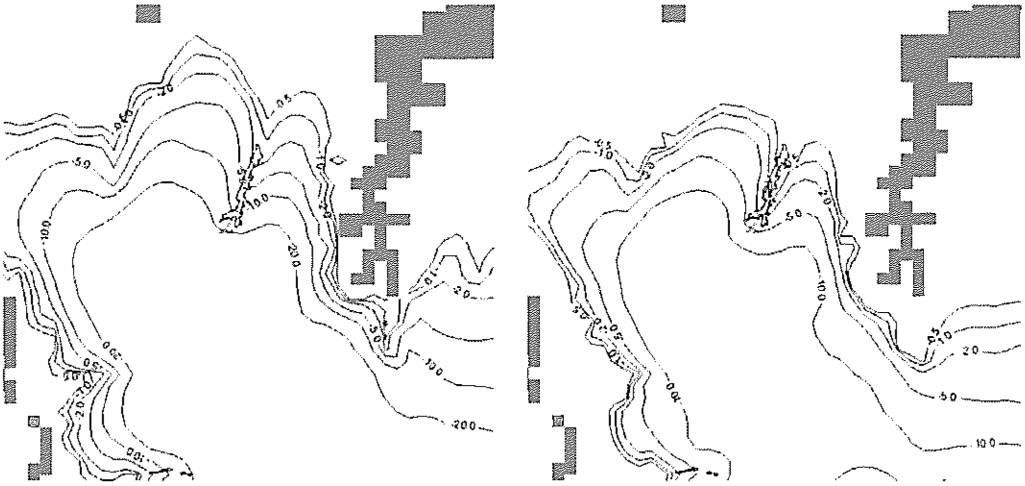
Figure 4.88 presents the modelled change in surface water flow in Trail Six Swamp in regard to the High Rainfall Scenario.

From **Figure 4.88**, the general response is, essentially, the same as that presented in **Figure 4.65**.

From **Figure 4.88**, the modelled change to surface water flow is a minor increase to 0.1ML/d (1.2L/s) in the 10th percentile model results and a 0.05ML/d (0.6L/s) decrease in the 90th percentile model results in early time. From **Figure 4.88**, at late time, there is a negligible change in surface water flow in the 10th percentile results and a 0.07ML/d (0.8L/s) decrease in the 90th percentile results.

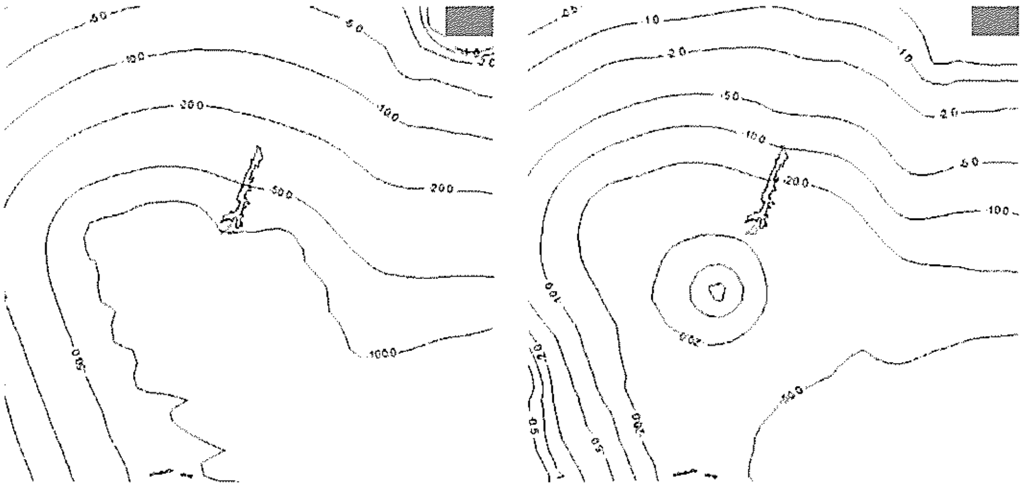


Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)

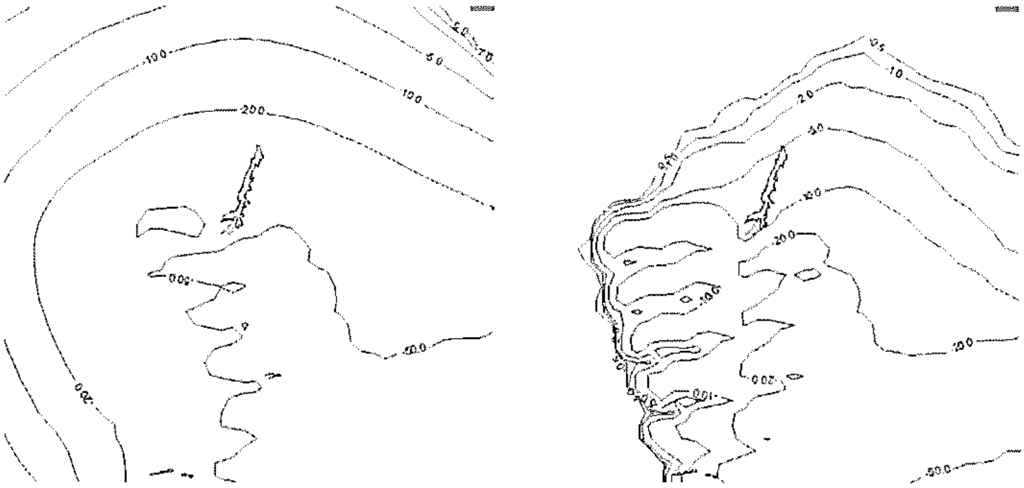


Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)

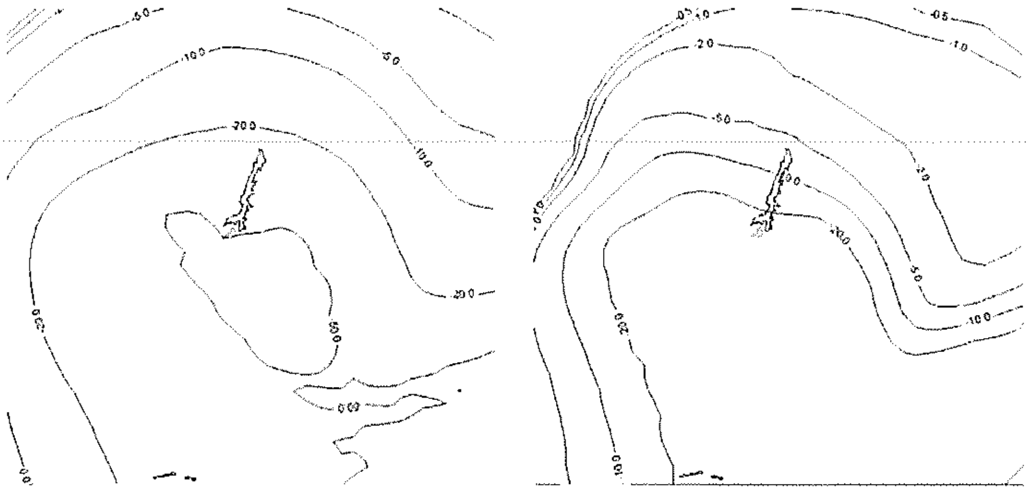
Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)



Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)



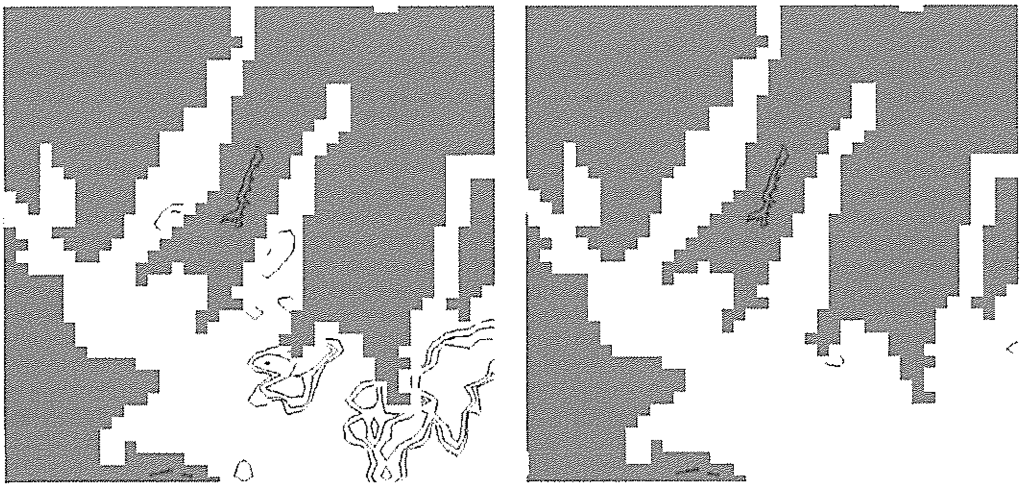
Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

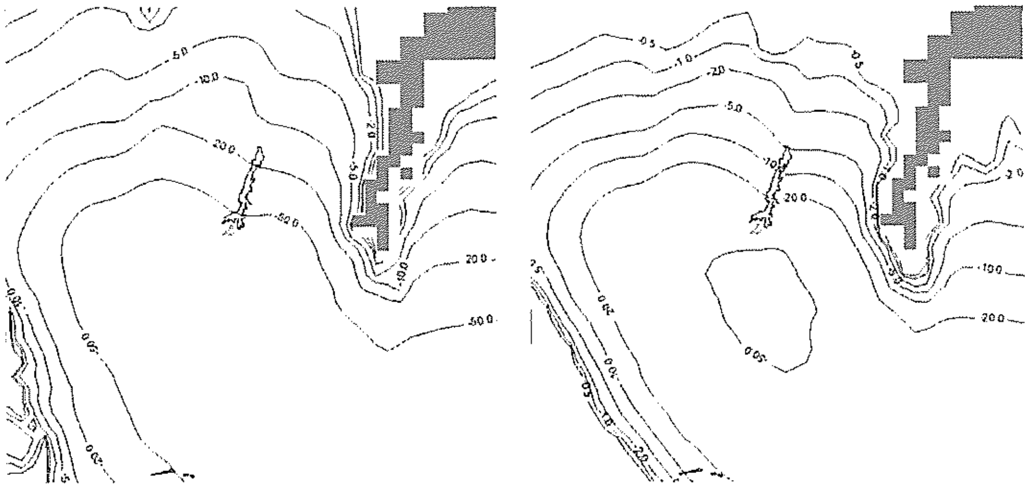
▩ - 'Pinched-out' cells   - Drain (DRN) cells

Figure 4.85: Predicted Drawdown (High Rainfall Scenario) – End of Mine Life: 31 December 2053 (SP190) – Trail Six Swamp

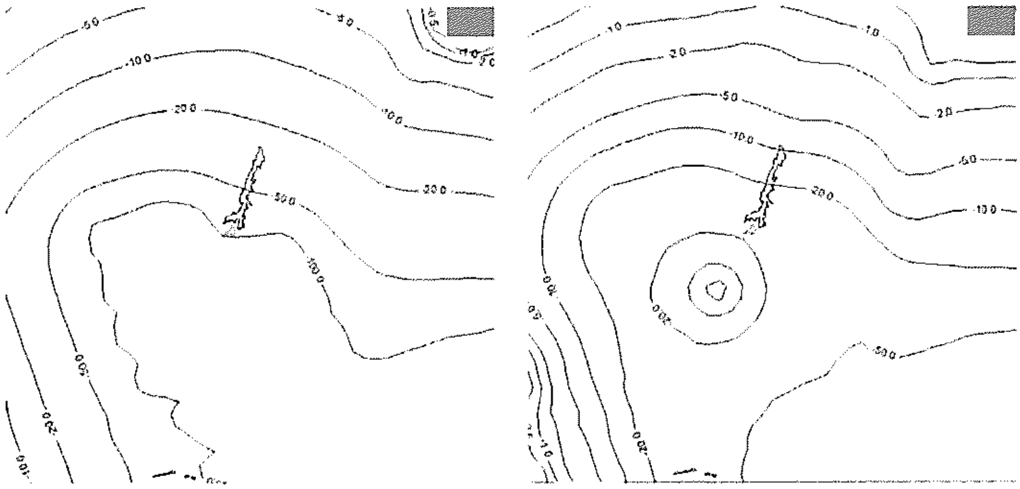


Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)

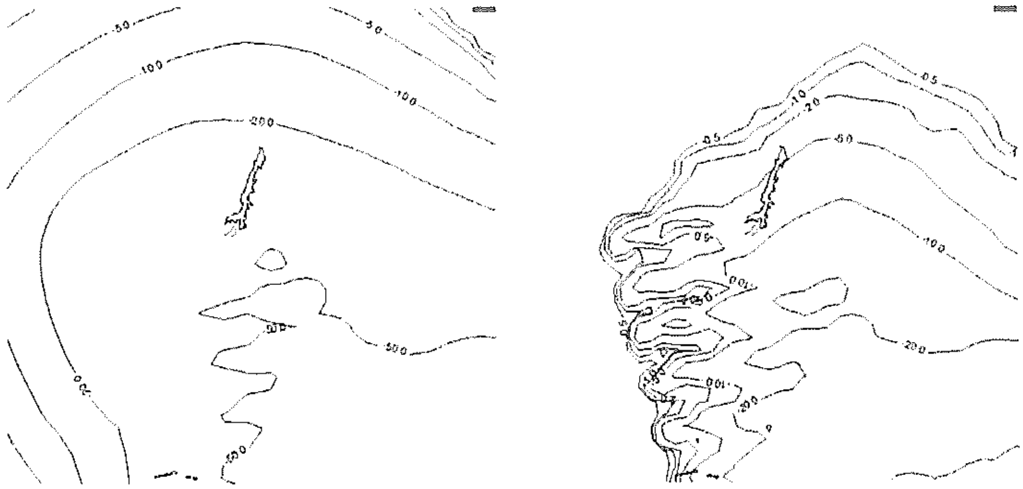
Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)



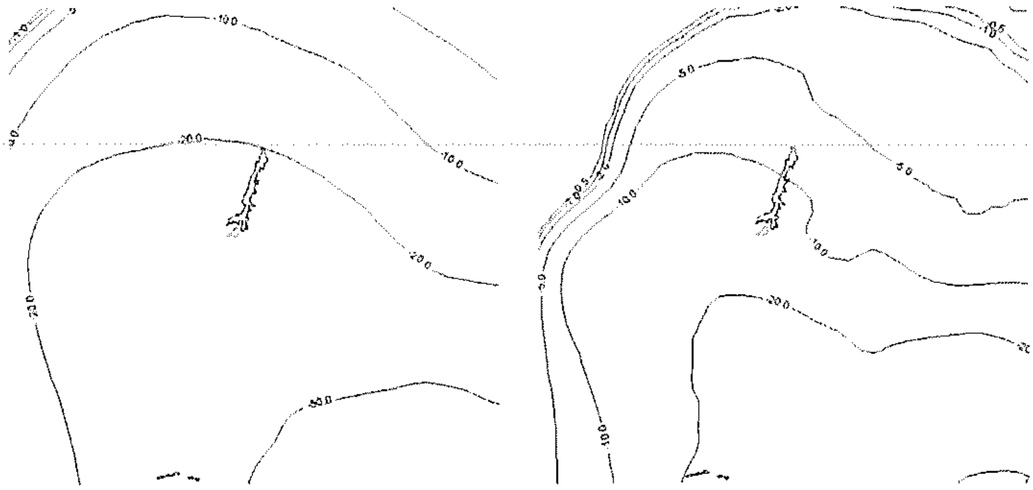
Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)



Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)



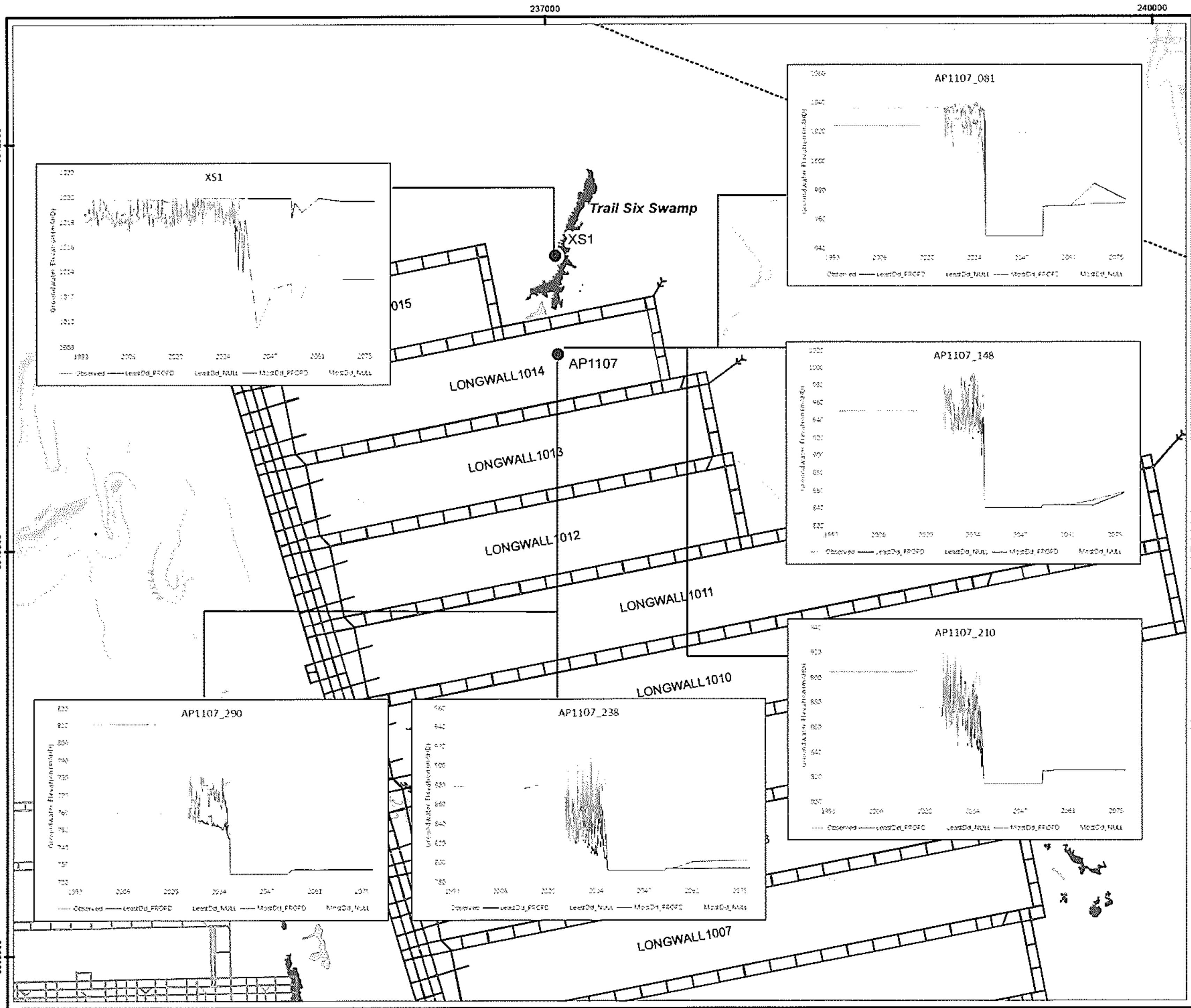
Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

- 'Pinched-out' cells   - Drain (DRN) cells

Figure 4.86: Predicted Drawdown (High Rainfall Scenario) – Recovery Phase: 31 December 2091 (SP197) – Trail Six Swamp



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 13-Sep-2019
Drawn By: JZ	Checked By: JB

Scale 1:25,000

0 0.5 1
km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs - High Rainfall Scenario (Trail Six Swamp)

FIGURE: 4.87

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D030_PredictiveUncertainty_TrailSix_UNC210.mxd
Reference © Department of Finance Services & Innovation 2018

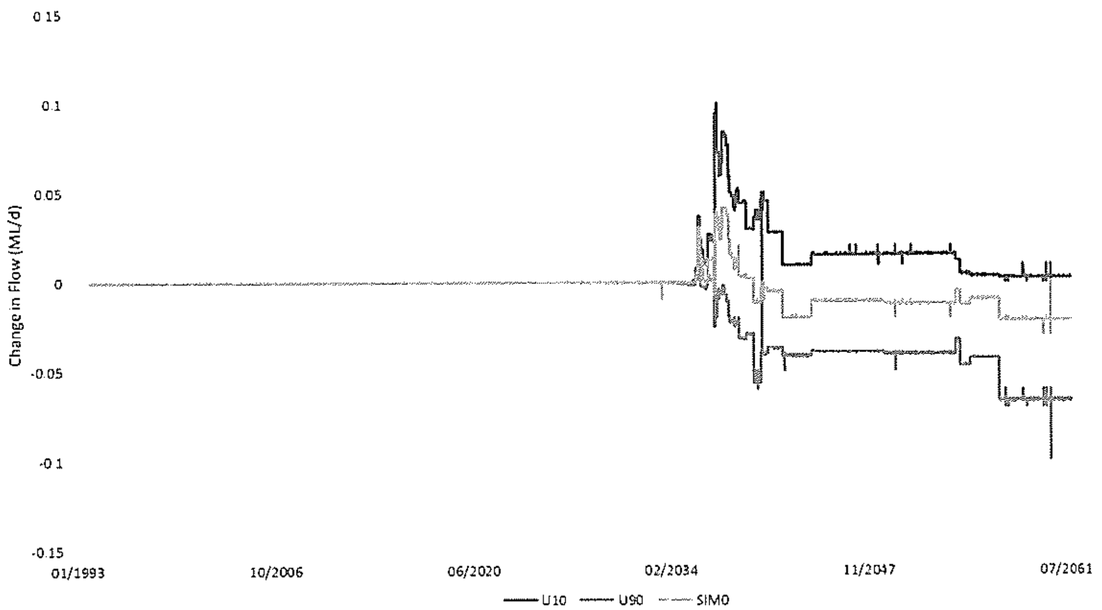


Figure 4.88: Predicted Change to Surface Water Flow – High Rainfall Scenario (Trail Six Swamp)

4.16.3.2 Low Rainfall Scenario

The model control file associated with the prediction simulation is:

- R02RevB_UNC190_01a.gwv

Wolgan River Swamp Upper Swamp

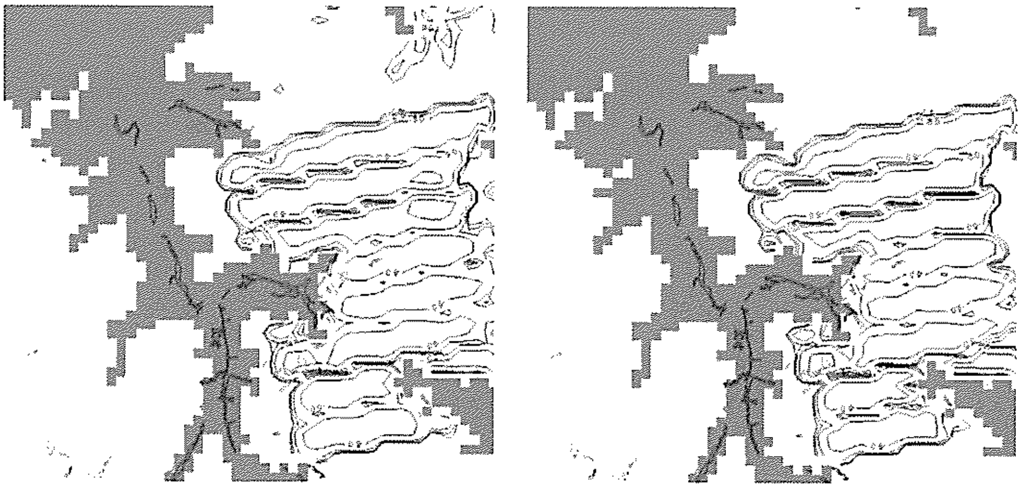
Figure 4.89 presents the 10th percentile (most negative) and 90th percentile (least negative) calculated drawdown in the vicinity of Wolgan River Swamp Upper Swamp at 31 December 2053 (SP190) for the Low Rainfall scenario. **Figure 4.90** presents the 10th percentile (most negative) and 90th percentile (least negative) calculated drawdown during the recovery phase at 31 December 2091 (SP197) for the Low Rainfall scenario.

From **Figure 4.89**, the modelled drawdown in the Banks Wall Sandstone, Layer 13, which underlies the Wolgan River Swamp Upper Swamp is less than 0.5m. From **Figure 4.90**, the residual drawdown, during the recovery phase, is also less than 0.5m in the Wolgan River Swamp Upper Swamp.

Figure 4.91 presents groundwater hydrographs in the vicinity of Wolgan River Swamp Upper Swamp. As noted above, synthetic swamp monitoring piezometers were included for Wolgan River Swamp Upper Swamp because there is currently no groundwater level monitoring in Wolgan River Swamp Upper Swamp.

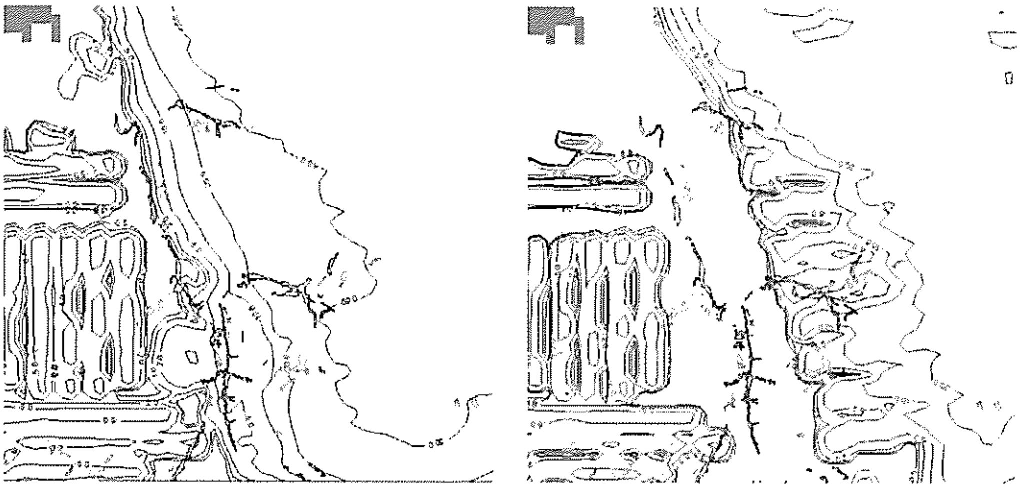
From **Figure 4.91**, model results indicate that the predicted drawdown in Wolgan River Swamp Upper Swamp ranges between negligible change to a decline of 0.1m. The results presented in **Figure 4.91**, are essentially the same as that presented in **Figure 4.46** with respect to median rainfall conditions.

Figure 4.92 presents the predicted change in groundwater contribution to surface water flow due to the Proposal.

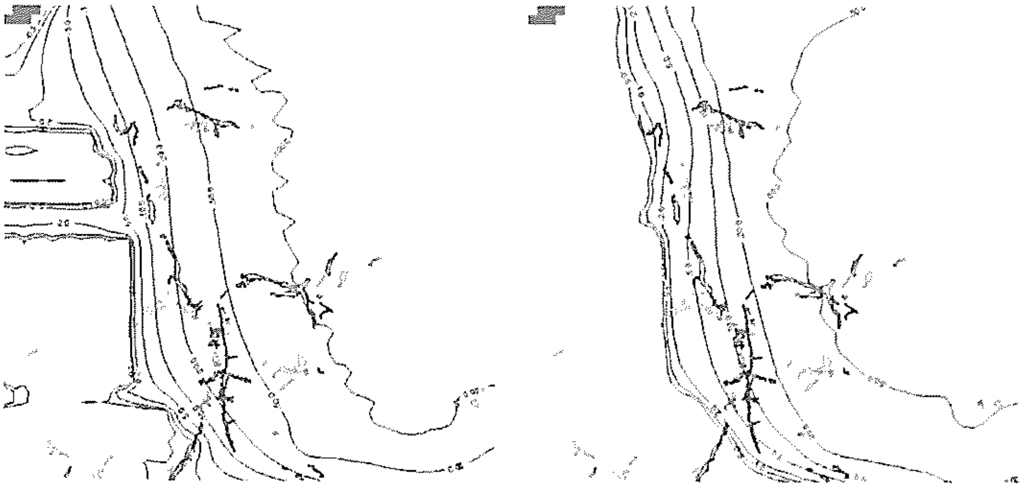


Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)

Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)

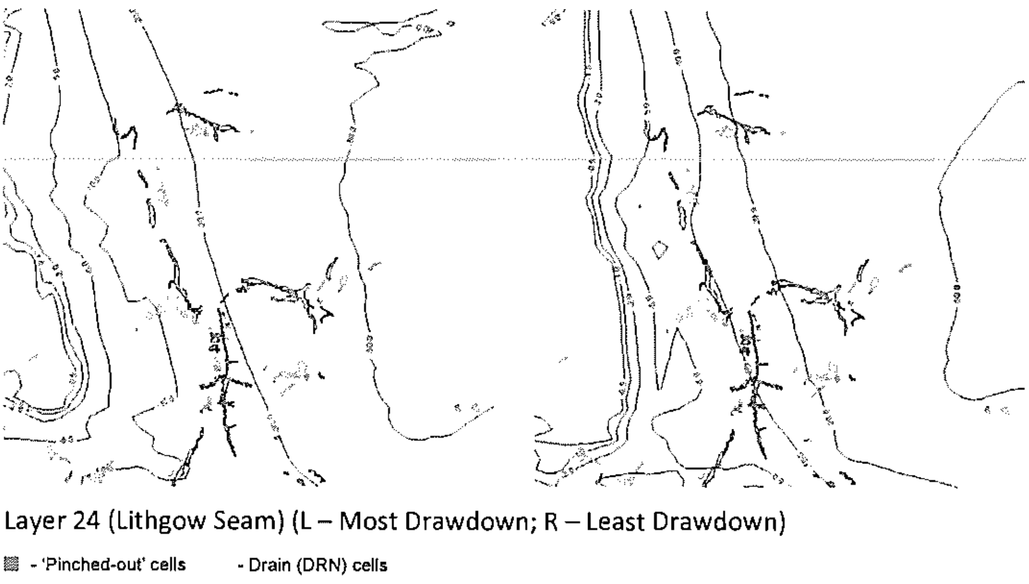


Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)



Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)

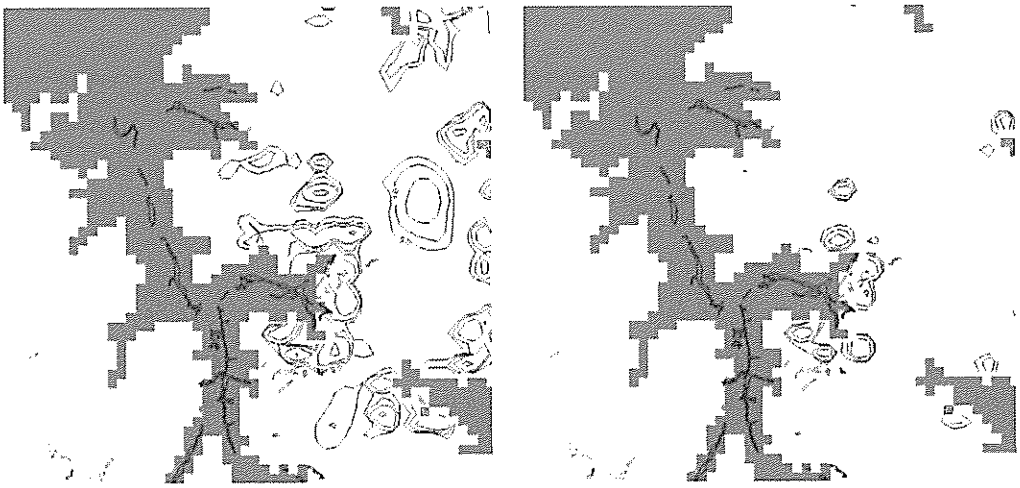
Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



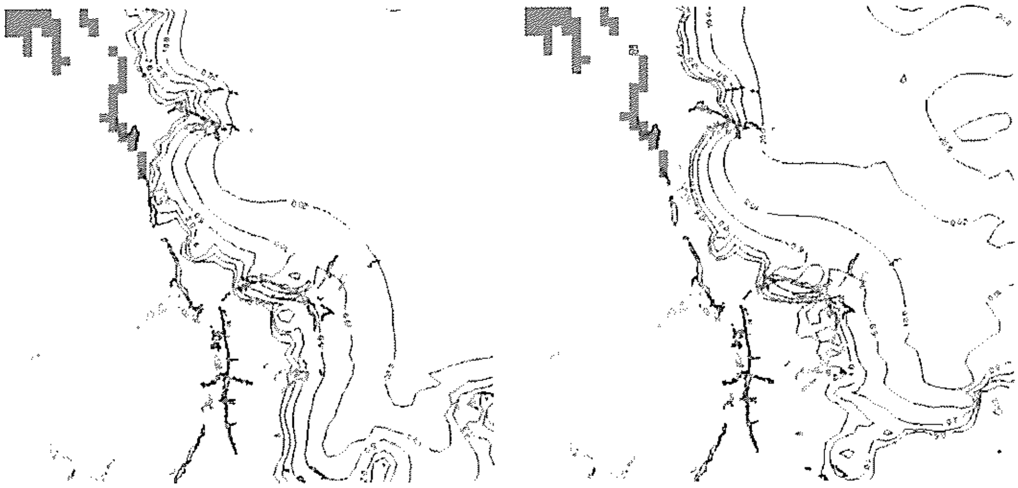
Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

▩ - 'Pinched-out' cells - Drain (DRN) cells

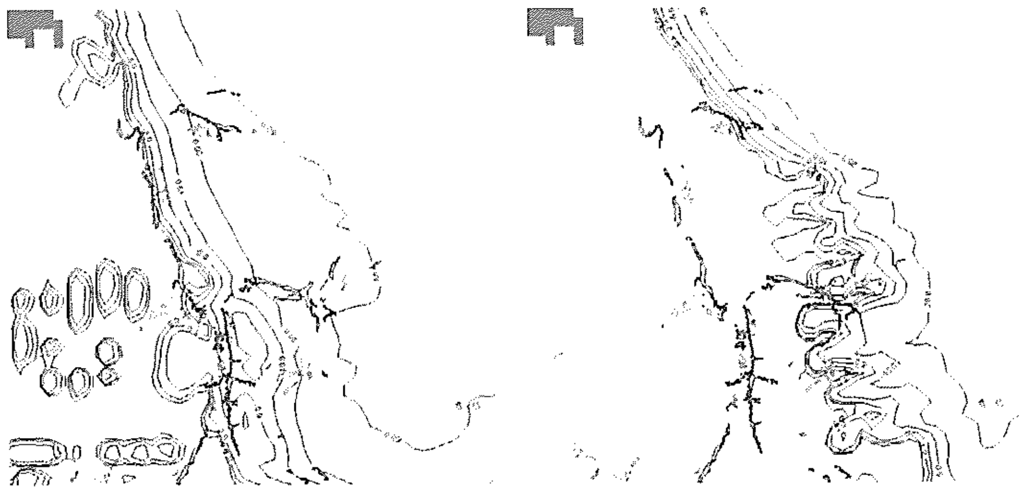
Figure 4.89: Predicted Drawdown (Low Rainfall Scenario) – End of Mine Life: 31 December 2053 (SP190) – Wolgan River Swamp Upper, Tri-Star, Wolgan River and Twin Gully Swamps



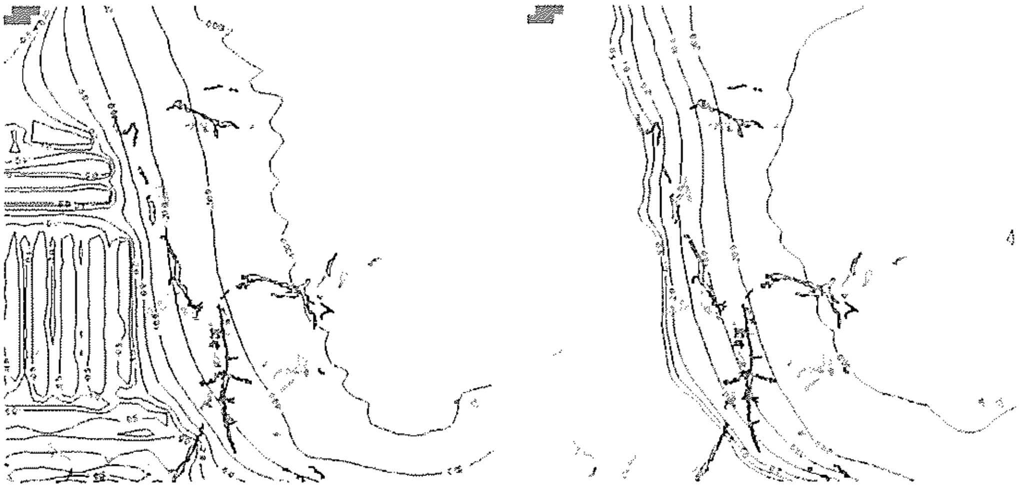
Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)



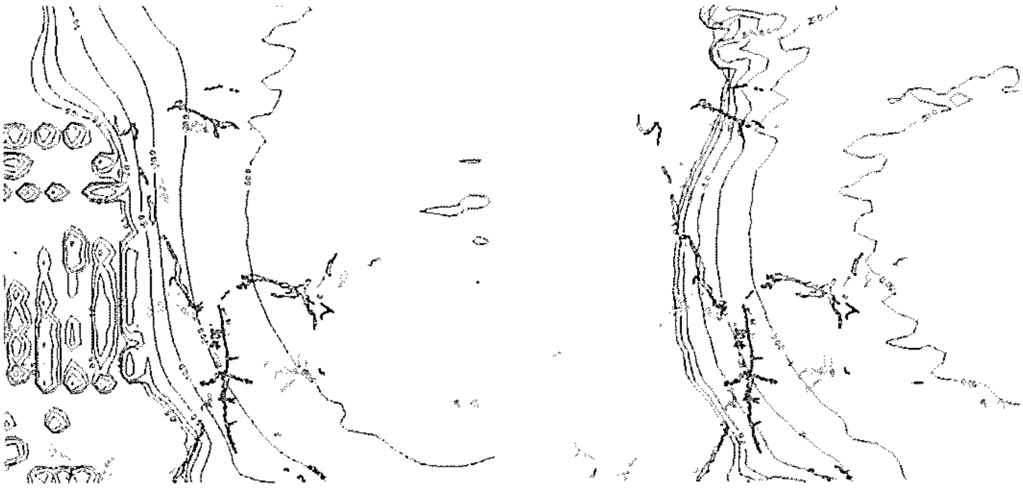
Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)



Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)



Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)

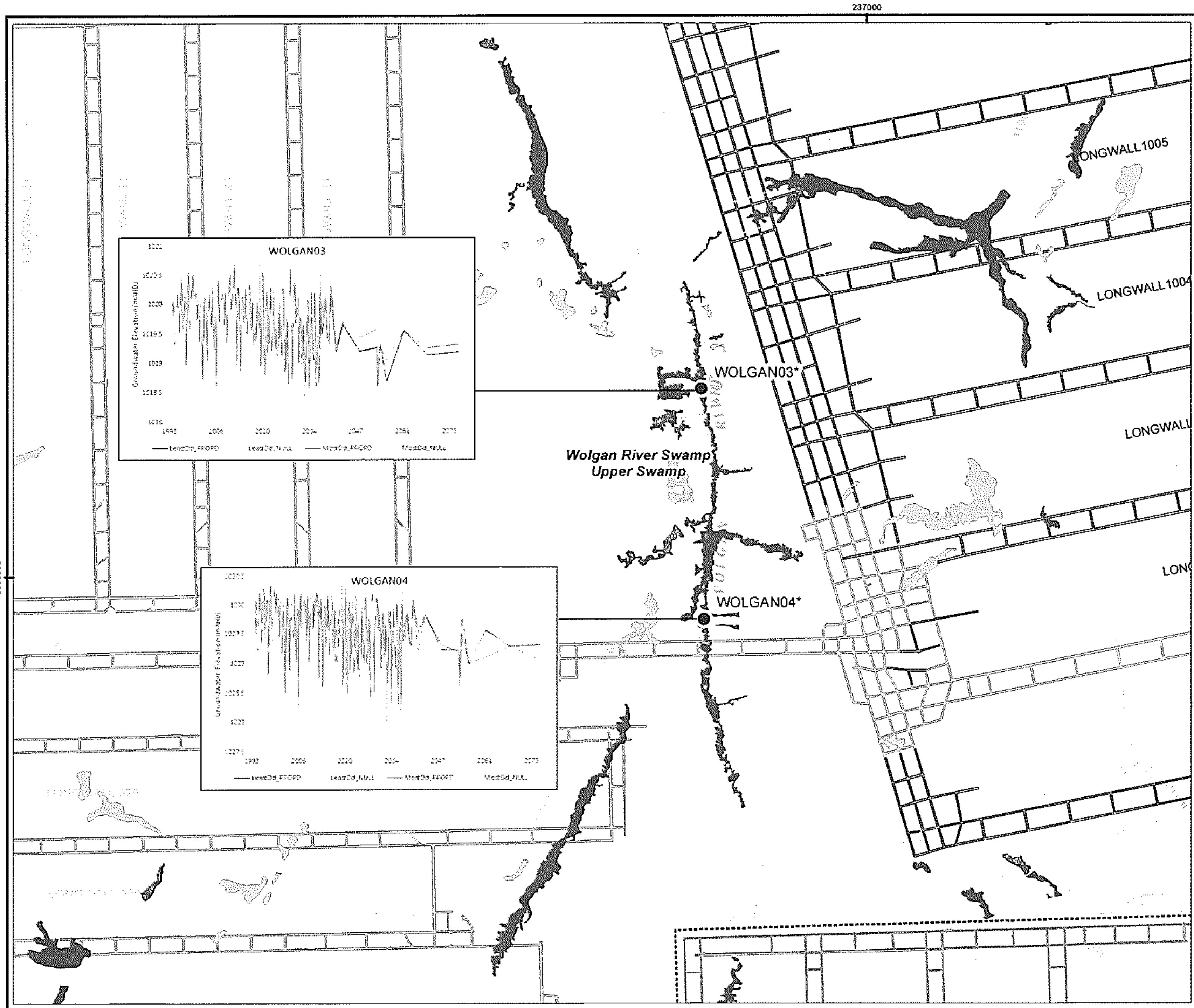


Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)

Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

- 'Pinched-out' cells - Drain (DRN) cells

Figure 4.90: Predicted Drawdown (Low Rainfall Scenario) – Recovery Phase: 31 December 2091 (SP197) – Wolgan River Swamp Upper, Tri-Star, Wolgan River and Twin Gully Swamps



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

* Synthetic monitoring location, which doesn't exist.

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:15,000	

0 0.25 0.5
km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs – Low Rainfall Scenario (Wolgan River Swamp Upper Swamp)

FIGURE: 4.91

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D050_PredictiveUncertainty_WR_Upper_U150.mxd
Reference © Department of Finance Services & Innovation 2018

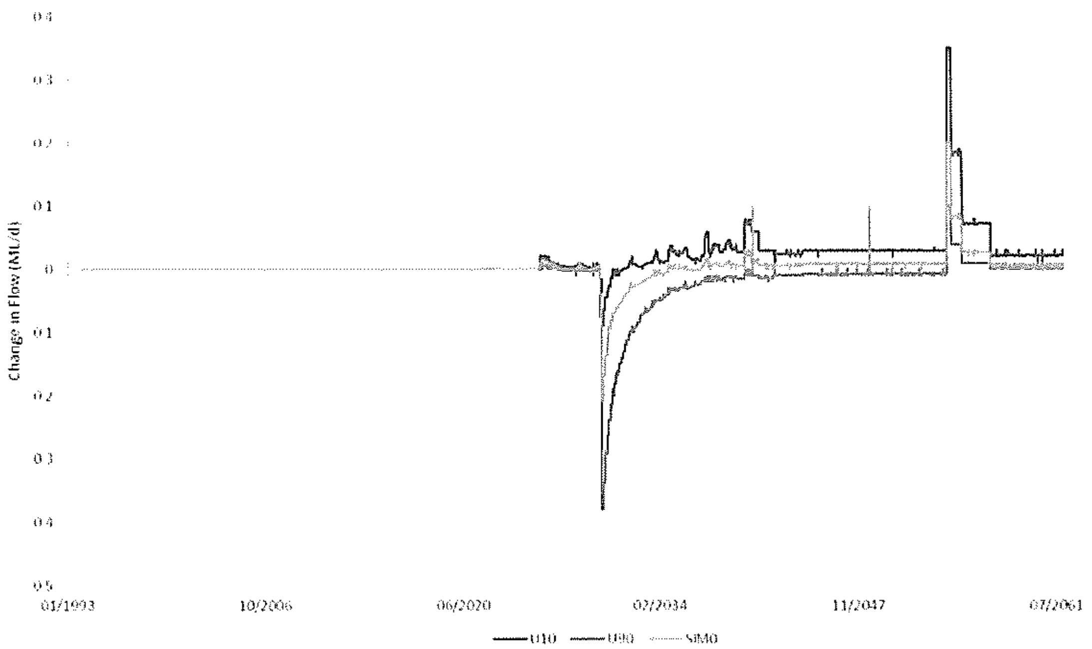


Figure 4.92: Predicted Change to Surface Water Flow – Low Rainfall Scenario (Wolgan River Swamp Upper Swamp)

From **Figure 4.92** the modelled change, initially, ranges between a decline of 0.1ML/d and a decline of 0.4ML/d. Following that initial period, the modelled change ranges between an increase of 0.02ML/d and a decline of 0.01ML/d. The results presented in **Figure 4.92** are very similar to that presented in **Figure 4.47**.

Tri-Star Swamp

Figure 4.89 presents the 10th and 90th difference in modelled groundwater elevation at the end of mining in December 2053 (SP190) for the Low Rainfall Scenario. **Figure 4.90** presents the equivalent drawdown during the recovery phase in December 2091 (SP197).

The results presented in **Figure 4.89** and **Figure 4.90** are, essentially, the same as that presented in **Figure 4.44** and **Figure 4.45** (median rainfall conditions) and also **Figure 4.69** and **Figure 4.70** (high rainfall conditions). i.e. there is little difference to predicted change because of the assumed climatic scenario.

Figure 4.93 presents the modelled difference in groundwater level at selected monitoring locations in Tri-Star Swamp.

Comparing **Figure 4.93** with **Figure 4.48** and **Figure 4.73**, the results are very similar. From **Figure 4.93**, the modelled decline in groundwater level in piezometer TS1 is 0.7m (least drawdown results) or 1.Sm (most drawdown results). At piezometer TS2, the modelled change is a decrease of 0.2m (least drawdown results) or 0.9m (most drawdown results). At piezometer TS3, the modelled change is a decrease of 6m in the least drawdown results and a 10m decrease for the most drawdown results. Piezometer **AP9PR** indicates a sharp drop due to influence of the Stacked Drains, as does piezometer AP10PR_150 and AP10PR_248. Modelling does not indicate that groundwater in Tri-Star Swamp piezometers will occur.

Figure 4.94 presents the modelled change in surface water flow at Tri-Star Swamp during the Low Rainfall Scenario.

Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:30,000	

0 0.5 1
km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs – Low Rainfall Scenario (Tri-Star Swamp)

FIGURE: 4.93

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D031_PredictiveUncertainty_TriStar_UNC190.mxd
Reference © Department of Finance Services & Innovation 2018

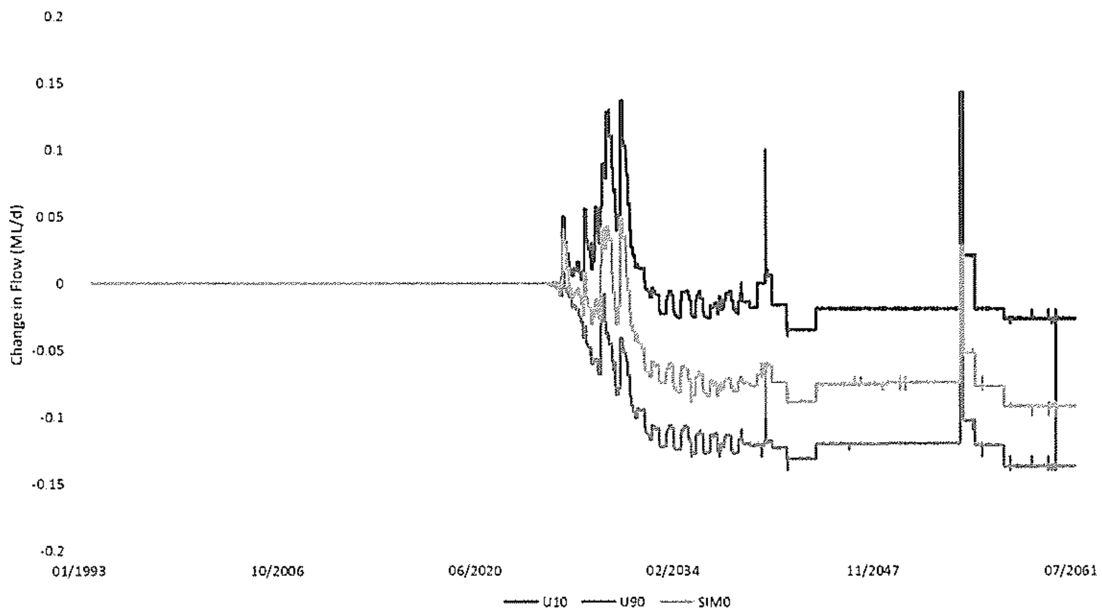


Figure 4.94: Predicted Change to Surface Water Flow – Low Rainfall Scenario (Tri-Star Swamp)

From **Figure 4.94**, the modelled change in surface water flow is essentially the same as that predicted in the median rainfall scenario (refer **Figure 4.49**) and high rainfall scenario (refer **Figure 4.74**). Accordingly, a discussion of the results is not repeated.

Wolgan River Swamp

Figure 4.89 presents the range of modelled drawdown due to the Proposal at the end of mining in December 2053 (SP190) for the Low Rainfall Scenario. **Figure 4.90** presents the equivalent drawdown during the recovery phase in December 2091 (SP197).

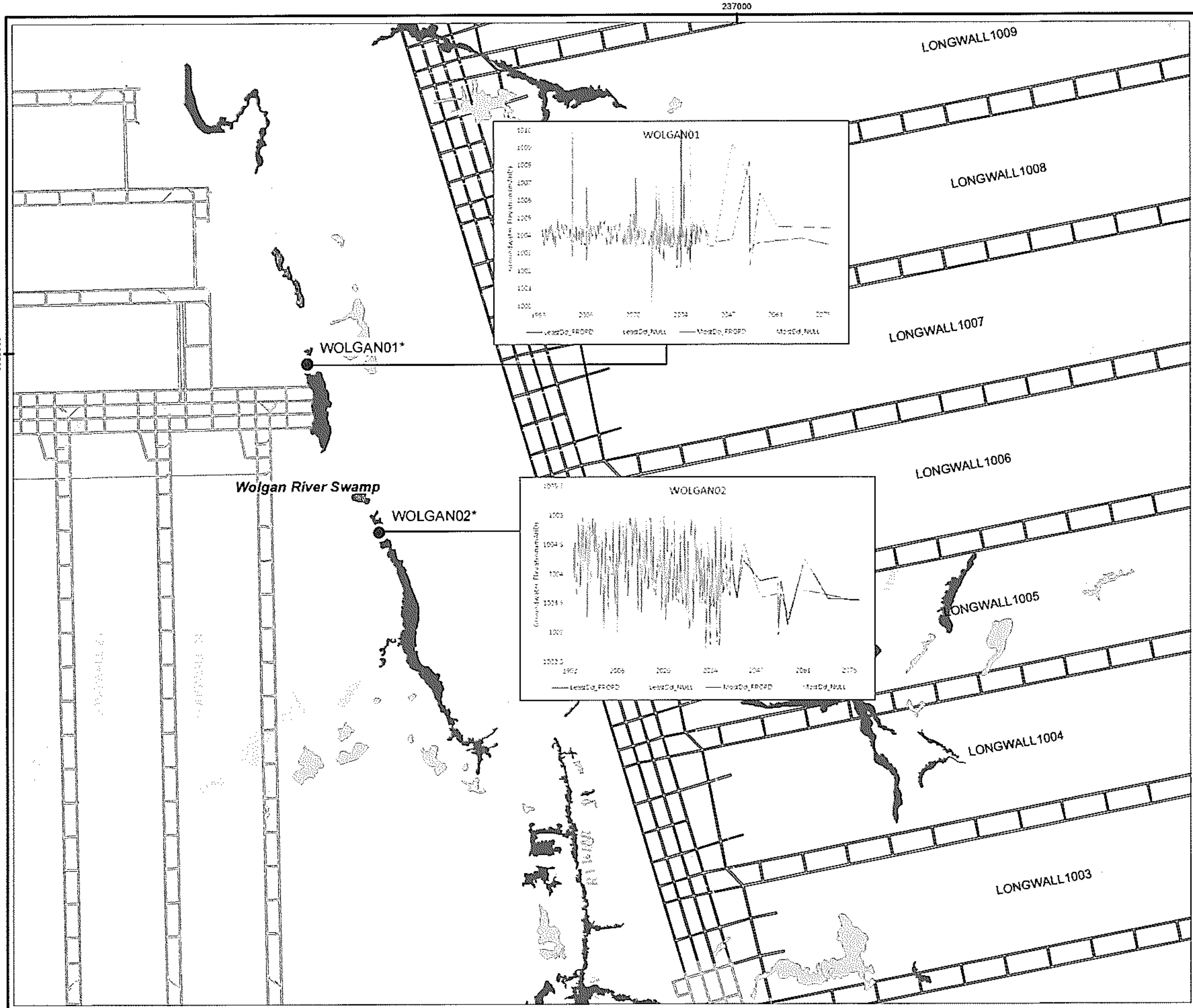
From **Figure 4.89**, drawdown in the Banks Wall Sandstone (Layer 13) is less than 0.5m. From **Figure 4.90**, the drawdown in the Banks Wall Sandstone during the recovery phase is also less than 0.5m. Accordingly, it is not expected that groundwater hydrographs for Wolgan River Swamp will indicate a significant drawdown.

Figure 4.95 presents modelled groundwater hydrographs in Wolgan River Swamp. As noted previously, there are no swamp monitoring piezometers currently installed in Wolgan River Swamp, therefore synthetic locations were used.

From **Figure 4.95**, modelling predicts there will be negligible change to swamp water level in Wolgan River Swamp due to the Proposal.

Figure 4.96 presents the modelled change to groundwater contribution to surface water flow in Wolgan River Swamp.

From **Figure 4.96**, the modelled change in surface water flow, initially, ranges between an increase of 0.1ML/d (1.1L/s) and a decline of 0.5ML/d (5.7L/s). Following that initial period the modelled change ranges between an increase of 0.05ML/d (0.6L/s) and a decline of 0.15ML/d (1.7L/s).



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

* Synthetic monitoring location, which doesn't exist.

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1 | Date: 18-Oct-2019

Drawn By: JZ | Checked By: JB

Scale 1:15,000

0 0.25 0.5
km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs – Low Rainfall Scenario (Wolgan River Swamp)

FIGURE: 4.95

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D051_PredictiveUncertainty_WRS_U190.mxd
Reference © Department of Finance, Services & Innovation 2018

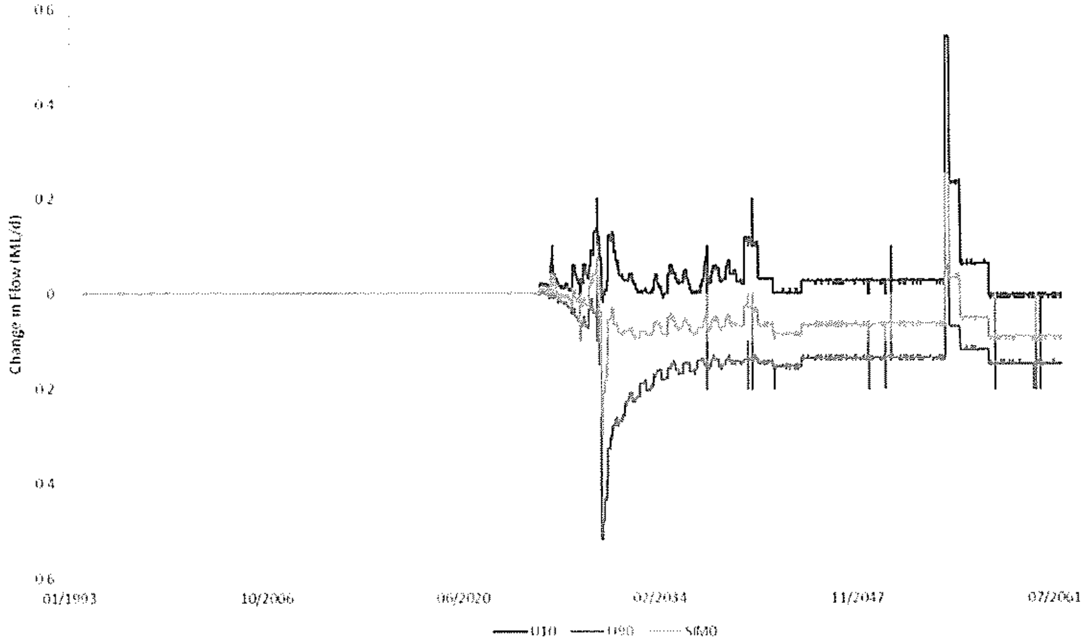


Figure 4.96: Predicted Change to Surface Water Flow – Low Rainfall Scenario (Wolgan River Swamp)

Twin Gully Swamp

Figure 4.89 presents the 10th and 90th difference in modelled groundwater elevation at the end of mining in December 2053 (SP190) for the Low Rainfall Scenario. **Figure 4.90** presents the equivalent drawdown during the recovery phase in December 2091 (SP197).

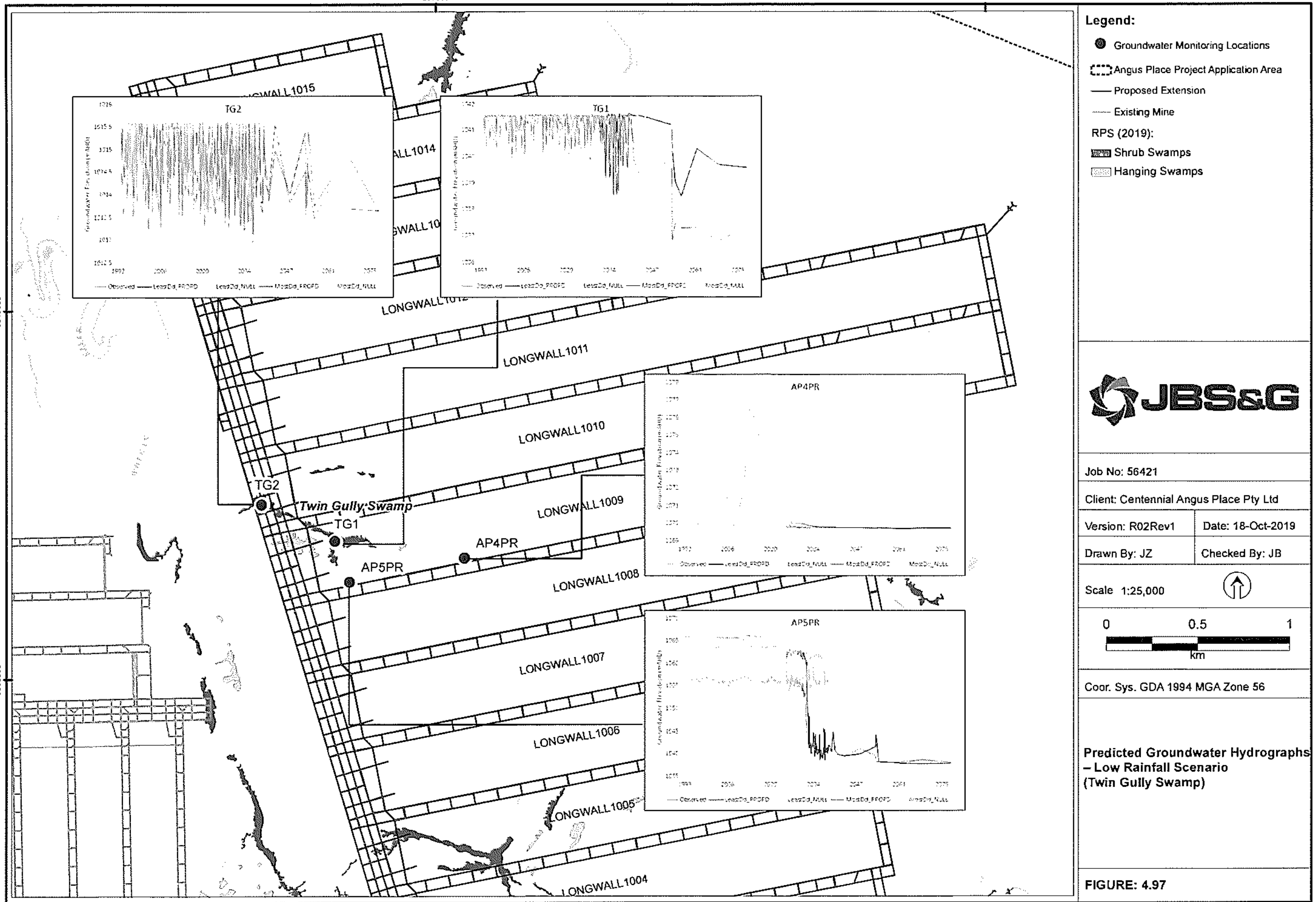
Figure 4.97 presents selected hydrographs in the vicinity of Twin Gully Swamp for the Low Rainfall Scenario.

From **Figure 4.97**, the results for the Low Rainfall Scenario are quite similar to that predicted in the median rainfall condition (refer **Figure 4.53**) and the High Rainfall Scenario (refer **Figure 4.77**).

From **Figure 4.97**, there is minimal modelled drawdown in piezometer TG2. From **Figure 4.97**, in monitoring piezometer TG1, modelled drawdown ranges up to 2m in the 'least drawdown' results and is 4.5m in the 'most drawdown' results. There is minimal modelled change in piezometer AP4PR in **Figure 4.97**. At monitoring piezometer AP5PR, the 'least drawdown' results are a decrease of 16m and the 'most drawdown' results are a decrease of 22m.

Figure 4.98 presents the modelled change in surface water flow at Twin Gully in the Low Rainfall Scenario.

From **Figure 4.98**, the modelled change is an increase of 0.08ML/d (0.9L/s) in the 10th percentile results in early time and is a 0.01ML/d (0.1L/s) decrease in the 90th percentile results. From **Figure 4.98**, at late time, there is a predicted increase of 0.01ML/d (0.1L/s) in the 10th percentile results and a 0.03ML/d (0.3L/s) decrease in the 90th percentile results.



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Reference: © Department of Finance, Services & Innovation 2018

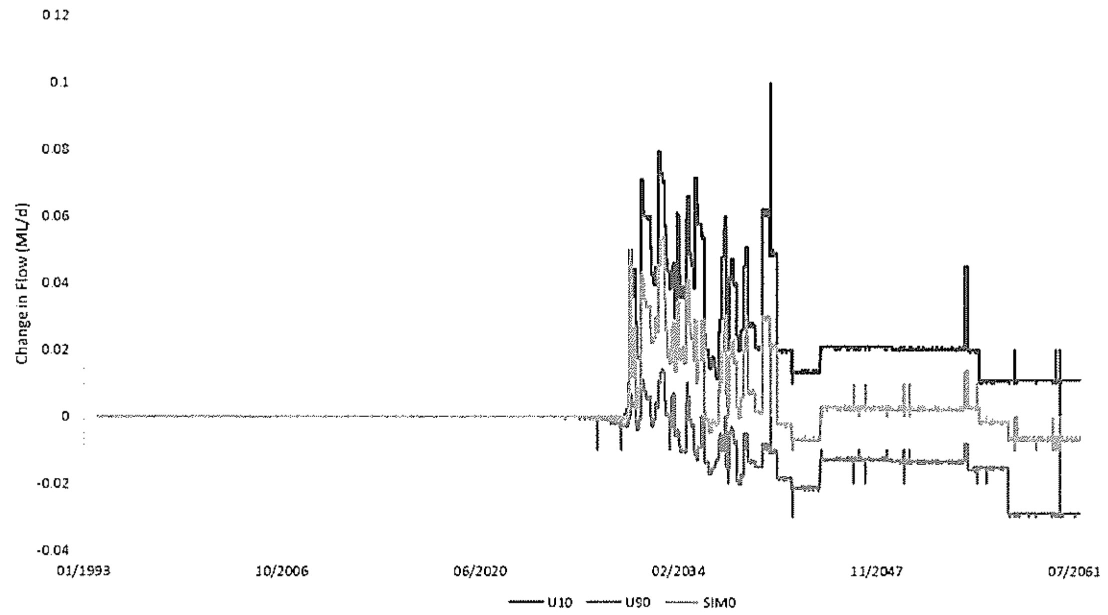


Figure 4.98: Predicted Change to Surface Water Flow – Low Rainfall Scenario (Twin Gully Swamp)

Crocodile Swamp

Figure 4.99 presents the calculated drawdown in the vicinity of Crocodile Swamp in December 2053 (SP190). As per the approach used above, the 10th percentile and 90th percentile from the prediction simulations incorporating uncertainty analysis were used to generate the figure.

Figure 4.100 presents the calculated drawdown during the recovery phase in December 2091 (SP197).

From **Figure 4.99**, there is significant drawdown in the Banks Wall Sandstone that underlies Crocodile Swamp at the end of mining in 2053. From **Figure 4.100**, the drawdown in the Banks Walls Sandstone is still significant beneath Crocodile Swamp in 2091.

It is highlighted that the results presented in **Figure 4.99** and **Figure 4.100** are very similar to that presented for the median rainfall conditions (refer **Figure 4.56** and **Figure 4.57**).

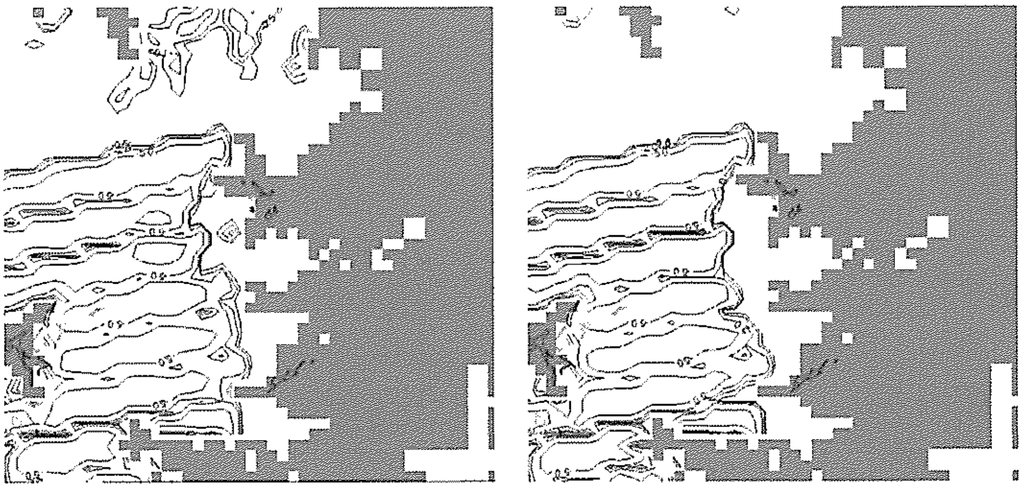
Figure 4.101 presents modelled groundwater hydrographs in the vicinity of Crocodile Swamp.

From **Figure 4.101**, the modelled drawdown in synthetic piezometer CROC01 ranges between 0.1m up to 1.5m and is very similar to that found in the simulations considering median rainfall conditions.

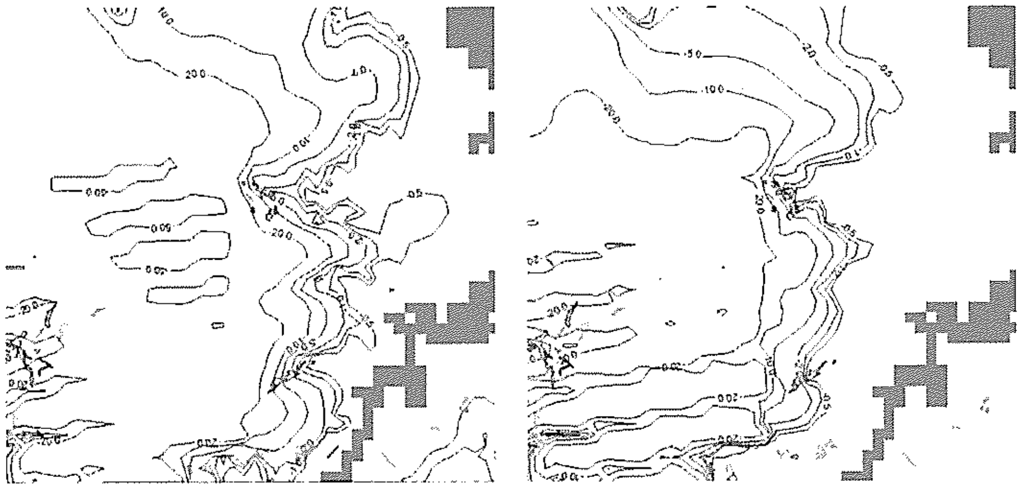
From **Figure 4.101**, the modelled drawdown in standpipe piezometer AP1104 ranges between 0.2 and 0.4m. As per the findings for median rainfall conditions, model results for vibrating wire piezometer AP1104 indicates complete depressurisation of hydrogeologic units below 170mBGL.

Figure 4.102 presents the modelled change in surface water flow due to the Proposal in Crocodile Swamp.

From **Figure 4.102**, the modelled change ranges between no change and a decline of 0.005ML/d (0.06L/s).

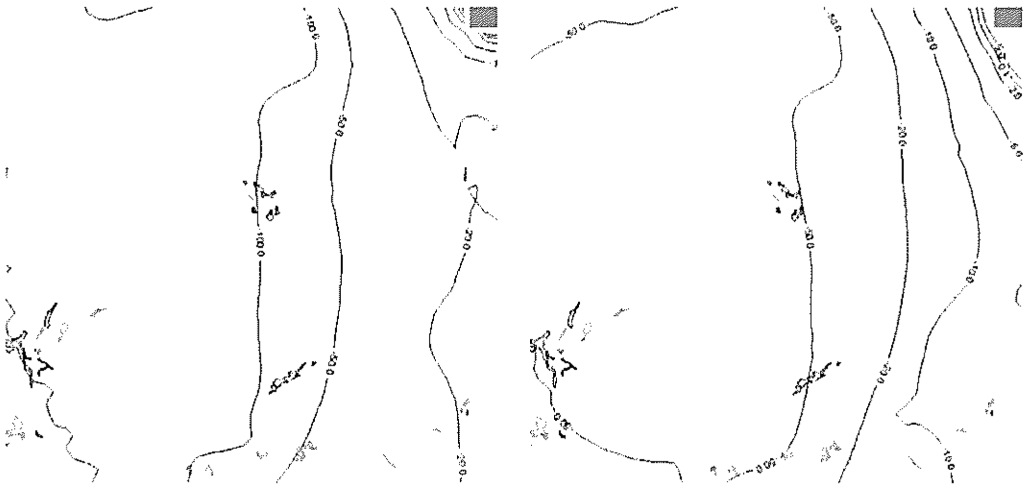


Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)

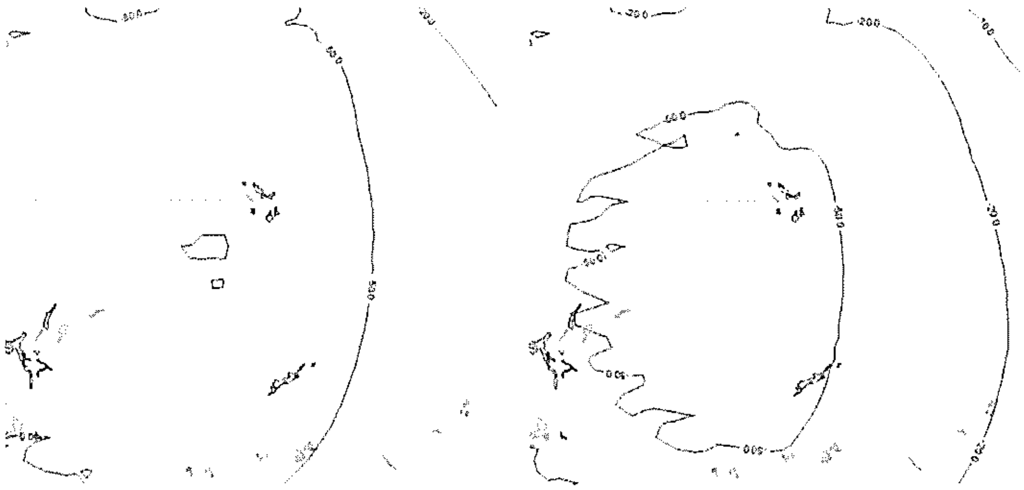


Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)

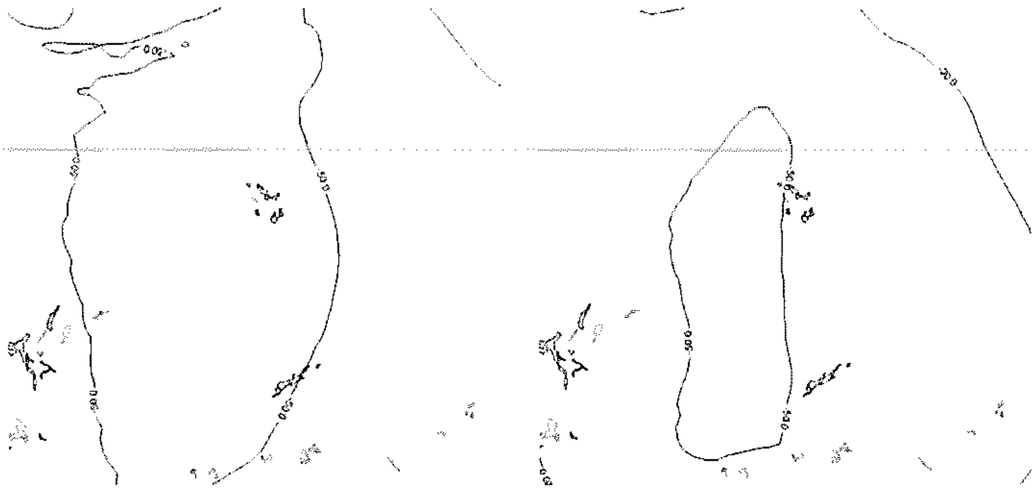
Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)



Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)



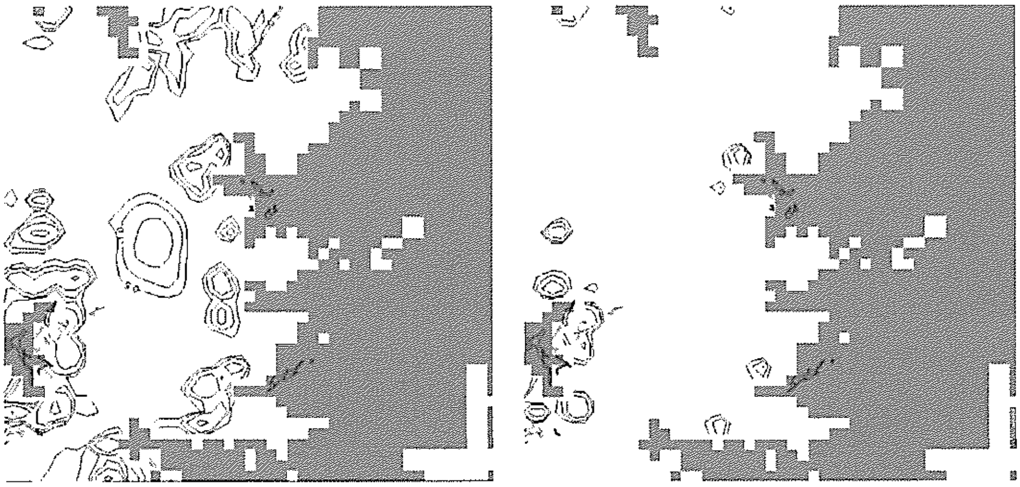
Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



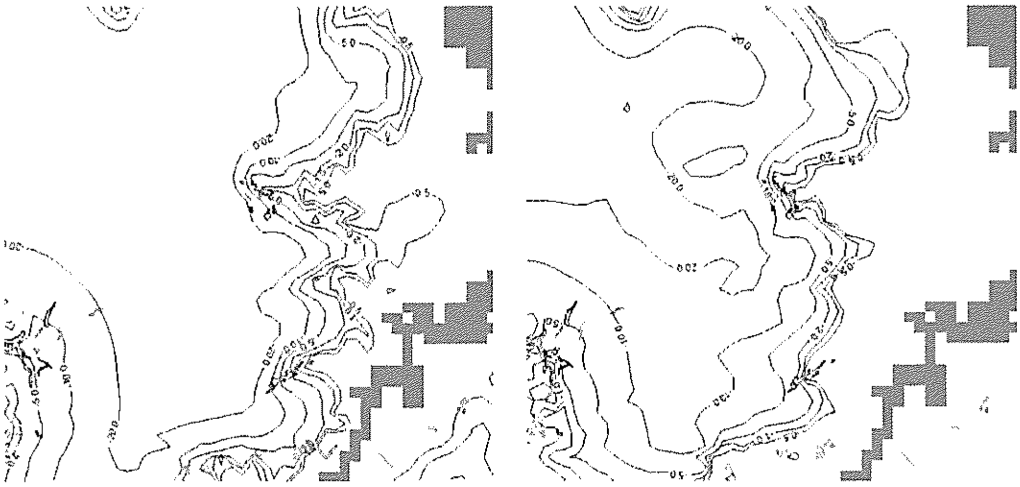
Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

- 'Pinched-out' cells - Drain (DRN) cells

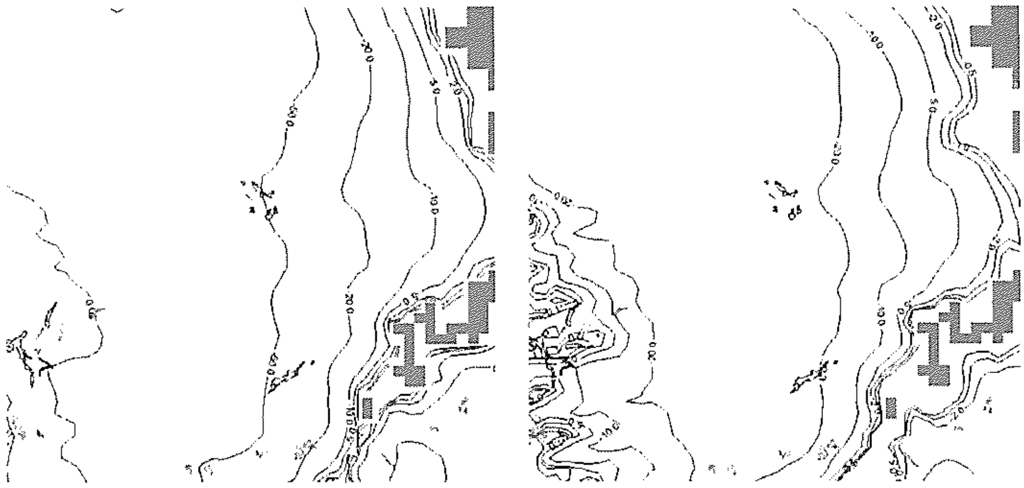
Figure 4.99: Predicted Drawdown (Low Rainfall Scenario) – End of Mine Life: 31 December 2053 (5P190) – Crocodile Swamp and Birds Rock Swamp



Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)

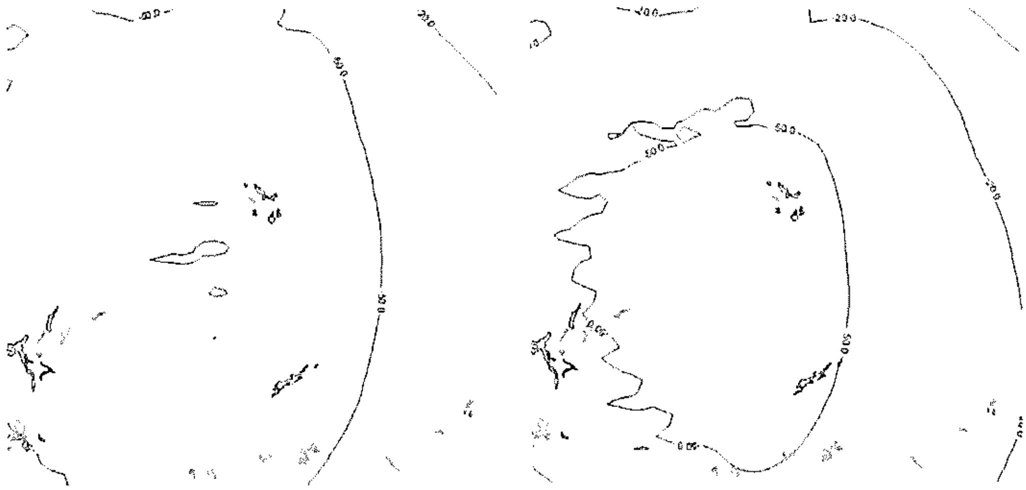


Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)



Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)

Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)

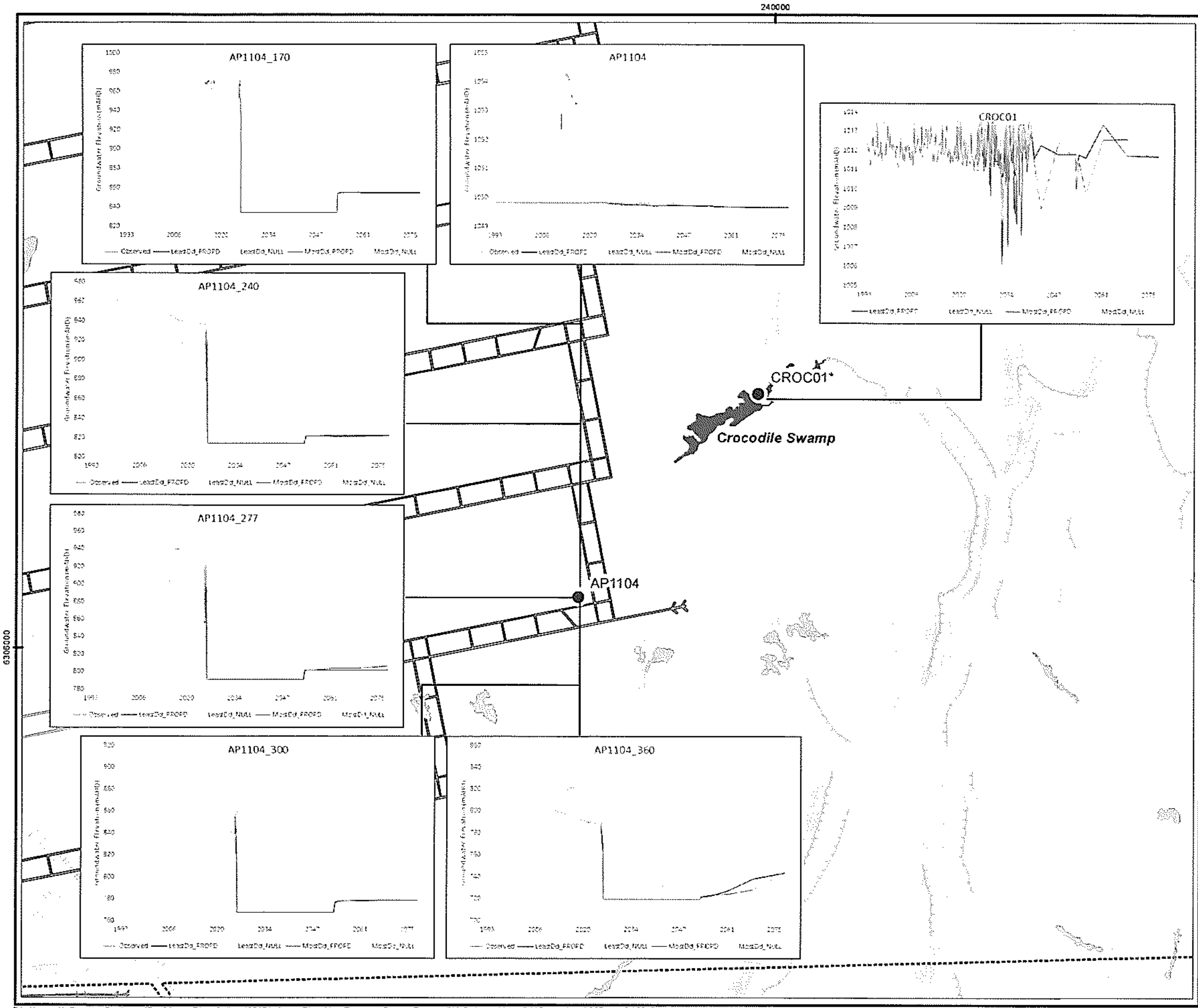


Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)

Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

▩ - 'Pinched-out' cells - Drain (DRN) cells

Figure 4.100: Predicted Drawdown (Low Rainfall Scenario) – Recovery Phase: 31 December 2091 (SP197) – Crocodile Swamp and Birds Rock Swamp



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

* Synthetic monitoring location, which doesn't exist.

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB

Scale 1:15,000

0 0.25 0.5
km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs – Low Rainfall Scenario (Crocodile Swamp)

FIGURE: 4.101

File Name N:\Projects\Centennial\Coal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D052_PredictiveUncertainty_Crocodile_U190.mxd
Reference © Department of Finance Services & Innovation 2018

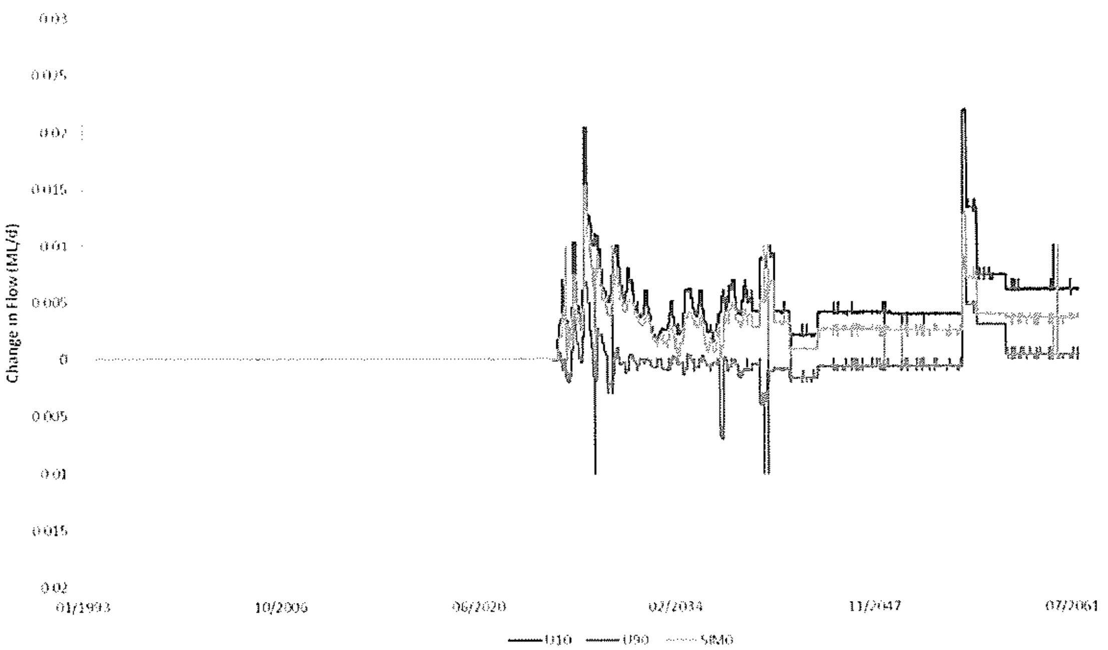


Figure 4.102: Predicted Change to Surface Water Flow – Low Rainfall Scenario (Crocodile Swamp)

<u>Birds Rock Swamp</u>

Figure 4.99 presents the modelled drawdown in December 2053 (SP190) in the vicinity of Birds Rock Swamp. **Figure 4.100** presents the modelled drawdown during the recovery phase in December 2091 (SP197) at the same extent.

From **Figure 4.99**, there is significant drawdown in the Banks Wall Sandstone that underlies Birds Rock Swamp at the end of mining in 2053. **Figure 4.100** indicates that drawdown in the Banks Walls Sandstone is still significant beneath Birds Rock Swamp in 2091.

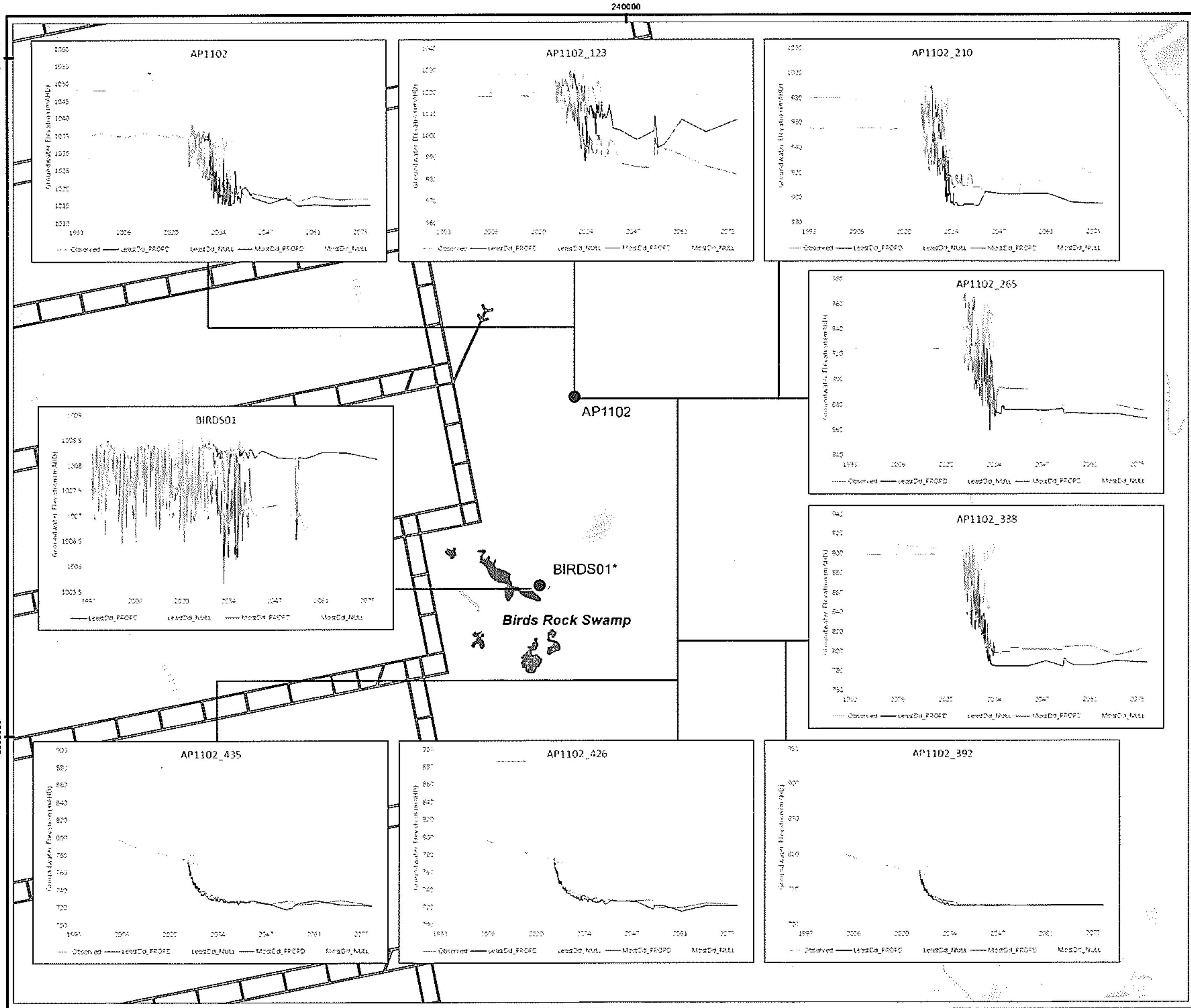
Figure 4.103 presents groundwater hydrographs in the vicinity of Birds Rock Swamp. As noted above, a swamp monitoring piezometer is not currently installed in Birds Rock Swamp, therefore a synthetic monitoring location was used instead.

From **Figure 4.103**, modelling indicates that Birds Rock Swamp may experience a drawdown of between 0.2m and 1.4m. The magnitude of drawdown is slightly higher than that presented in **Figure 4.60** with respect to median flow conditions but not significantly so.

From **Figure 4.103**, standpipe piezometer AP1102 is influenced by its proximity to the 1000 Panel Area and the range of calculated drawdown is similar to that presented in **Figure 4.60** for median rainfall conditions. From **Figure 4.103**, model results at vibrating wire piezometer AP1102 indicates significant depressurisation effects due to mining of the 1000 Panel Area below 210mBGL, as is expected.

Figure 4.104 presents the modelled change to groundwater contribution to surface water flow due to the Proposal.

From **Figure 4.104**, modelling predicts an initial, short-lived, increase in groundwater contribution to surface water flow up to 0.1ML/d. The modelled increase is due to the effect of the changes to hydraulic properties of the uppermost model cell. From **Figure 4.104**, the modelled change in flow ranges between no change and a decline of 0.04ML/d (0.5L/s).



Legend:

- Groundwater Monitoring Locations
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine

RPS (2019):

- Shrub Swamps
- Hanging Swamps

* Synthetic monitoring location, which doesn't exist.

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Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1 | Date: 18-Oct-2019

Drawn By: JZ | Checked By: JB

Scale 1:15,000

0 0.25 0.5 km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs - Low Rainfall Scenario (Birds Rock Swamp)

FIGURE: 4.103

File Name N:\Projects\Centennial\Coal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D053_PredictiveUncertainty_BirdsRock_U190.mxd
Reference © Department of Finance Services & Innovation 2018

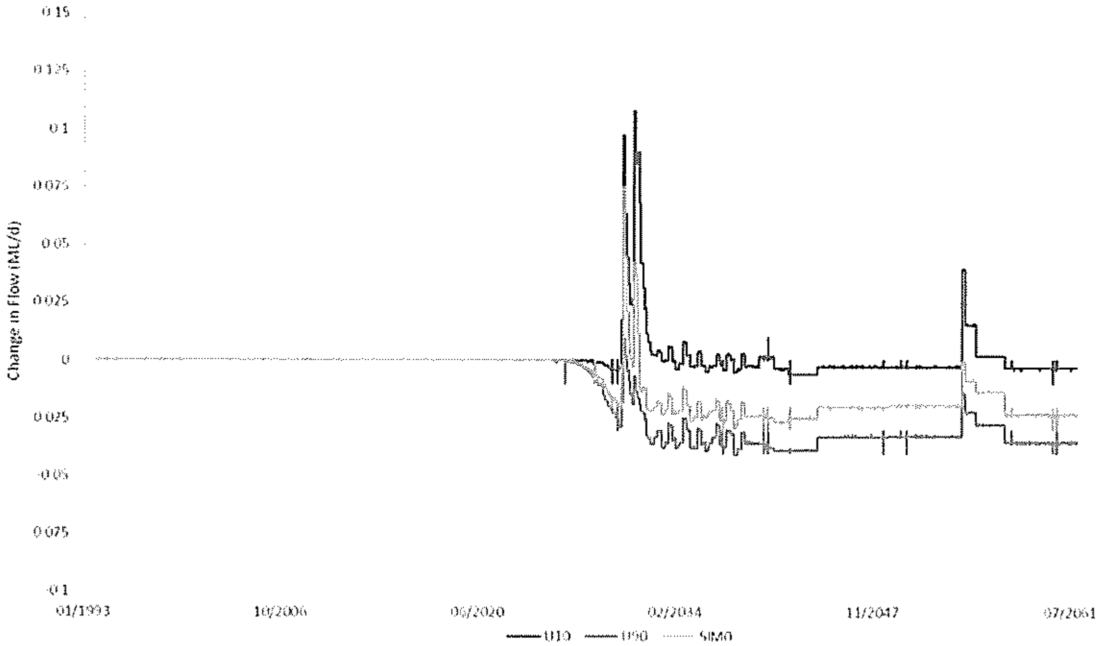


Figure 4.104: Predicted Change to Surface Water Flow – Low Rainfall Scenario (Birds Rock Swamp)

<u>Trail Six</u>

Figure 4.105 presents the modelled difference in groundwater elevation between Proposed and Null Case for the Low Rainfall Scenario. The 10th (most negative) and 90th (least negative) percentile differences are presented in **Figure 4.105**. **Figure 4.105** presents model output in December 2053 (SP190), which is coincident with the end of mine life.

Figure 4.106 presents the modelled difference in groundwater elevation in December 2091 (SP197).

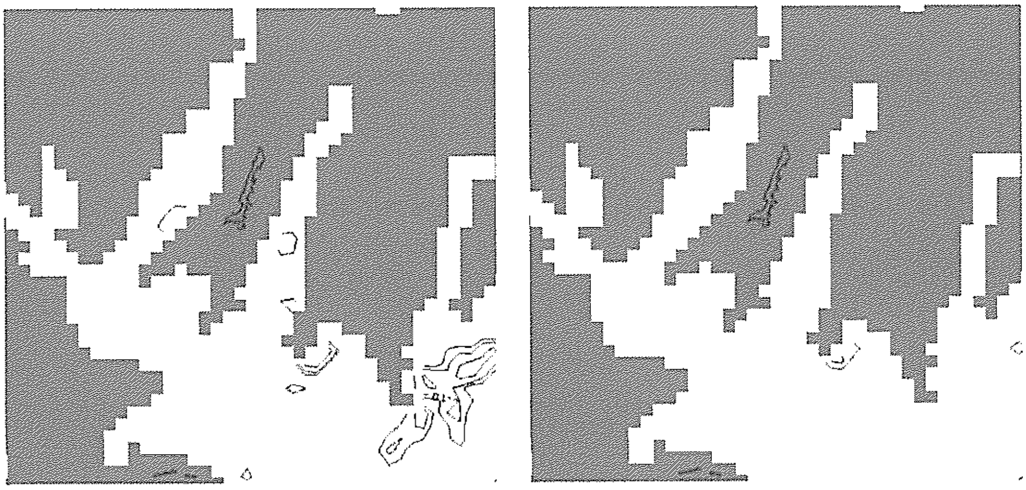
The results presented in **Figure 4.105** and **Figure 4.106** are very similar to that presented for the median rainfall conditions and High Rainfall Scenario results.

Figure 4.107 presents the difference in groundwater level at selected monitoring locations in the vicinity of Trail Six Swamp.

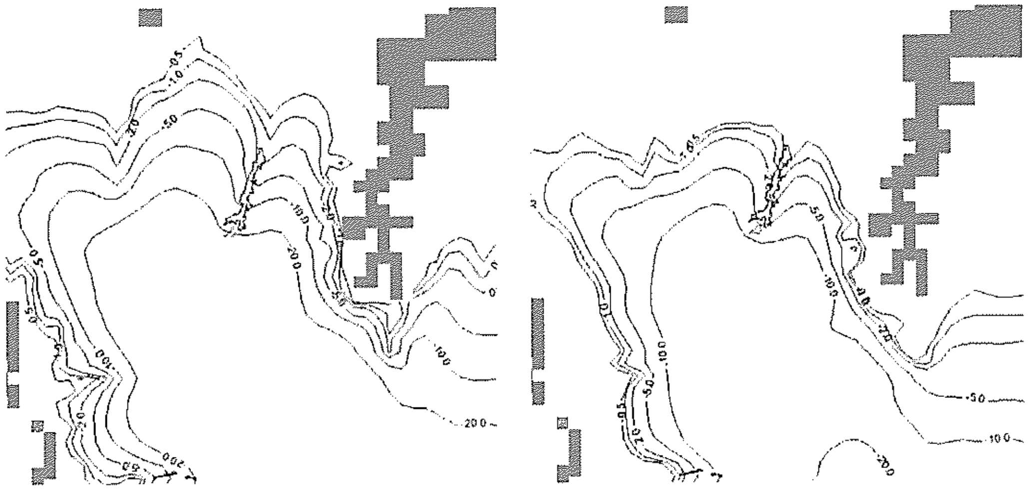
From **Figure 4.107**, the drawdown in piezometer XS1 ranges between 1.5m and 9m and is similar to that found in the median rainfall condition results. From **Figure 4.107**, each of the vibrating wire piezometer sensors at site AP1107 shows influence from the Stacked Drains. At monitoring location AP1107_081, the drawdown is 70m in the least drawdown results and is 90m in the most drawdown results. In general, the results presented in **Figure 4.107** are very similar to that presented in **Figure 4.64** (median rainfall conditions).

Figure 4.108 presents the modelled change in surface water flow in Trail Six Swamp considering Low Rainfall conditions.

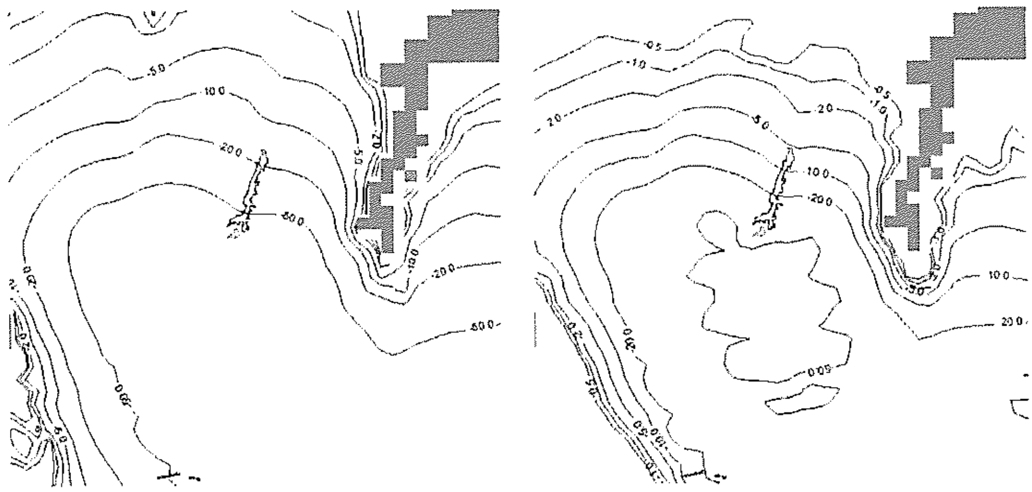
From **Figure 4.108**, the predicted change in surface water flow in Trail Six Swamp is an increase of 0.08ML/d (0.9L/s) in the 10th percentile results in early time and a 0.03ML/d (0.3L/s) decrease in the 90th percentile results. From **Figure 4.108**, at late time, the predicted change is a 0.01ML/d (0.1L/s) increase in the 10th percentile results and a 0.04ML/d (0.5L/s) decrease in the 90th percentile results.



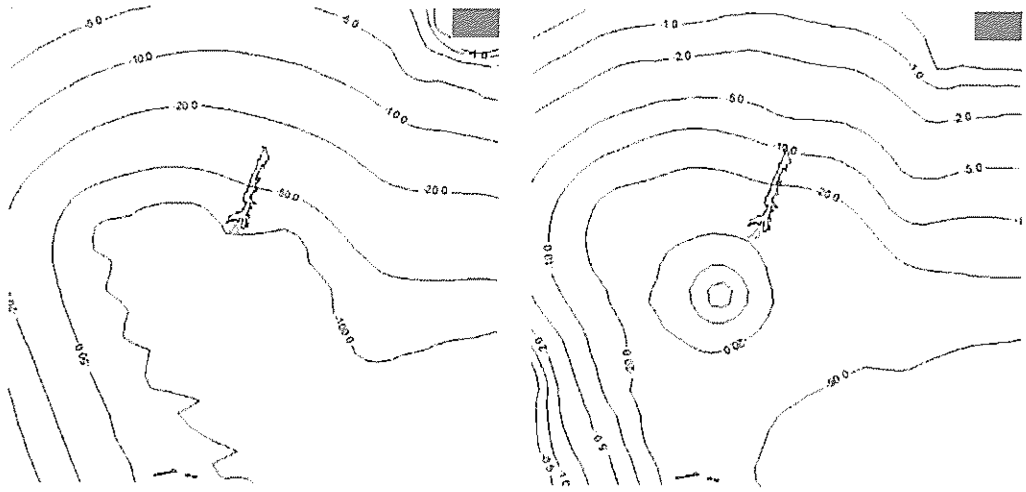
Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)



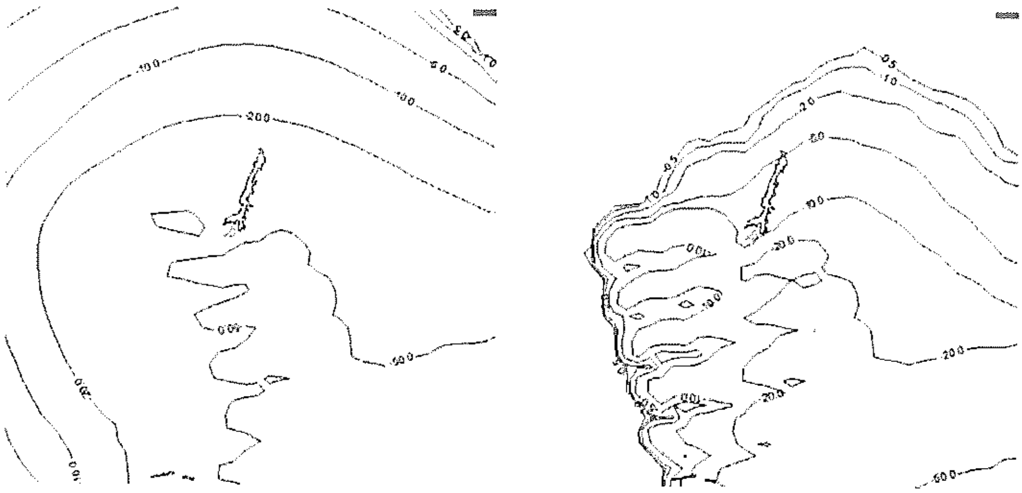
Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)



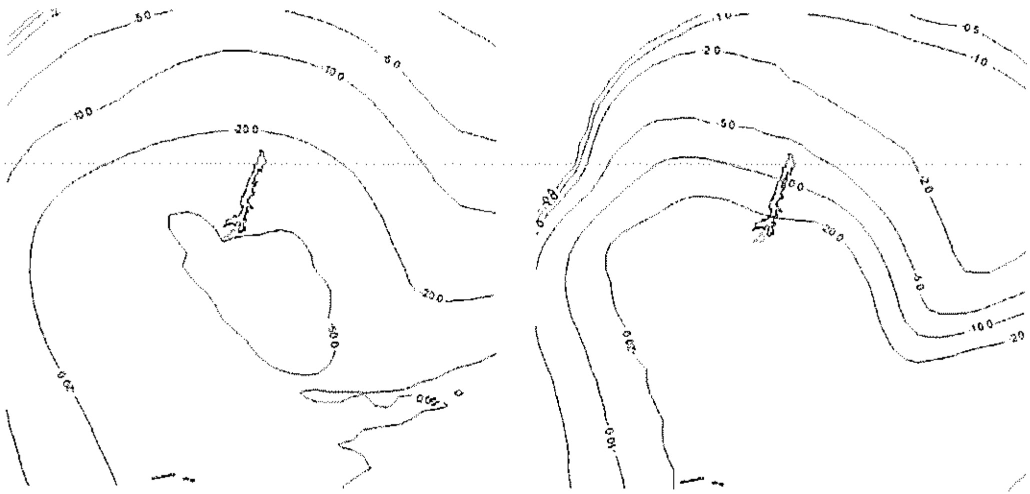
Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)



Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)



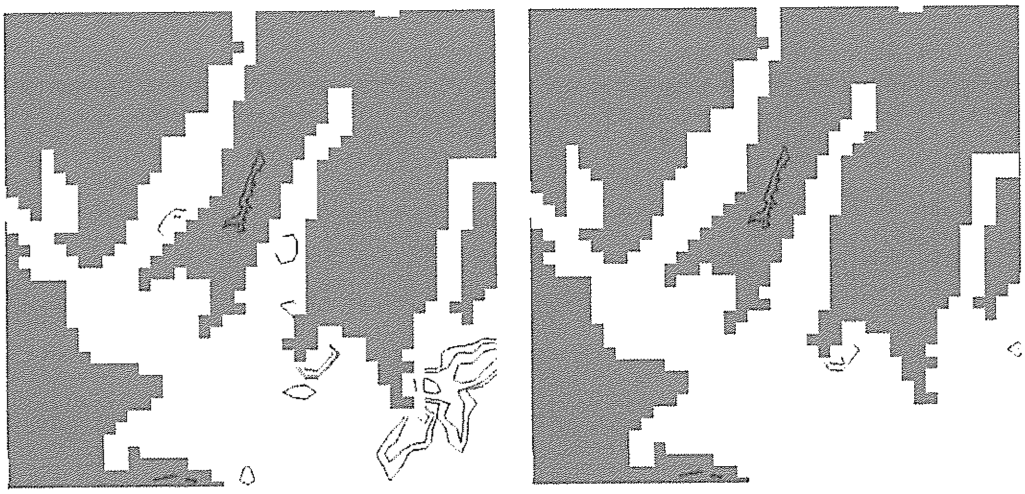
Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



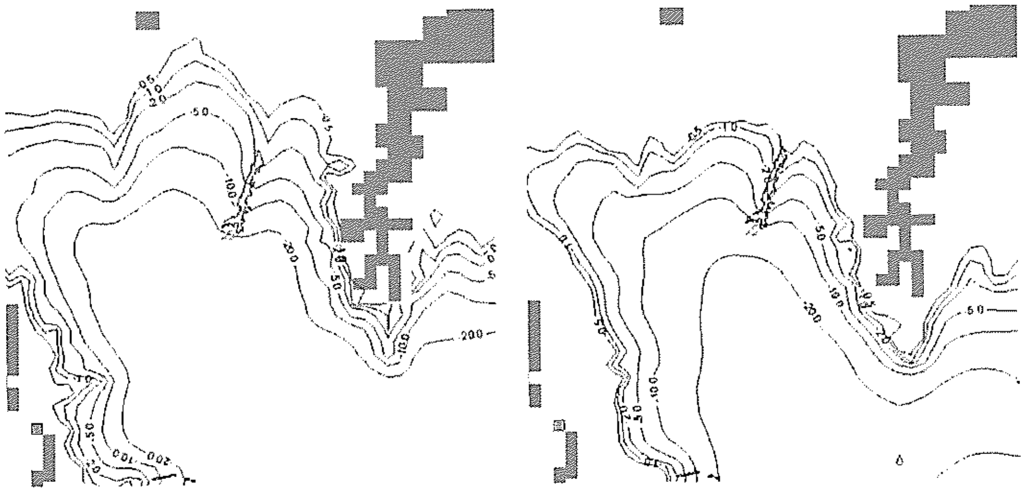
Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

- 'Pinched-out' cells - Drain (DRN) cells

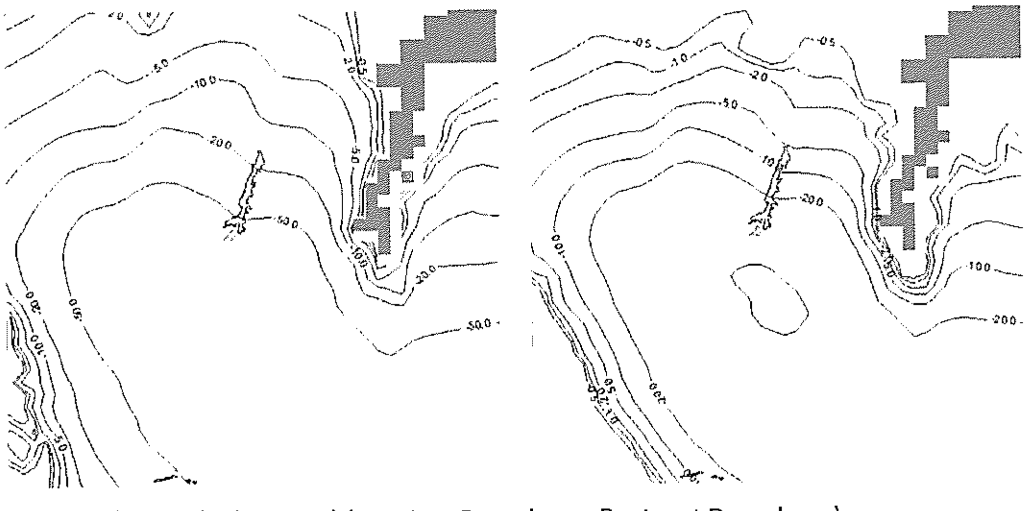
Figure 4.105: Predicted Drawdown (Low Rainfall Scenario) – End of Mine Life: 31 December 2053 (SP190) – Trail Six Swamp



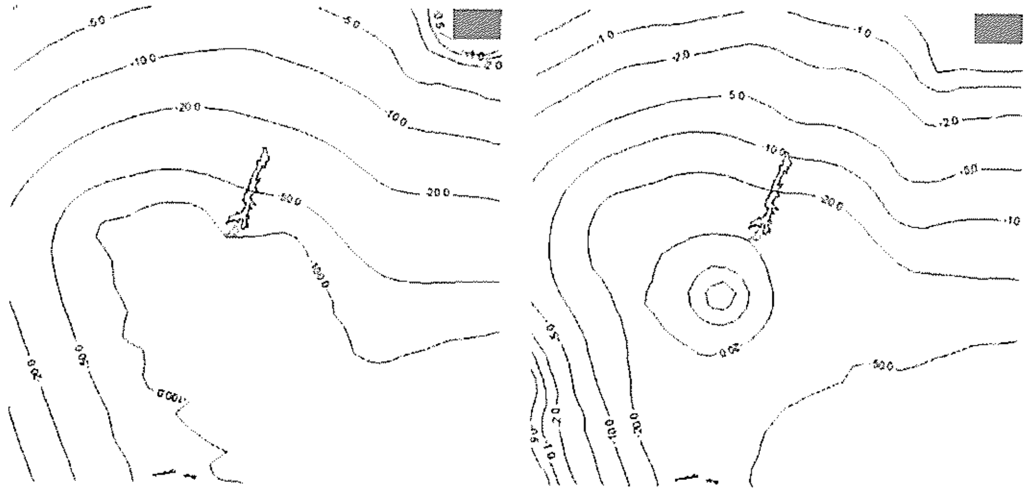
Layer 9 (Sandstone between YS4 and YS5) (L – Most Drawdown; R – Least Drawdown)



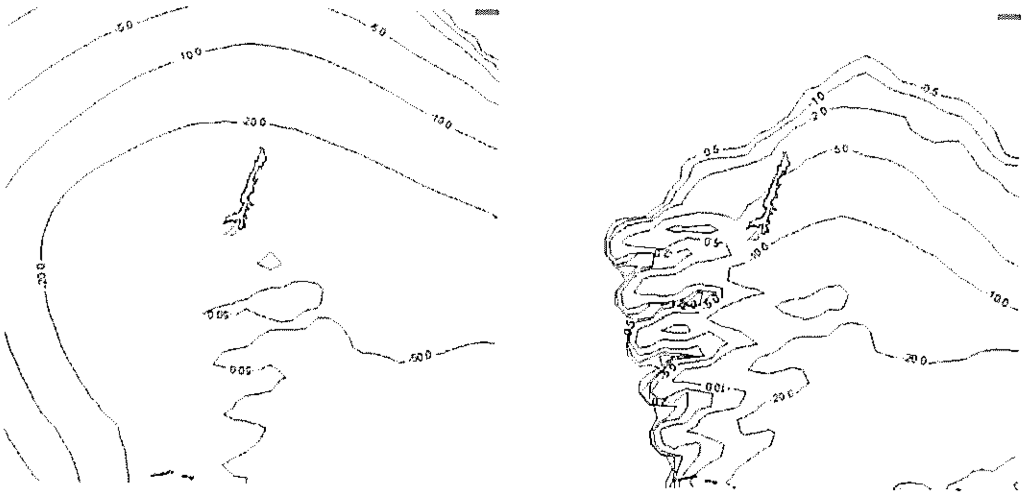
Layer 13 (Banks Wall Sandstone) (L – Most Drawdown; R – Least Drawdown)



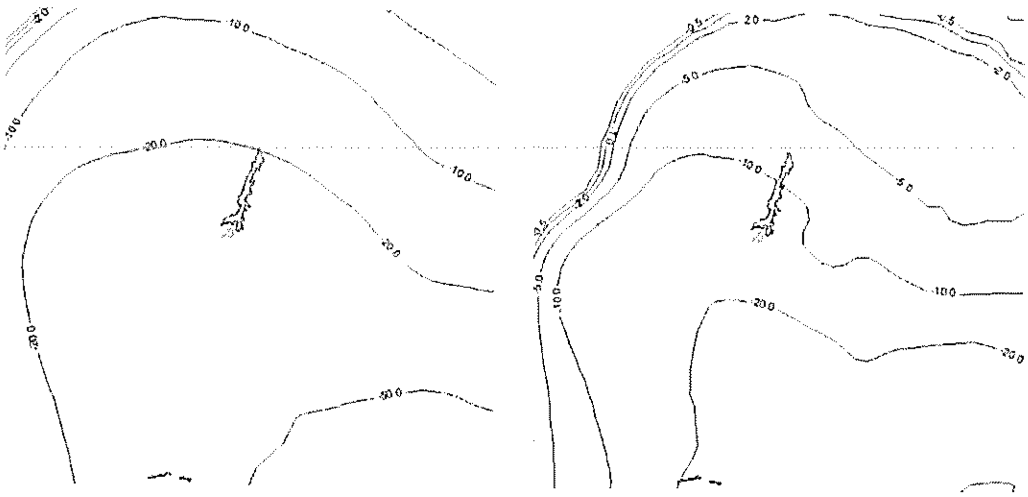
Layer 15 (Mt York Claystone) (L – Most Drawdown; R – Least Drawdown)



Layer 18 (Katoomba Seam) (L – Most Drawdown; R – Least Drawdown)



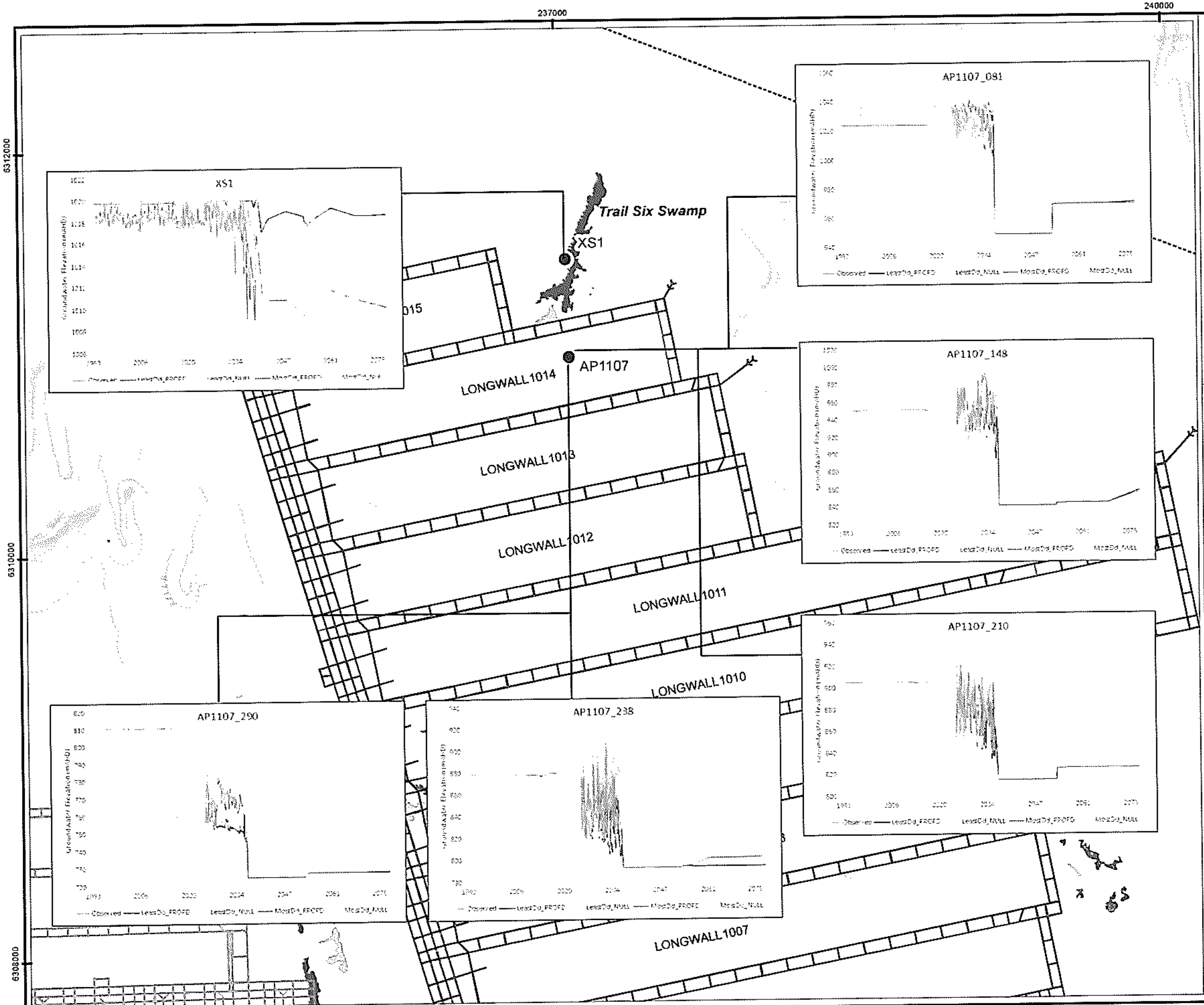
Layer 21 (Denman Formation) (L – Most Drawdown; R – Least Drawdown)



Layer 24 (Lithgow Seam) (L – Most Drawdown; R – Least Drawdown)

▨ - 'Pinched-out' cells - Drain (DRN) cells

Figure 4.106: Predicted Drawdown (Low Rainfall Scenario) – Recovery Phase: 31 December 2091 (SP197) – Trail Six Swamp



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Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB

Scale 1:25,000

0 0.5 1
km

Coor. Sys. GDA 1994 MGA Zone 56

Predicted Groundwater Hydrographs – Low Rainfall Scenario (Trail Six Swamp)

FIGURE: 4.107

File Name N:\Projects\Centennial\Coal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D033_PredictiveUncertainty_TrailSix_UNC190.mxd
Reference © Department of Finance Services & Innovation 2018

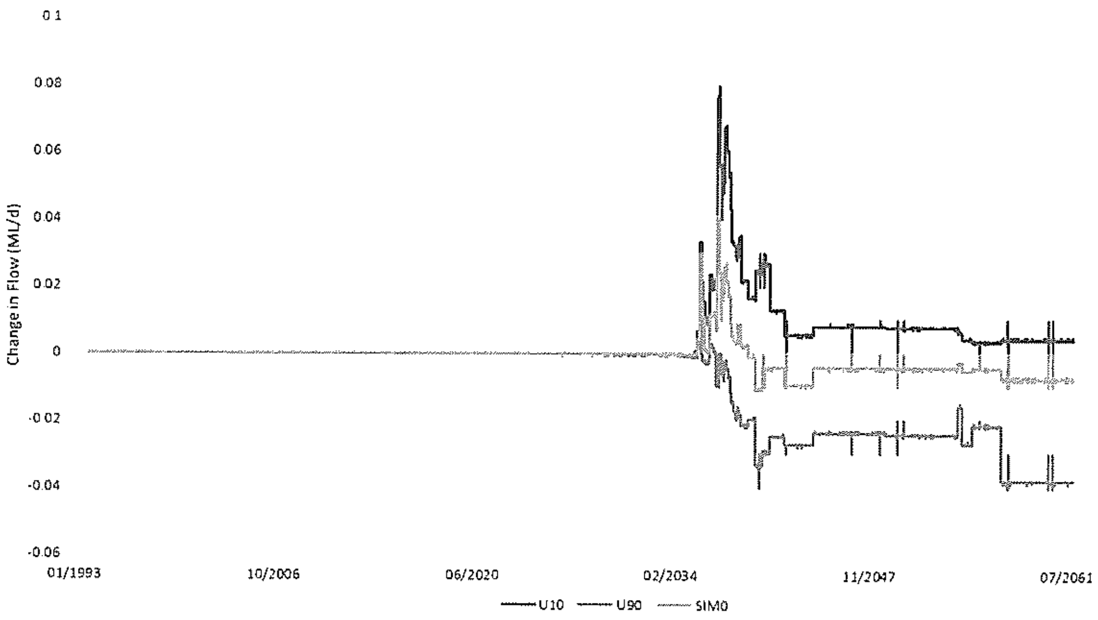

Figure 4.108: Predicted Change to Surface Water Flow – Low Rainfall Scenario (Trail Six Swamp)

4.17 Summary of Model Results including Uncertainty Analysis

Prediction simulations have been prepared incorporating uncertainty analysis. In addition, climate change scenarios have also been prepared.

Model results indicated that there is expected to be a decline in water table level within each of the THPSS in the vicinity of the 1000 Panel Area, with the exception of Wolgan River Swamp Upper Swamp and Wolgan River. Wolgan River Swamp Upper Swamp and Wolgan River Swamp have a significant contributing catchment, both from a groundwater and surface water perspective. Accordingly, there is negligible predicted change in water table level within those swamps.

Modelling indicates that the change in surface water flow is expected to be minor, with an initial increase in surface water flow due to changes to hydraulic properties in the uppermost cell above the Stacked Drains, followed by a medium term and long term decrease, albeit of minor to moderate magnitude.

Long-term recovery of water table level beneath THPSS is not expected to occur within the 50 year post mining prediction period.

Consideration of High Rainfall and Low Rainfall Scenario results implies that predicted modelled changes under median rainfall conditions are consistent with either climate change scenario. i.e. there is limited influence of climate on model predictions.

Modelled combined mine dewatering, including Springvale Mine, is consistent with that found in the COSFLOW model, although the combined dewatering rate is higher in the updated model.

5. Licensing

5.1 Groundwater Licensable Take

There are several groundwater sources in the vicinity of Angus Place Colliery. The location of the groundwater sources is presented in **Figure 5.1**.

The approach adopted to determining groundwater licensable take was to identify the Stacked Drain cells associated with the Proposed and Null Cases and demarcate those cells according to groundwater source. The calculated licensable take from the Stacked Drain cells was then adjusted to account for change to the exchange between the groundwater sources, and also adjusted to account for change to surface water.

For change to surface water, where there was a licensable take from surface water, that amount was deducted from the groundwater licensable take. Conversely, where there was an increase in discharge from groundwater to surface water, that additional loss from groundwater was added to the licensable take identified by the Stacked Drain cells for the respective groundwater sources.

It is noted that, as presented in JBS&G (2019), during calibration of the SAPSWBM a factor of 20% was applied to outflow from the groundwater model to surface water, in order to fit manual gauging observations in Twin Gully and Tri-Star Swamps. Accordingly, that 20% whole-of-model calibration factor was also used during calculation of the licensing requirement with respect to surface water contribution.

It is further noted that, because Springvale Mine is also being maintained in a dewatered state (to 810mAHD) through to December 2053 (SP190) in the Proposed Case, except for the short period April 2025 through December 2027, consideration could be given to apportioning the change to surface water and the change to exchange between groundwater sources between the Amended Project (1000 Panel Area) and Springvale Mine. For simplicity however, it was decided to assign 100% of the change to surface water, as relevant, and 100% of the change to the exchange between groundwater sources to the Amended Project (1000 Panel Area) and 0% to Springvale Mine.

Accordingly, potential changes to surface water licensing requirements at Springvale Mine, due to the extension in duration of operation of Springvale Mine, have been accounted for by the Amended Project (1000 Panel Area). Similarly, potential changes to groundwater licensing requirements at Springvale Mine, outside of mine dewatering rates, due to the extension of operation of Springvale Mine have been accounted for by the Amended Project (1000 Panel Area).

Figure 5.2 presents the licensable take from groundwater sources for Angus Place Colliery due to the Proposal. It is noted that the licensable take in **Figure 5.2** includes 300, 700, 800, 900 and the 1000 Panel Areas compared to the Null Case. It is noted that 'wy' in **Figure 5.2** is an abbreviation of 'water year'. In Australia, a 'water year' is defined as being from July through to June. The water year is defined as July to June so that administration of water licensing can be conducted in the off-season (winter). **Table 5.1** presents the same data as **Figure 5.2**, however, in tabular format.

It is noted that predictive uncertainty results are not presented with respect to calculation of licensable take. Model output presented in **Figure 5.2** is from the Proposed and Null Case simulation using calibrated parameter values (referred to as model run 'SIM0').

It is noted that there was no significant groundwater take from groundwater sources other than the Sydney Basin Coxs River Groundwater Source and the Sydney Basin Richmond Groundwater Source.

Legend:
Angus Place Project Application Area
Proposed Extension
Existing Mine
Model Mesh
Groundwater Sources
Sydney Basin - Coxs River Sandstone
Sydney Basin - Richmond Sandstone
Sydney Basin - North
Coxs River Fractured Rock
Sydney Basin - Macquarie Bogan

JBS&G

Job No: 56421
Client: Centennial Angus Place Pty Ltd
Version: R02Rev1 | Date: 02-Sep-2019
Drawn By: JZ | Checked By: JB
Scale 1:200,000
0 2.5 5 km
Coor. Sys. GDA 1994 MGA Zone 56

Location of Groundwater Sources in the vicinity of Angus Place Colliery

FIGURE: 5.1

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D035_GWSources.mxd
Reference: © Department of Finance, Services & Innovation 2018

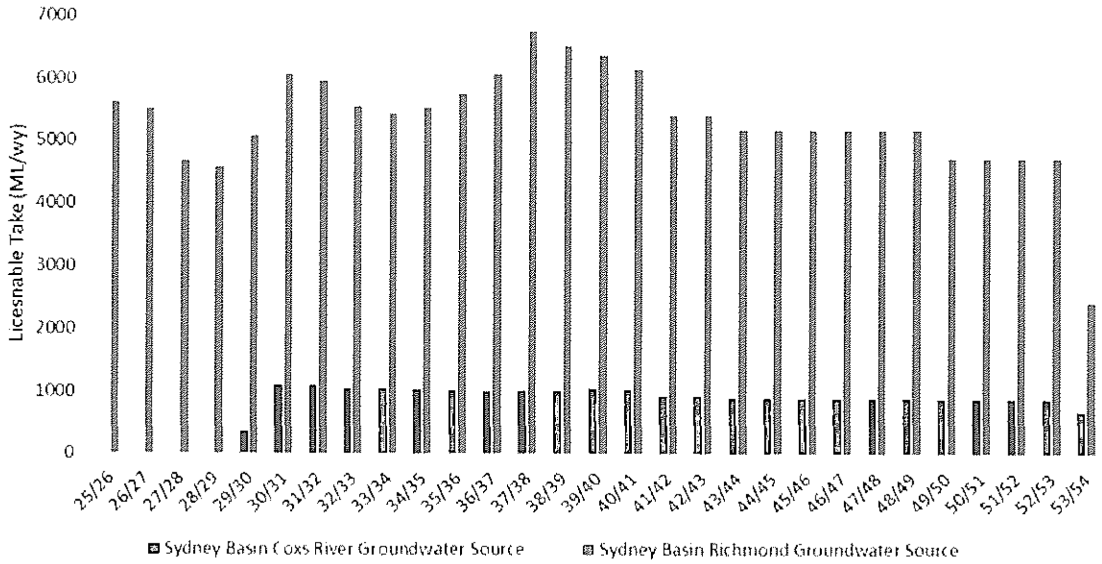

Figure 5.2: Licensable Take (Groundwater): Angus Place Colliery including 1000 Panel Area

Table 5.1: Licensable Take (ML) (Groundwater): Angus Place Colliery including 1000 Panel Area

Water Year	Sydney Basin Coxs River Groundwater Source	Sydney Basin Richmond Groundwater Source
25/26	0	5614
26/27	0	5525
27/28	0	4684
28/29	0	4576
29/30	357	5089
30/31	1099	6068
31/32	1096	5964
32/33	1056	5545
33/34	1043	5442
34/35	1031	5538
35/36	1025	5758
36/37	998	6068
37/38	1016	6761
38/39	1022	6523
39/40	1045	6378
40/41	1034	6148
41/42	932	5414
42/43	932	5414
43/44	905	5175
44/45	905	5175
45/46	905	5175
46/47	905	5175
47/48	905	5175
48/49	905	5175
49/50	888	4724
50/51	888	4724
51/52	888	4724
52/53	888	4724
53/54	681	2424

5.2 Surface Licensable Water Take

There are several surface water sources in the vicinity of Angus Place Colliery. The location of the surface water sources is presented in **Figure 5.3**.

The take from surface water sources due to mining activity was calculated based on the difference in outflow from drain (DRN) cells and river (RIV) within each of the surface water sources between the Proposed and Null Cases. As noted in **Section 5.1**, the whole-of-model calibration factor identified for the SAPSWBM was also used during calculation of the licensing requirement with respect to surface water. Accordingly, the predicted take presented in **Figure 5.4** represents the additional take due to the Amended Project (1000 Panel Area). As explained in **Section 5.1**, potential changes to surface water licensing requirements for Springvale Mine have been accounted for by the Amended Project (1000).

It is noted that predictive uncertainty results are not presented with respect to calculation of licensable take. Model output presented in **Figure S.4** is calculated from the Proposed and Null Case simulations using calibrated parameter values.

Table 5.2 presents the data presented in **Figure 5.4** but in tabular format.

It is noted that there was only surface water take from the Wywandy Management Zone and the Colo River Management Zone due to the Proposal.

Legend:

- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- Model Mesh
- Hawkesbury and Lower Nepean Rivers Water Source (Capertee River Zone)
- Hawkesbury and Lower Nepean Rivers Water Source (Colo River Zone)
- Turon Crudine River Water Source
- Upper Nepean and Upstream Warragamba Water Source (Wywandy Zone)
- Upper Nepean and Upstream Warragamba Water Source (Dharabuladh Zone)

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 02-Sep-2019
Drawn By: JZ	Checked By: JB
Scale 1:200,000	
0 2.5 5 km	
Coor. Sys. GDA 1994 MGA Zone 56	

Location of Surface Water Sources in the vicinity of Angus Place Colliery

FIGURE: 5.3

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D036_SWSources.mxd
Reference: © Department of Finance, Services & Innovation 2018

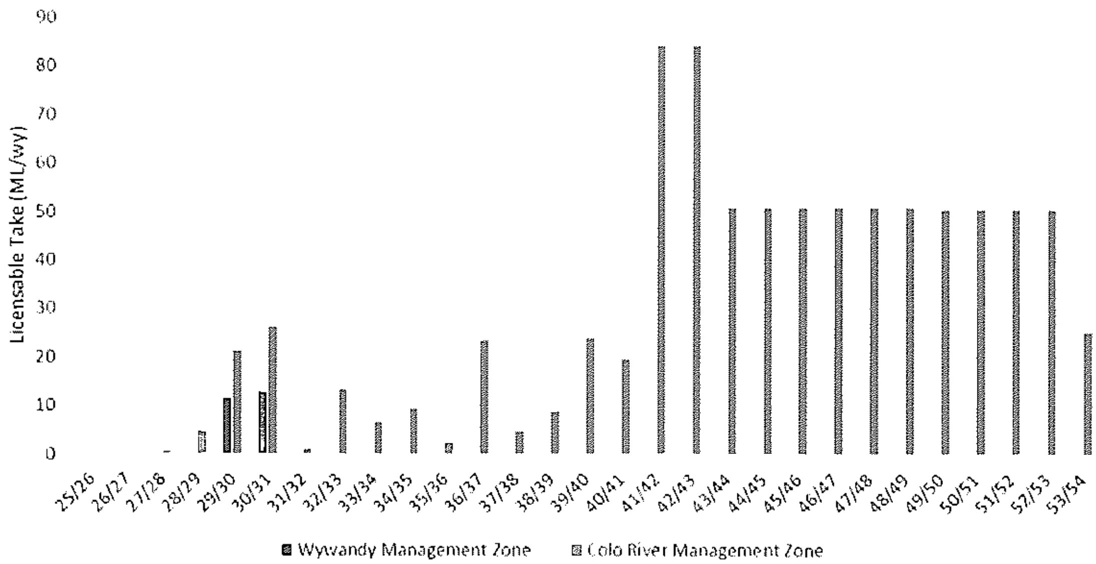

Figure 5.4: Licensable Take (Surface Water): Angus Place Colliery including 1000 Panel Area

Table 5.2: Licensable Take (ML) (Surface Water): Angus Place Colliery including 1000 Panel Area

Text	Wywandy Management Zone	Colo River Management Zone
25/26	0	0
26/27	0	0
27/28	0	1
28/29	0	5
29/30	12	21
30/31	13	26
31/32	0	1
32/33	0	13
33/34	0	7
34/35	0	10
35/36	0	2
36/37	0	24
37/38	0	5
38/39	0	9
39/40	0	24
40/41	0	20
41/42	0	84
42/43	0	84
43/44	0	51
44/45	0	51
45/46	0	51
46/47	0	51
47/48	0	51
48/49	0	51
49/50	0	51
50/51	0	51
51/52	0	51
52/53	0	51
53/54	0	25

5.3 Mine Closure Licensing Requirement

Results are presented in **Table 5.1** and **Table 5.2** through to 2053/2054. For **Table 5.1**, the calculated groundwater take, after 2053/54, drops significantly; however, for **Table 5.2**, the calculated surface water take, after 2053/54, does increase.

The reason that results after 2053/54 are not presented in **Table 5.1** and **Table 5.2** is because they are considered overly conservative. This is due to the assumed magnitude of the change to hydraulic properties ('full profile') imposed following cessation of dewatering in the model at the end of 2053. At present, the magnitude of the change to hydraulic properties are uncalibrated because the approach in the model was 'Stacked Drains'. Accordingly, the magnitude of the change to hydraulic properties assumed may be overstated by up to an order of magnitude.

The licensing requirement, beyond 2053/54, will be addressed during Mine Closure Planning.

6. Conclusions

6.1 General Summary

The groundwater model for Angus Place Colliery Mine Extension Project: Amended Project has been significantly revised compared to that presented in CSIRO (2013).

The current model is based on MODFLOW-USG and solves the variably saturated flow equation (Richards Equation) using a quad-tree refined mesh (grid cell size ranging from 100 to 400m).

Whilst changes to the hydrologic regime at THPSS in the 1000 Panel Area were identified in RPS (2014a), the magnitude of those changes have been found, through observation at the adjacent operation at Springvale Mine, to be have been underestimated in the COSFLOW model, as it was configured at that time.

Calibration of the revised groundwater model is relatively good, with an acceptable match to observed mine dewatering rates and change to water table level within the Gang Gang Swamp catchment at Springvale Mine. As noted in **Section 4.12**, it was important to match the hydrologic response in Gang Gang Swamp catchment as adverse changes have been observed at that location.

Model simulations incorporating predictive uncertainty analysis (299 parameter sets) have been successfully completed and 10th percentile and 90th percentile results indicated that adverse impact to water table level within THPSS is expected.

As presented in **Section 4.14**, expected changes, however, to surface water flow are minor. As presented, this is due to the change to hydraulic properties above the mining cell leading to increased seepage flow within the catchment of the THPSS, which is of similar magnitude to the decrease in groundwater/surface water interaction along the watercourse and swamp itself.

Climate change analysis, based on the NARCliM, indicates that model results are consistent in both a High Rainfall and Low Rainfall environment with that simulated for median rainfall conditions.

Modelled licensing requirement for Angus Place Colliery, including the 1000 Panel Area, in the period to 2053/2054, is at maximum 6505ML in water year 2037/2038 from the Sydney Basin Richmond Groundwater Source and is at maximum 1213ML in water year 2039/2040 from the Sydney Basin Coxs River Groundwater Source.

The maximum surface water licensing requirement for Angus Place Colliery, including the 1000 Panel Area, in the period to 2053/2054, is 6SML in water year 2030/2031 in the Upper Nepean and Upstream Warragamba Water Source, Wywandy Management Zone and is 418ML in water year 2041/2042 in the Hawkesbury and Lower Nepean Rivers Water Source, Colo Management Zone.

Analysis indicates that the significant decreases in water table levels within THPSS would not recover within the 50 year post-mining prediction period.

6.2 Response to IESC Comments

IESC01) Requirement to characterise existing surface water, groundwater and ecological conditions for the majority of Temperate Highland Peat Swamps on Sandstone (THPSS).

Since the time of Angus Place Mine Extension Project, significant additional investigation has been undertaken on the THPSS at both Angus Place Colliery and Springvale Mine.

Surface water flow data is presented in the Swamp Water Balance Model report (JBS&G, 2019).

Groundwater monitoring data at Tri-Star, Twin Gully and Trail Six Swamp is presented in this report, together with model calibration. Further data, such as soil moisture data is presented in the Groundwater Impact Assessment.

Ecological assessment is presented in the Ecological Impact Assessment.

IESC02) Seasonal surface water flow and an assessment, or estimation, of the baseflow component of the Coxs River.

The groundwater model, both with respect to model calibration and model simulation, is based on quarterly stress periods to incorporate seasonal variation. As presented, historical climate data was used during the calibration period and NARCliM based climate data was used for the prediction period.

Modelled contribution of groundwater to surface water flow was implemented in the groundwater model through inclusion of all surface watercourses and seepage fluxes where particular layers terminate as an outcrop in cliffsides.

The relative change to contribution of groundwater to surface water flow was then assessed using the Swamp Water Balance Model, which comprises 998 sub-catchments.

IESC03) Inclusion of all swamps in the groundwater model.

As presented in this report, all THPSS swamps have been included in the groundwater model.

IESC04) Finer scaled, site specific models, informed by a conceptualisation of the hydrology and hydrogeology, would be needed to have confidence in the predictions of groundwater impacts to individual swamps.

Site specific groundwater models were investigated during development of the Swamp Water Balance Model. It was found, however, that a regional groundwater model was necessary due to the scale of changes due to mining. Accordingly, finer scale modelling was achieved through the Swamp Water Balance Model, which received output from the regional groundwater model.

Further detail is presented in the Swamp Water Balance Model report (JBS&G, 2019).

IESC05) Water quality impact estimations for the Coxs River need to consider the increased discharge volumes to Coxs River resulting from reduced demand from the Wallerawang Power Station.

This aspect was addressed at the time through the Regional Water Quality Impact Assessment Model (RWQIAM). In any regard, in accordance with Angus Place Colliery Modification 5 (JBS&G, 2018), Angus Place Mine Extension Project: Amended Project will become a nil discharge site from 1 January 2020.

IESC06) Confidence in groundwater model predictions is limited by a lack of site-specific hydrogeological data and lineament groundwater flow behaviour.

Site-specific hydrogeological data from Springvale Mine and Angus Place Colliery is available and comprises hydraulic testing (packer tests) at multiple locations. That data is presented in the Groundwater Impact Assessment.

The updated groundwater model considers the role of lineaments through a Pilot Point methodology (heterogeneity). As noted above, in an earlier version of the groundwater model, representation of lineaments using hydraulic values that were piece-wise constant was not successful. Adoption of a Pilot Point methodology, where heterogeneity was incorporated, was found to be necessary to achieve model calibration. This is confirmed by parameter sensitivity analysis (identifiability) which indicates that horizontal and vertical distribution of parameter values was important. i.e. there were particular layers at certain locations where Pilot Points were sensitive, not all layers.

With respect to hydraulic data, the entire groundwater monitoring network at Springvale Mine, Angus Place Colliery and at Clarence Colliery is included in the groundwater model. Overall, a good fit to observed groundwater elevation and water table levels was achieved, especially with respect to, now observed, impacts to THPSS such as at Gang Gang Swamp at Springvale Mine. Accordingly, the updated model provides an improved prediction compared to the COSFLOW model.

Lastly, the fit to observed mine dewatering rates is also considered to be good. Furthermore, because of the duration of mining at Angus Place Colliery, since 1979, considerable confidence can be placed on observed dewatering rates insofar as long-term experience.

Predictive uncertainty analysis, incorporating the stochastic methodology identified in the Explanatory Note prepared by the IESC (2018b), has also been successfully deployed in the updated groundwater model.

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Appendix A Risk Assessment

A1. Risk Assessment

A comprehensive risk assessment was undertaken during development of the numerical groundwater model.

As discussed in **Section 4.1**, whilst the risk assessment process was instigated during work at Springvale Mine, the issues identified for Springvale Mine are the same as that identified for the Angus Place Mine Extension Project: Amended Project.

The risk assessment is provided next and is in the Centennial format.

Administration

Risk Assessment Title:	Springvale Mine Groundwater Uncertainty Analysis 2018
Revision:	1
Region:	Centennial Coal
Site:	Operations
Department:	
Equipment / Process:	
Stature Risk Assessment No.:	1001184011
Study Lifecycle State:	Risk Assessment In Progress
Potential Hazard No.:	
PULSE Actions Required URL:	
Site Risk Assessment Ref. No. (Optional):	

Springvale Mine Groundwater Uncertainty Analysis 2018

1. Background

Springvale Mine is an underground coal mine operated by Springvale Coal Pty Ltd (Springvale Coal), a wholly owned subsidiary of Centennial Coal Company Ltd (Centennial) under a joint venture arrangement between Centennial Springvale Pty Ltd and Springvale SK Kores Pty Ltd. Springvale Mine commenced mining operations in 1995 and currently has approval to extract up to 5.5 million tonnes per annum (Mtpa) of run of mine (ROM) coal under consent SSD 5594. Coal is delivered by overland conveyor to Western Coal Services Project (SSD 5579) for further processing or directly to Mount Piper Power Station or Lidsdale Siding for export.

As part of the groundwater model review, required under Schedule 4 Condition 14 of SSD 5594, a new hydrogeological model (MODFLOW) is being developed, which addresses limitations in the current COSFLOW hydrogeological model for Springvale Mine and Angus Place Colliery developed by CSIRO in 2013. Consideration of the most recent modelling standards and IESC requirements (IESC (2018a,b)are considered. As required by IESC (2018b) on uncertainty analysis in groundwater modelling, a risk assessment is required to define how model predictions and uncertainty associated with these predictions can aid in decision making in approvals.

The level of effort applied to uncertainty analysis is a decision that is a function of the risk being managed.

Springvale Mine Groundwater Uncertainty Analysis 2018

2. Objective

The following Hierarchy of Controls offers a framework for considering the effectiveness of controls. Note that the effectiveness of a control that is intended to reduce a risk decreases from top to bottom of the list. In other words, the closer the control type is to the top of the hierarchy, the more potentially effective the control.

·Eliminate the hazard or energy source (do not use the energy)
·Minimise or replace the hazard or energy source (reduce the amount of energy to a less damaging level or replace the energy with another that has less potential negative consequences)
·Control the hazard or energy using engineered devices (ex. Lock outs, chemical containers, mechanical roof support, gas monitors, etc.)
·Control the hazard or energy by using physical barriers (ex. machine guarding, fences or enclosures, etc.)
·Control the hazard or energy with procedures (ex. Isolation procedures, standard operating procedures, etc.)
·Control the hazard or energy with personal protective equipment (ex. hard hats, boots with toe caps, gloves, safety glasses, welding gear, etc.)
·Control the hazard or energy with warnings and awareness (ex. posters, labels, warning signs, verbal warnings, etc.)

The objective of this risk assessment is to facilitate a structured process to enable a critical and objective appraisal of the modelling process for the Springvale groundwater model

Springvale Mine Groundwater Uncertainty Analysis 2018

Potential hazards identified from the groundwater model may include:
Impacts to GDEs (terrestrial)
Impacts to GDEs (aquatic)
Impacts to nearby water users
Impacts to water quality
Impacts to surface to groundwater connectivity

Springvale Mine Groundwater Uncertainty Analysis 2018

Springvale Mine Development Consent Boundary (including ANGUS PLACE)

Springvale Mine Groundwater Uncertainty Analysis 2018

4b. Boundary Definition

Springvale Mine Groundwater Uncertainty Analysis 2018

Risk Assessment Methods

Workplace Risk Assessment and Control (WRAC): Yes
Fault Tree Analysis (FTA):
Safety Integrity Level Analysis to Australian Standard 61508 (SIL):
Bow Tie Analysis (BTA):
Failure Modes and Effects Analysis (FMEA):
Hazard and Operability Analysis (HAZOP):

Springvale Mine Groundwater Uncertainty Analysis 2018

6. Previous Risk Assessment and other documents to be used and/or referenced

Document Name	Title	Version	Referenced Document Date
Development Consent	State Significant Development Consent SSD-5594 Springvale Mine Extension Project	1	25-Sep-2015
Report: Subsidence Predictions and Impact Assessments	Springvale Colliery Extraction Plan for LW425 to LW427 - Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Extraction Plan for Longwalls 425 to 427 in the Lithgow Seam	1	
Site Management Plan	Springvale Mine Water Management Plan	1	18-Oct-2017
Investigation report - approval condition requirement	Springvale Verification of Inflows - LW421	1	06-Dec-2017
Hydrogeological model report	Extraction plan for Longwall 424-427: interim outcomes from the groundwater model	1	26-Mar-2018
Hydrogeological model report	Springvale Hydrogeological Model - Interim Report	1	07-Dec-2017
Presentation	JBSG Risk Assessment Workshop – Introduction/Conceptual Model	1	16-Aug-2018
IESC (2018a)	*Information guidelines for proponents preparing coal seam gas and large coal mining development proposals*. Guideline document prepared by the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development of the Australian Department of Environment and Energy. Reference No. n/a, dated May 2018.	1	15-May-2018
IESC (2018b)	*Draft Explanatory Note, Uncertainty Analysis in Groundwater Modelling*. Report prepared by H. Middlemis and L.J.M. Peeters for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development of the Australian Department of Environment and Energy. Reference No. n/a, dated January 2018.	1	15-May-2018

Springvale Mine Groundwater Uncertainty Analysis 2018

An appreciation for new guideline documents produced by IESC (2018)

Springvale Mine Groundwater Uncertainty Analysis 2018

8. Venue and Time

Date	Description	Location	Start Time	End Time	Comment
1. 16-Aug-2018	Scoping Study	Lidsdale House Conference Room	8:30 AM	12:00 PM	
2. 24-Aug-2018	Risk Assessment	Engineering Office - Fassifern	9:00 AM	1:30 PM	Amendments to scoping following Noel Merrick

Springvale Mine Groundwater Uncertainty Analysis 2018

9. Team Selection

Name	Position	Company	Industry Start Date	E-Mail Address	Role	Experience relevant to the role in the risk assessment	Pulse User No.	Attendance	
								1. 16-Aug-2018	2. 24-Aug-2018
Lachlan Hammersley	Manager of Water Engineering	Centennial			Risk Assessment Owner	Water manager		P	P
Dr Justin Bell	Principal hydrogeologist	JBS&G			Consultant	Hydrogeologist Modeller		P	P
Peter Corbett	General Manager - Technical Services	Centennial			Facilitator	General manager		P	P
Nagindar Singh	Approvals manager	Centennial			Team Member	Environmental and approval requirements		P	P
Catherine Suggate	Environment and Community Coordinator	Centennial			Team Member	Environmental and approval requirements		P	pr

Springvale Mine Groundwater Uncertainty Analysis 2018

Instructions

WRAC Analysis Incident Builder (hover for instructions):

Step	Events	caused by	Hazards / Causes	resulting in	Consequences / Outcomes
1. Perched groundwater	1.1. Drawdown effect of upper aquifers resulting in aquifer depressurisation and increased fracturing potentially affecting groundwater quality and available resource greater than approved	caused by	1. Over estimation of model parameters 2. Under estimation of model parameters 3. Adaptive management mining changes less than adequate 4. Model conceptualisation does not reflect natural system adequately 5. Effect of geological structures 6. Monitoring and baseline data LTA 7. Limitations in vertical stratification	resulting in	1. Environmental impact (eg GDEs, flora/fauna) 2. Legal non-compliance 3. Social impact 4. Business impact
2. Shallow Groundwater	2.1. Drawdown effect of upper aquifers resulting in aquifer depressurisation and increased fracturing potentially affecting groundwater quality and available resource greater than approved	caused by	1. Over estimation of model parameters 2. Under estimation of model parameters 3. Adaptive management mining changes less than adequate 4. Model conceptualisation does not reflect natural system adequately 5. Effect of geological structures 6. Monitoring and baseline data LTA 7. Limitations in vertical stratification	resulting in	1. Environmental impact (eg GDEs, flora/fauna) 2. Legal non-compliance 3. Social impact 4. Business impact
3. Deep Groundwater	3.1. Draining of groundwater from surrounding and overlying strata into the mine greater than approved	caused by	1. Over estimation of model parameters 2. Under estimation of model parameters 3. Adaptive management mining changes less than adequate 4. Model conceptualisation does not reflect natural system adequately 5. Effect of geological structures 6. Monitoring and baseline data LTA 7. Limitations in vertical stratification	resulting in	1. Environmental impact (eg GDEs, flora/fauna) 2. Legal non-compliance 3. Social impact 4. Business impact
4. Natural Features - Newnes Plateau Hanging Swamp	4.1. Drawdown effect of upper aquifers resulting in aquifer depressurisation and increased fracturing potentially affecting groundwater quality	caused by	1. Adaptive management mining changes less than adequate 2. Under estimation of model parameters 3. Over estimation of model	resulting in	1. Environmental impact (eg GDEs, flora/fauna) 2. Legal non-compliance 3. Social impact 4. Business impact

Springvale Mine Groundwater Uncertainty Analysis 2018

Instructions

WRAC Analysis Incident Builder (hover for instructions):

Step	Events	caused by	Hazards Causes	resulting in	Consequences Outcomes
	Events				
	and available resource greater than approve		parameters 4. Model conceptualisation does not reflect natural system adequately 5. Effect of geological structures 6. Monitoring and baseline data LTA 7. lack of knowledge of GDE dependence and resilience		
5. Natural Features - Newnes Plateau Shrub Swamps (NPSS)	5.1. Drawdown effect of upper aquifers resulting in aquifer depressurisation and increased fracturing potentially affecting groundwater quality and available resource greater than approve	caused by	1. Adaptive management mining changes less than adequate 2. Under estimation of model parameters 3. Over estimation of model parameters 4. Model conceptualisation does not reflect natural system adequately 5. Effect of geological structures 6. Monitoring and baseline data LTA 7. lack of knowledge of GDE dependence and resilience	resulting in	1. Environmental impact (eg GDEs, flora/fauna) 2. Legal non-compliance 3. Social impact 4. Business impact
6. Surface and groundwater connectivity	6.1. Loss of baseflow to creeks or swamps, greater than approved	caused by	1. Adaptive management mining changes less than adequate 2. Under estimation of model parameters 3. Over estimation of model parameters 4. Model conceptualisation does not reflect natural system adequately 5. Effect of geological structures 6. Monitoring and baseline data LTA	resulting in	1. Environmental impact (eg GDEs, flora/fauna) 2. Legal non-compliance 3. Social impact 4. Business impact
	6.2. Aquifer interference policy - 1% change in salinity—Change in perched groundwater chemistry	caused by	1. Subsidence modelling LTA	resulting in	1. Business impact 2. Environmental impact (eg GDEs, flora/fauna) 3. Legal non-compliance
7. Groundwater bores	7.1. Loss or depressurisation of private bores located within or potentiallly affected by mining	caused by	1. Model conceptualisation does not reflect natural system adequately 2. Effect of geological structures 3. Monitoring and baseline data LTA	resulting in	1. Environmental impact (eg GDEs, flora/fauna) 2. Legal non-compliance 3. Social impact 4. Business impact

Springvale Mine Groundwater Uncertainty Analysis 2018

Instructions
WRAC Analysis Incident Builder (hover for instructions):

Step	Events	caused by	Hazards / Causes	resulting in	Consequences / Outcomes
	7.2. Unable to determine compliance - lack of awarness of unregistered bores	caused by	1. Access issues 2. Monitoring program LTA	resulting in	1. Environmental impact (eg GDEs, flora/fauna) 2. Legal non-compliance 3. Social impact 4. Business impact
8. Groundwater dependent ecosystems	8.1. Impact to high priority to GDEs (WSP) due to the depressurisation of groundwater environment greater than approved	caused by	1. Model conceptualisation does not reflect natural system adequately 2. Adaptive management mining changes less than adequate 3. Under estimation of model parameters 4. Over estimation of model parameters 5. Effect of geological structures 6. Monitoring and baseline data LTA 7. lack of knowledge of GDE dependence and resilience	resulting in	1. Environmental impact (eg GDEs, flora/fauna) 2. Legal non-compliance 3. Social impact 4. Business impact
	8.2. Other GDEs (faculative and stygo)	caused by	1. Model conceptualisation does not reflect natural system adequately 2. Adaptive management mining changes less than adequate 3. Under estimation of model parameters 4. Over estimation of model parameters 5. Model conceptualisation does not reflect natural system adequately 6. Effect of geological structures 7. Monitoring and baseline data LTA	resulting in	1. Environmental impact (eg GDEs, flora/fauna) 2. Legal non-compliance 3. Social impact 4. Business impact
9. Groundwater licensing	9.1. inadequate licence allocation (groundwater)	caused by	1. Effect of geological structures 2. Model conceptualisation does not reflect natural system adequately 3. Monitoring and baseline data LTA 4. Adaptive management mining changes less than adequate	resulting in	1. Environmental impact (eg GDEs, flora/fauna) 2. Legal non-compliance 3. Social impact 4. Business impact
	9.2. inadequate licence allocation in correct source	caused by	1. method of calculation	resulting in	1. Environmental impact (eg GDEs, flora/fauna) 2. Legal non-compliance

Springvale Mine Groundwater Uncertainty Analysis 2018

Instructions

WRAC Analysis Incident Builder (hover for instructions):

Step	Events	caused by	Hazards / Causes	resulting in	Consequences / Outcomes
					3. Social impact
					4. Business impact
	9.3. inadequate licence allocation (surface water loss)	caused by	1. Effect of geological structures	resulting in	1. Environmental impact (eg GDEs, flora/fauna)
			2. Model conceptualisation does not reflect natural system adequately		2. Legal non-compliance
			3. Monitoring and baseline data LTA		3. Social impact
					4. Business impact
10. Groundwater quality	10.1. AIP - change of beneficial use cateogry	caused by	1. Effect of geological structures	resulting in	1. Environmental impact (eg GDEs, flora/fauna)
			2. Model conceptualisation does not reflect natural system adequately		2. Legal non-compliance
			3. Monitoring and baseline data LTA		3. Social impact
			4. change by unexpected change in gw chemistry		4. Business impact
11. Validation of model parameters with site data	11.1. depressurisation or drawdown exceeding approved predictions	caused by	1. post mining hydraulic conductivity	resulting in	1. Environmental impact (eg GDEs, flora/fauna)
			2. inconsistent field data		2. Legal non-compliance
			3. Scaling effects between field and model space		3. Social impact
			4. unsaturated flow characteristics		4. Business impact
			5. height of fracturing estimation		
			6. method of implementation of modelled fracturing (porous medium or stacked drains)		
			7. Effect of geological structures		
	11.2. Inflows exceeding licence conditions (allocation and discharge)	caused by	1. post mining hydraulic conductivity	resulting in	1. Environmental impact (eg GDEs, flora/fauna)
			2. inconsistent field data		2. Legal non-compliance
			3. Scaling effects between field and model space		3. Social impact
			4. unsaturated flow characteristics		4. Business impact
			5. method of implementation of modelled fracturing (porous medium or stacked drains)		
			6. height of fracturing estimation		
			7. Effect of geological structures		
12. Site water and salt balance	12.1. groundwater volumes result in a change in the site water and salt balance predicting increase in discharges or salt load	caused by	1. Adaptive management mining changes less than adequate	resulting in	1. Environmental impact (eg GDEs, flora/fauna)
			2. Effect of geological structures		2. Legal non-compliance
			3. Model conceptualisation does not reflect natural system adequately		3. Social impact
					4. Business impact

Springvale Mine Groundwater Uncertainty Analysis 2018

Instructions
WRAC Analysis Incident Builder (hover for instructions):

Step	Events	caused by	Hazards / Causes	resulting in	Consequences / Outcomes
			4. Monitoring and baseline data LTA 5. Over estimation of model parameters 6. Under estimation of model parameters 7. Inability to characterise 3d salinity distribution through meaurements or modelling		
13. Surface water users	13.1. loss of surface water to groundwater causes impacts to surface water extractors and water dependent infrastructure/recreation	caused by	1. Adaptive management mining changes less than adequate 2. Effect of geological structures 3. Model conceptualisation does not reflect natural system adequately 4. Monitoring and baseline data LTA 5. Over estimation of model parameters 6. Under estimation of model parameters	resulting in	1. Environmental impact (eg GDEs, flora/fauna) 2. Legal non-compliance 3. Social impact 4. Business impact
14. Cumulative impacts	14.1. Reevaluation of cumulative impacts as a result of groundwater model revision indicates change	caused by	1. Adaptive management mining changes less than adequate 2. Effect of geological structures 3. Model conceptualisation does not reflect natural system adequately 4. Monitoring and baseline data LTA 5. Over estimation of model parameters 6. Under estimation of model parameters	resulting in	1. Environmental impact (eg GDEs, flora/fauna) 2. Legal non-compliance 3. Social impact 4. Business impact
	14.2. Neighbouring developments change	caused by	1. inappropriate zone of impact determined 2. Unexpected activity within defined zone of impact 3. Incomplete knowledge of mine plans of neighbouring developments	resulting in	1. Environmental impact (eg GDEs, flora/fauna) 2. Legal non-compliance 3. Social impact 4. Business impact

Springvale Mine Groundwater Uncertainty Analysis 2018

Scope Confirmation

Approver	Scope Confirmation	Date	Comments
1. Lachlan Hammersley [Lachlan.Hammersley]	Yes	August 24, 2018	

Springvale Mine Groundwater Uncertainty Analysis 2018

Administration

Risk Assessment Title:	Springvale Mine Groundwater Uncertainty Analysis 2018
Revision:	1
Region:	Centennial Coal
Site:	Operations
Department:	
Equipment / Process:	
Stature Risk Assessment No.:	1001184011
Study Lifecycle State:	Risk Assessment In Progress
Potential Hazard No.:	
PULSE Actions Required URL:	
Site Risk Assessment Ref. No. (Optional):	

Springvale Mine Groundwater Uncertainty Analysis 2018

Executive Summary of Top 10 Risks

Background	Potential Incident	RR

Springvale Mine Groundwater Uncertainty Analysis 2018

Executive Summary of Top 10 Severities

Background	Potential Incident	MRC

Springvale Mine Groundwater Uncertainty Analysis 2018

Study Approval

Approver	Approved / Rejected	Date	Comments

Springvale Mine Groundwater Uncertainty Analysis 2018

1. Background

Springvale Mine is an underground coal mine operated by Springvale Coal Pty Ltd (Springvale Coal), a wholly owned subsidiary of Centennial Coal Company Ltd (Centennial) under a joint venture arrangement between Centennial Springvale Pty Ltd and Springvale SK Kores Pty Ltd. Springvale Mine commenced mining operations in 1995 and currently has approval to extract up to 5.5 million tonnes per annum (Mtpa) of run of mine (ROM) coal under consent SSD 5594. Coal is delivered by overland conveyor to Western Coal Services Project (SSD 5579) for further processing or directly to Mount Piper Power Station or Lidsdale Siding for export.

As part of the groundwater model review, required under Schedule 4 Condition 14 of SSD 5594, a new hydrogeological model (MODFLOW) is being developed, which addresses limitations in the current COSFLOW hydrogeological model for Springvale Mine and Angus Place Colliery developed by CSIRO in 2013. Consideration of the most recent modelling standards and IESC requirements (IESC (2018a,b)are considered. As required by IESC (2018b) on uncertainty analysis in groundwater modelling, a risk assessment is required to define how model predictions and uncertainty associated with these predictions can aid in decision making in approvals.

The level of effort applied to uncertainty analysis is a decision that is a function of the risk being managed.

Springvale Mine Groundwater Uncertainty Analysis 2018

2. Objective

The following Hierarchy of Controls offers a framework for considering the effectiveness of controls. Note that the effectiveness of a control that is intended to reduce a risk decreases from top to bottom of the list. In other words, the closer the control type is to the top of the hierarchy, the more potentially effective the control.

·Eliminate the hazard or energy source (do not use the energy)
·Minimise or replace the hazard or energy source (reduce the amount of energy to a less damaging level or replace the energy with another that has less potential negative consequences)
·Control the hazard or energy using engineered devices (ex. Lock outs, chemical containers, mechanical roof support, gas monitors, etc.)
·Control the hazard or energy by using physical barriers (ex. machine guarding, fences or enclosures, etc.)
·Control the hazard or energy with procedures (ex. Isolation procedures, standard operating procedures, etc.)
·Control the hazard or energy with personal protective equipment (ex. hard hats, boots with toe caps, gloves, safety glasses, welding gear, etc.)
·Control the hazard or energy with warnings and awareness (ex. posters, labels, warning signs, verbal warnings, etc.)

The objective of this risk assessment is to facilitate a structured process to enable a critical and objective appraisal of the modelling process for the Springvale groundwater model

Springvale Mine Groundwater Uncertainty Analysis 2018

Potential hazards identified from the groundwater model may include:
Impacts to GDEs (terrestrial)
Impacts to GDEs (aquatic)
Impacts to nearby water users
Impacts to water quality
Impacts to surface to groundwater connectivity

Springvale Mine Groundwater Uncertainty Analysis 2018

Springvale Mine Development Consent Boundary (including ANGUS PLACE)

Springvale Mine Groundwater Uncertainty Analysis 2018

4b. Boundary Definition

Springvale Mine Groundwater Uncertainty Analysis 2018

Risk Assessment Methods

Workplace Risk Assessment and Control (WRAC): Yes
Fault Tree Analysis (FTA):
Safety Integrity Level Analysis to Australian Standard 61508 (SIL):
Bow Tie Analysis (BTA):
Failure Modes and Effects Analysis (FMEA):
Hazard and Operability Analysis (HAZOP):

Springvale Mine Groundwater Uncertainty Analysis 2018

6. Previous Risk Assessment and other documents to be used and/or referenced

Document Name	Title	Version	Referenced Document Date
Development Consent	State Significant Development Consent SSD-5594 Springvale Mine Extension Project	1	25-Sep-2015
Report: Subsidence Predictions and Impact Assessments	Springvale Colliery Extraction Plan for LW425 to LW427 - Subsidence Predictions and Impact Assessments for the Natural and Built Features in Support of the Extraction Plan for Longwalls 425 to 427 in the Lithgow Seam	1	
Site Management Plan	Springvale Mine Water Management Plan	1	18-Oct-2017
Investigation report - approval condition requirement	Springvale Verification of Inflows - LW421	1	06-Dec-2017
Hydrogeological model report	Extraction plan for Longwall 424-427: interim outcomes from the groundwater model	1	26-Mar-2018
Hydrogeological model report	Springvale Hydrogeological Model - Interim Report	1	07-Dec-2017
Presentation	JBSG Risk Assessment Workshop – Introduction/Conceptual Model	1	16-Aug-2018
IESC (2018a)	*Information guidelines for proponents preparing coal seam gas and large coal mining development proposals* . Guideline document prepared by the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development of the Australian Department of Environment and Energy. Reference No. n/a, dated May 2018.	1	15-May-2018
IESC (2018b)	*Draft Explanatory Note, Uncertainty Analysis in Groundwater Modelling*. Report prepared by H. Middlemis and L.J.M. Peeters for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development of the Australian Department of Environment and Energy. Reference No. n/a, dated January 2018.	1	15-May-2018

Springvale Mine Groundwater Uncertainty Analysis 2018

An appreciation for new guideline documents produced by IESC (2018)

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8. Venue and Time

Date	Description	Location	Start Time	End Time	Comment
1. 16-Aug-2018	Scoping Study	LIdsdale House Conference Room	8:30 AM	12:00 PM	
2. 24-Aug-2018	Risk Assessment	Engineering Office - Fassifern	9:00 AM	1:30 PM	Amendments to scoping following Noel Merrick

Springvale Mine Groundwater Uncertainty Analysis 2018

9. Risk Assessment Team Selection

Name	Position	Company	Industry Start Date	E-Mail Address	Role	Experience relevant to the role in the risk assessment	Pulse User No.	Attendance	
								1. 16-Aug-2018	2. 24-Aug-2018
Lachlan Hammersley	Manager of Water Engineering	Centennial			Risk Assessment Owner	Water manager		P	P
Dr Justin Bell	Principal hydrogeologist	JBS&G			Consultant	Hydrogeologist Modeller		P	P
Peter Corbett	General Manager - Technical Services	Centennial			Facilitator	General manager		P	P
Nagindar Singh	Approvals manager	Centennial			Team Member	Environmental and approval requirements		P	P
Catherine Suggate	Environment and Community Coordinator	Centennial			Team Member	Environmental and approval requirements		P	pr

Springvale Mine Groundwater Uncertainty Analysis 2018

10. Scope Confirmation

Approver	Scope Confirmation	Date	Comments
1. Lachlan Hammersley [Lachlan.Hammersley]	Yes	August 24, 2018	

Springvale Mine Groundwater Uncertainty Analysis 2018

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control	Bow Tie Extension
1. Perched groundwater	There is a risk to Operations from ::: Drawdown effect of upper aquifers resulting in aquifer depressurisation and increased fracturing potentially affecting groundwater quality and available resource greater than approved ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Limitations in vertical stratification or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	1.1.a. Mine footprint is less than approved 1.1.b. Mine method does not change 1.1.c. Environmental monitoring program is continually being reviewed and evolving from IMP and government agencies 1.1.d. Independent and peer review of numerical and conceptual groundwater model 1.1.e. Uncertainity assessment (type 1) has been undertaken 1.1.f. Consideration of operational mining and environmental data to confirm predictions	B (Pb)	2 (E)	12 (S)	1. Conceptual model is being reviewed in consultation with the IMP 2. Numerical model is being redeveloped in consutation with regulator, peers, IMP 3. Consideration of operational mining and environmental data to confirm predictions 4. Level Uncertainity analysis will be increased 5. Increasing environmental monitoring as a result of IMP recommendations (soil moisture probs, ERT) 6. Ongoing engagement with IMP	
2. Shallow Groundwater	There is a risk to Operations from ::: Drawdown effect of upper aquifers resulting in aquifer depressurisation and increased fracturing potentially affecting groundwater quality and available resource greater than approved ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Limitations in vertical stratification or Model conceptualisation does not reflect natural system	2.1.a. Mine footprint is less than approved 2.1.b. Mine method does not change 2.1.c. Environmental monitoring program is continually being reviewed and evolving from IMP and government agencies. Existing monitoring determined to be sufficient 2.1.d. Independent and peer review of numerical and conceptual groundwater model 2.1.e. Uncertainity assessment (type 1) has been undertaken	B (Pb)	1 (E)	7 (M)	1. Conceptual model is being reviewed in consultation with the IMP 2. Numerical model is being redeveloped in consutation with regulator, peers, IMP 3. Consideration of operational mining and environmental data to confirm predictions 4. Level Uncertainity analysis will be increased 6. Ongoing engagement with IMP	

Springvale Mine Groundwater Uncertainty Analysis 2018

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control	Bow Tie Extension
	adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	2.1.f. Consideration of operational mining and environmental data to confirm predictions					
3. Deep Groundwater	There is a risk to Operations from ::: Draining of groundwater from surrounding and overlying strata into the mine greater than approved ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Limitations in vertical stratification or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	3.1.a. Mine footprint is less than approved 3.1.b. Mine method does not change 3.1.c. Environmental monitoring program is continually being reviewed and evolving from IMP and government agencies. Existing monitoring determined to be sufficient 3.1.d. Independent and peer review of numerical and conceptual groundwater model 3.1.e. Uncertainity assessment (type 1) has been undertaken 3.1.f. Consideration of operational mining and environmental data to confirm predictions	C (Pb)	1 (E)	4 (L)	4. Level Uncertainity analysis will be increased 6. Ongoing engagement with IMP	
4. Natural Features - Newnes Plateau Hanging Swamp	There is a risk to Operations from ::: Drawdown effect of upper aquifers resulting in aquifer depressurisation and increased fracturing potentially affecting groundwater quality and available	4.1.a. Ecological (visual) monitoring 4.1.b. Continual investigations to assist in detailed geological understanding 4.1.c. Environmental monitoring program is continually being reviewed and	C (Pb)	3 (E)	13 (S)	1. Conceptual model is being reviewed in consultation with the IMP 7. Numerical model is being redeveloped in consutation with regulator, peers, IMP - Water balance from seepage faces are being further interograted 3. Consideration of operational mining and environmental data to confirm predictions	

Springvale Mine Groundwater Uncertainty Analysis 2018

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control	Bow Tie Extension
	resource greater than approve ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or lack of knowledge of GDE dependence and resilience or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	evolving from IMP and government agencies 4.1.d. Consideration of operational mining and environmental data to confirm predictions				4. Level Uncertainity analysis will be increased	
5. Natural Features - Newnes Plateau Shrub Swamps (NPSS)	There is a risk to Operations from ::: Drawdown effect of upper aquifers resulting in aquifer depressurisation and increased fracturing potentially affecting groundwater quality and available resource greater than approve ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or lack of knowledge of GDE dependence and resilience or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model	5.1.a. Mine footprint is less than approved 5.1.b. Mine method does not change 5.1.c. Environmental monitoring program is continually being reviewed and evolving from IMP and government agencies 5.1.d. Independent and peer review of numerical and conceptual groundwater model 5.1.e. Uncertainity assessment (type 1) has been undertaken 5.1.f. Consideration of operational mining and environmental data to confirm predictions 5.1.g. Management plan for	B (Pb)	4 (E)	22 (E)	1. Conceptual model is being reviewed in consultation with the IMP 2. Numerical model is being redeveloped in consutation with regulator, peers, IMP 3. Consideration of operational mining and environmental data to confirm predictions 4. Level Uncertainity analysis will be increased 5. Increasing environmental monitoring as a result of IMP recommendations (soil moisture probs, ERT) 6. Ongoing engagement with IMP	

Springvale Mine Groundwater Uncertainty Analysis 2018

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control	Bow Tie Extension
	parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	THPSS					
6. Surface and groundwater connectivity	There is a risk to Operations from ::: Loss of baseflow to creeks or swamps, greater than approved ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	6.1.a. Mine footprint is less than approved 6.1.b. Mine method does not change 6.1.c. Independent and peer review of numerical and conceptual groundwater model 6.1.d. hydrological model of shrub swamp 6.1.e. hydrogeological confirmation of re-emergenece of flow following IMP request to confirm connectivity 6.1.f. geochemical tracer investigation	B (Pb)	2 (E)	12 (S)	8. Uncertainity considerations applied to hydrological model of shrub swamps 1. Conceptual model is being reviewed in consultation with the IMP 7. Numerical model is being redeveloped in consutation with regulator, peers, IMP - Water balance from seepage faces are being further interograted 3. Consideration of operational mining and environmental data to confirm predictions 4. Level Uncertainity analysis will be increased	
	There is a risk to Operations from ::: Aquifer interference policy - 1% change in salinity—Change in perched groundwater chemistry ::: Caused by: Subsidence modelling LTA Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance.	6.2.a. Environmental monitoring program is continually being reviewed and evolving from IMP and government agencies 6.2.b. Consideration of operational mining and environmental data to confirm predictions	D (Pb)	2 (E)	5 (L)		
7. Groundwater bores	There is a risk to Operations from	7.1.a. No impacts identified at time of EIS	D (Pb)	2 (F)	5 (L)	9. Revisit groundwater users as part of modelling process being reviewed	

Springvale Mine Groundwater Uncertainty Analysis 2018

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control	Bow Tie Extension
	::: Loss or depressurisation of private bores located within or potentiallly affected by mining ::: Caused by: Effect of geological structures or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.						
	There is a risk to Operations from ::: Unable to determine compliance - lack of awarness of unregistered bores ::: Caused by: Access issues or Monitoring program LTA Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	7.2.a. No impacts identified at time of EIS	D (Pb)	2 (F)	5 (L)	9. Revisit groundwater users as part of modelling process being reviewed	
8. Groundwater dependent ecosystems	There is a risk to Operations from ::: Impact to high priority to GDEs (WSP) due to the depressurisation of groundwater environment greater than approved ::: Caused by: Adaptive management mining changes less than adequate or	8.1.a. Mine footprint is less than approved 8.1.b. Mine method does not change 8.1.c. Environmental monitoring program is continually being reviewed and evolving from IMP and government agencies 8.1.d. Independent and peer review of numerical and	B (Pb)	4 (E)	22 (E)	1. Conceptual model is being reviewed in consultation with the IMP 2. Numerical model is being redeveloped in consutation with regulator, peers, IMP 3. Consideration of operational mining and environmental data to confirm predictions 4. Level Uncertainity analysis will be increased 5. Increasing environmental monitoring as a result of IMP recommendations (soil moisture probs, ERT) 6. Ongoing engagement with IMP	

Springvale Mine Groundwater Uncertainty Analysis 2018

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control	Bow Tie Extension
	Effect of geological structures or lack of knowledge of GDE dependence and resilience or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	conceptual groundwater model 8.1.e. Uncertainty assessment (type 1) has been undertaken 8.1.f. Consideration of operational mining and environmental data to confirm predictions 8.1.g. Management plan for THPSS					
	There is a risk to Operations from ::: Other GDEs (faculative and stygo) ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	8.2.a. Regional Management plan established for stygofauna 8.2.b. Ongoing investigations by Ecologists	D (Pb)	2 (E)	5 (L)		
9. Groundwater licensing	There is a risk to Operations from ::: inadequate licence allocation (groundwater) ::: Caused by:	9.1.a. Strategic planning of water take 9.1.b. Ongoing engagement with regulator 9.1.c. Refinement of numerical modelling methodology to calculate take of water	C (Pb)	2 (L)	8 (M)	10. Administrative changes to WALs for multiple WSWAs 11. Ongoing engagement with regulator 15. Application for controlled allocation ongoing	

Springvale Mine Groundwater Uncertainty Analysis 2018

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control	Bow Tie Extension
	Adaptive management mining changes less than adequate or Effect of geological structures or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	9.1.d. Sufficient water access licences 9.1.e. Purchase of controlled allocation ongoing					
	There is a risk to Operations from ::: inadequate licence allocation in correct source ::: Caused by: method of calculation Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	9.2.a. Sufficient water access licences within correct sources 9.2.b. Strategic planning of water take	C (Pb)	2 (L)	8 (M)	12. Strategic planning of water take 13. Refinement of numerical modelling methodology to calculate take of water 14. Application for water sharing plan boundary modification	
	There is a risk to Operations from ::: inadequate licence allocation (surface water loss) ::: Caused by: Effect of geological structures or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	9.3.a. hydrological model of shrub swamp 9.3.b. hydrogeological confirmation of re-emergenece of flow following IMP request to confirm connectivity 9.3.c. geochemical tracer investigation 9.3.d. Regional water licence allocations	B (Pb)	2 (L)	12 (S)	16. Review of existing licence applications/status (zero share licences) - Consideration of NET take 8. Uncertainity considerations applied to hydrological model of shrub swamps 1. Conceptual model is being reviewed in consultation with the IMP 7. Numerical model is being redeveloped in consutation with regulator, peers, IMP - Water balance from seepage faces are being further interograted 3. Consideration of operational mining and environmental data to confirm predictions 4. Level Uncertainity analysis will be increased	
10. Groundwater	There is a risk to Operations from	10.1.a. Monitoring program	D	1	2		

Springvale Mine Groundwater Uncertainty Analysis 2018

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control	Bow Tie Extension
quality	::: AIP - change of beneficial use cateogry ::: Caused by: change by unexpected change in gw chemistry or Effect of geological structures or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	established - with TARPs - reviewed by IMP 10.1.b. Consideration of operational mining and environmental data to confirm predictions	(Pb)	(E)	(L)		
11. Validation of model parameters with site data	There is a risk to Operations from ::: depressurisation or drawdown exceeding approved predictions ::: Caused by: Effect of geological structures or height of fracturing estimation or inconsistent field data or method of implementation of modelled fracturing (porous medium or stacked drains) or post mining hydraulic conductivity or Scaling effects between field and model space or unsaturated flow characteristics Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	11.1.a. TARP investigation (SPR1101) piezometer shearing led to update Ditton Merrick Model - fracturing height confirmation 11.1.b. uncertainity (type 1) assessment 11.1.c. Consideration of operational mining and environmental data to confirm predictions 11.1.d. Literature review of hydraulic conductivity and storage parameters	B (Pb)	2 (F)	12 (S)	17. Consider post mining investigation above LW420 (similar to SPR1101 investigation) 18. Packer tests for geological boreholes forecast for southern blocks 20. Uncertainty assessment (type 3)	
	There is a risk to Operations from ::: Inflows exceeding licence	11.2.a. Ongoing management of current licence allocation vs take monitoring 11.2.b. Literature review of	B (Pb)	2 (F)	12 (S)	19. Increases environmental monitoring data 21. Uncertainty assessment (type 3)	

Springvale Mine Groundwater Uncertainty Analysis 2018

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control	Bow Tie Extension
	conditions (allocation and discharge) ::: Caused by: Effect of geological structures or height of fracturing estimation or inconsistent field data or method of implementation of modelled fracturing (porous medium or stacked drains) or post mining hydraulic conductivity or Scaling effects between field and model space or unsaturated flow characteristics Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	hydraulic conductivity and storage parameters					
12. Site water and salt balance	There is a risk to Operations from ::: groundwater volumes result in a change in the site water and salt balance predicting increase in discharges or salt load ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Inability to characterise 3d salinity distribution through meaurements or modelling or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of	12.1.a. Water and salt balance reviewed annually 12.1.b. Ongoing management of current licence allocation vs take monitoring 12.1.c. Environmental monitoring program in place 12.1.d. Management against consent and EPL conditions	B (Pb)	2 (F)	12 (S)	21. Uncertainty assessment (type 3)	

Springvale Mine Groundwater Uncertainty Analysis 2018

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control	Bow Tie Extension
	model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.						
13. Surface water users	There is a risk to Operations from ::: loss of surface water to groundwater causes impacts to surface water extractors and water dependent infrastructure/recreation ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	13.1.a. Take from the Coxs River is neg 13.1.b. Wolgan river users are outside area of impact 13.1.c. Current surface water take insignificant to catchment runoff	D (Pb)	1 (F)	2 (L)	22. Review surface water users	
14. Cumulative impacts	There is a risk to Operations from ::: Reevaluation of cumulative impacts as a result of groundwater model revision indicates change ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Model conceptualisation does not reflect natural system adequately	14.1.a. Model considers all adjacent operations (1979-present) 14.1.b. Model includes both SV and AP and one development staged	D (Pb)	2 (E)	5 (L)	23. Review of adjacent activities	

Springvale Mine Groundwater Uncertainty Analysis 2018

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control	Bow Tie Extension
	or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.						
	There is a risk to Operations from ::: Neighbouring developments change ::: Caused by: inappropriate zone of impact determined or Incomplete knowledge of mine plans of neighbouring developments or Unexpected activity within defined zone of impact Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	14.2.a. Angus place currently considered EIS 2016 mine plan	D (Pb)	2 (E)	5 (L)	24. Update numerical model to cover revised Angus Place mine plan (2018)	

Springvale Mine Groundwater Uncertainty Analysis 2018

Instructions
WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
5. Natural Features - Newnes Plateau Shrub Swamps (NPSS)	There is a risk to Operations from ::: Drawdown effect of upper aquifers resulting in aquifer depressurisation and increased fracturing potentially affecting groundwater quality and available resource greater than approve ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or lack of knowledge of GDE dependence and resilience or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	5.1.a. Mine footprint is less than approved 5.1.b. Mine method does not change 5.1.c. Environmental monitoring program is continually being reviewed and evolving from IMP and government agencies 5.1.d. Independent and peer review of numerical and conceptual groundwater model 5.1.e. Uncertainity assessment (type 1) has been undertaken 5.1.f. Consideration of operational mining and environmental data to confirm predictions 5.1.g. Management plan for THPSS	B (Pb)	4 (E)	22 (E)	1. Conceptual model is being reviewed in consultation with the IMP 2. Numerical model is being redeveloped in consutation with regulator, peers, IMP 3. Consideration of operational mining and environmental data to confirm predictions 4. Level Uncertainity analysis will be increased 5. Increasing environmental monitoring as a result of IMP recommendations (soil moisture probs, ERT) 6. Ongoing engagement with IMP
8. Groundwater dependent ecosystems	There is a risk to Operations from ::: Impact to high priority to GDEs (WSP) due to the depressurisation of groundwater environment greater than approved ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or lack of knowledge of GDE dependence and resilience or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of	8.1.a. Mine footprint is less than approved 8.1.b. Mine method does not change 8.1.c. Environmental monitoring program is continually being reviewed and evolving from IMP and government agencies 8.1.d. Independent and peer review of numerical and conceptual groundwater model 8.1.e. Uncertainity assessment (type 1) has been undertaken 8.1.f. Consideration of operational mining and	B (Pb)	4 (E)	22 (E)	1. Conceptual model is being reviewed in consultation with the IMP 2. Numerical model is being redeveloped in consutation with regulator, peers, IMP 3. Consideration of operational mining and environmental data to confirm predictions 4. Level Uncertainity analysis will be increased 5. Increasing environmental monitoring as a result of IMP recommendations (soil moisture probs, ERT) 6. Ongoing engagement with IMP

Springvale Mine Groundwater Uncertainty Analysis 2018

Instructions
WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
	model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal	environmental data to confirm predictions 8.1.g. Management plan for THPSS				
4. Natural Features - Newnes Plateau Hanging Swamp	There is a risk to Operations from ::: Drawdown effect of upper aquifers resulting in aquifer depressurisation and increased fracturing potentially affecting groundwater quality and available resource greater than approve ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or lack of knowledge of GDE dependence and resilience or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	4.1.a. Ecological (visual) monitoring 4.1.b. Continual investigations to assist in detailed geological understanding 4.1.c. Environmental monitoring program is continually being reviewed and evolving from IMP and government agencies 4.1.d. Consideration of operational mining and environmental data to confirm predictions	C (Pb)	3 (E)	13 (S)	1. Conceptual model is being reviewed in consultation with the IMP 7. Numerical model is being redeveloped in consutation with regulator, peers, IMP - Water balance from seepage faces are being further interograted 3. Consideration of operational mining and environmental data to confirm predictions 4. Level Uncertainity analysis will be increased
1. Perched groundwater	There is a risk to Operations from ::: Drawdown effect of upper aquifers resulting in aquifer depressurisation and increased fracturing potentially affecting groundwater quality and available resource greater than approved ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Limitations in	1.1.a. Mine footprint is less than approved 1.1.b. Mine method does not change 1.1.c. Environmental monitoring program is continually being reviewed and evolving from IMP and government agencies 1.1.d. Independent and peer review of numerical and conceptual groundwater model	B (Pb)	2 (E)	12 (S)	1. Conceptual model is being reviewed in consultation with the IMP 2. Numerical model is being redeveloped in consutation with regulator, peers, IMP 3. Consideration of operational mining and environmental data to confirm predictions 4. Level Uncertainity analysis will be increased 5. Increasing environmental monitoring as a result of IMP recommendations (soil moisture probs, ERT) 6. Ongoing engagement with IMP

Springvale Mine Groundwater Uncertainty Analysis 2018

Instructions
WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
	vertical stratification or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	1.1.e. Uncertainity assessment (type 1) has been undertaken 1.1.f. Consideration of operational mining and environmental data to confirm predictions				
6. Surface and groundwater connectivity	There is a risk to Operations from ::: Loss of baseflow to creeks or swamps, greater than approved ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	6.1.a. Mine footprint is less than approved 6.1.b. Mine method does not change 6.1.c. Independent and peer review of numerical and conceptual groundwater model 6.1.d. hydrological model of shrub swamp 6.1.e. hydrogeological confirmation of re-emergenece of flow following IMP request to confirm connectivity 6.1.f. geochemical tracer investigation	B (Pb)	2 (E)	12 (S)	8. Uncertainity considerations applied to hydrological model of shrub swamps 1. Conceptual model is being reviewed in consultation with the IMP 7. Numerical model is being redeveloped in consutation with regulator, peers, IMP - Water balance from seepage faces are being further interograted 3. Consideration of operational mining and environmental data to confirm predictions 4. Level Uncertainity analysis will be increased
9. Groundwater licensing	There is a risk to Operations from ::: inadequate licence allocation (surface water loss) ::: Caused by: Effect of geological structures or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA	9.3.a. hydrological model of shrub swamp 9.3.b. hydrogeological confirmation of re-emergenece of flow following IMP request to confirm connectivity 9.3.c. geochemical tracer investigation 9.3.d. Regional water licence allocations	B (Pb)	2 (L)	12 (S)	16. Review of existing licence applications/status (zero share licences) - Consideration of NET take 8. Uncertainity considerations applied to hydrological model of shrub swamps 1. Conceptual model is being reviewed in consultation with the IMP 7. Numerical model is being redeveloped in consutation with regulator, peers, IMP - Water balance from seepage faces are being further interograted 3. Consideration of operational mining and environmental data to confirm predictions 4. Level Uncertainity analysis will be increased

Springvale Mine Groundwater Uncertainty Analysis 2018

Instructions
WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
	Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.					
11. Validation of model parameters with site data	There is a risk to Operations from ::: depressurisation or drawdown exceeding approved predictions ::: Caused by: Effect of geological structures or height of fracturing estimation or inconsistent field data or method of implementation of modelled fracturing (porous medium or stacked drains) or post mining hydraulic conductivity or Scaling effects between field and model space or unsaturated flow characteristics Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	11.1.a. TARP investigation (SPR1101) piezometer shearing led to update Ditton Merrick Model - fracturing height confirmation 11.1.b. uncertainity (type 1) assessment 11.1.c. Consideration of operational mining and environmental data to confirm predictions 11.1.d. Literature review of hydraulic conductivity and storage parameters	B (Pb)	2 (F)	**12 (S)**	17. Consider post mining investigation above LW420 (similar to SPR1101 investigation) 18. Packer tests for geological boreholes forecast for southern blocks 20. Uncertainty assessment (type 3)
11. Validation of model parameters with site data	There is a risk to Operations from ::: Inflows exceeding licence conditions (allocation and discharge) ::: Caused by: Effect of geological structures or height of fracturing estimation or inconsistent field data or method of implementation of modelled fracturing (porous medium or stacked drains) or post mining hydraulic conductivity or Scaling effects between field and model space or unsaturated flow characteristics Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	11.2.a. Ongoing management of current licence allocation vs take monitoring 11.2.b. Literature review of hydraulic conductivity and storage parameters	B (Pb)	2 (F)	**12 (S)**	19. Increases environmental monitoring data 21. Uncertainty assessment (type 3)
12. Site water and salt balance	There is a risk to Operations from	12.1.a. Water and salt balance reviewed annually	B (Pb)	2 (F)	**12 (S)**	21. Uncertainty assessment (type 3)

Springvale Mine Groundwater Uncertainty Analysis 2018

Instructions

WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
	::: groundwater volumes result in a change in the site water and salt balance predicting increase in discharges or salt load ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Inability to characterise 3d salinity distribution through meaurements or modelling or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	12.1.b. Ongoing management of current licence allocation vs take monitoring 12.1.c. Environmental monitoring program in place 12.1.d. Management against consent and EPL conditions				
9. Groundwater licensing	There is a risk to Operations from ::: inadequate licence allocation (groundwater) ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	9.1.a. Strategic planning of water take 9.1.b. Ongoing engagement with regulator 9.1.c. Refinement of numerical modelling methodology to calculate take of water 9.1.d. Sufficient water access licences 9.1.e. Purchase of controlled allocation ongoing	C (Pb)	2 (L)	8 (M)	10. Administrative changes to WALs for multiple WSWAs 11. Ongoing engagement with regulator 15. Application for controlled allocation ongoing
9. Groundwater licensing	There is a risk to Operations from	9.2.a. Sufficient water access licences within correct sources	C (Pb)	2 (L)	8 (M)	12. Strategic planning of water take 13. Refinement of numerical modelling methodology to calculate take of water

Springvale Mine Groundwater Uncertainty Analysis 2018

Instructions
WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
	::: inadequate licence allocation in correct source ::: Caused by: method of calculation Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	9.2.b. Strategic planning of water take				14. Application for water sharing plan boundary modification
2. Shallow Groundwater	There is a risk to Operations from ::: Drawdown effect of upper aquifers resulting in aquifer depressurisation and increased fracturing potentially affecting groundwater quality and available resource greater than approved ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Limitations in vertical stratification or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	2.1.a. Mine footprint is less than approved 2.1.b. Mine method does not change 2.1.c. Environmental monitoring program is continually being reviewed and evolving from IMP and government agencies. Existing monitoring determined to be sufficient 2.1.d. Independent and peer review of numerical and conceptual groundwater model 2.1.e. Uncertainity assessment (type 1) has been undertaken 2.1.f. Consideration of operational mining and environmental data to confirm predictions	B (Pb)	1 (E)	7 (M)	1. Conceptual model is being reviewed in consultation with the IMP 2. Numerical model is being redeveloped in consutation with regulator, peers, IMP 3. Consideration of operational mining and environmental data to confirm predictions 4. Level Uncertainity analysis will be increased 6. Ongoing engagement with IMP
6. Surface and groundwater connectivity	There is a risk to Operations from ::: Aquifer interference policy - 1% change in salinity—Change in perched groundwater chemistry ::: Caused by: Subsidence modelling LTA	6.2.a. Environmental monitoring program is continually being reviewed and evolving from IMP and government agencies 6.2.b. Consideration of operational mining and	D (Pb)	2 (E)	5 (L)	

Springvale Mine Groundwater Uncertainty Analysis 2018

Instructions
WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
	Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance.	environmental data to confirm predictions				
7. Groundwater bores	There is a risk to Operations from ::: Loss or depressurisation of private bores located within or potentiallly affected by mining ::: Caused by: Effect of geological structures or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	7.1.a. No impacts identified at time of EIS	D (Pb)	2 (F)	5 (L)	9. Revisit groundwater users as part of modelling process being reviewed
7. Groundwater bores	There is a risk to Operations from ::: Unable to determine compliance - lack of awarness of unregistered bores ::: Caused by: Access issues or Monitoring program LTA Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	7.2.a. No impacts identified at time of EIS	D (Pb)	2 (F)	5 (L)	9. Revisit groundwater users as part of modelling process being reviewed
8. Groundwater dependent ecosystems	There is a risk to Operations from ::: Other GDEs (faculative and stygo) ::: Caused by: Adaptive management mining changes less than adequate or Effect of	8.2.a. Regional Management plan established for stygofauna 8.2.b. Ongoing investigations by Ecologists	D (Pb)	2 (E)	5 (L)	

Springvale Mine Groundwater Uncertainty Analysis 2018

Instructions
WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
	geological structures or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.					
14. Cumulative impacts	There is a risk to Operations from ::: Reevaluation of cumulative impacts as a result of groundwater model revision indicates change ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	14.1.a. Model considers all adjacent operations (1979-present) 14.1.b. Model includes both SV and AP and one development staged	D (Pb)	2 (E)	5 (L)	23. Review of adjacent activities
14. Cumulative impacts	There is a risk to Operations from ::: Neighbouring developments change ::: Caused by: inappropriate zone of impact determined or Incomplete knowledge of mine plans of neighbouring developments or Unexpected activity	14.2.a. Angus place currently considered EIS 2016 mine plan	D (Pb)	2 (E)	5 (L)	24. Update numerical model to cover revised Angus Place mine plan (2018)

Springvale Mine Groundwater Uncertainty Analysis 2018

Instructions
WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
	within defined zone of impact Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.					
3. Deep Groundwater	There is a risk to Operations from ::: Draining of groundwater from surrounding and overlying strata into the mine greater than approved ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Limitations in vertical stratification or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	3.1.a. Mine footprint is less than approved 3.1.b. Mine method does not change 3.1.c. Environmental monitoring program is continually being reviewed and evolving from IMP and government agencies. Existing monitoring determined to be sufficient 3.1.d. Independent and peer review of numerical and conceptual groundwater model 3.1.e. Uncertainity assessment (type 1) has been undertaken 3.1.f. Consideration of operational mining and environmental data to confirm predictions	C (Pb)	1 (E)	4 (L)	4. Level Uncertainity analysis will be increased 6. Ongoing engagement with IMP
10. Groundwater quality	There is a risk to Operations from ::: AIP - change of beneficial use cateogry ::: Caused by: change by unexpected change in gw chemistry or Effect of geological structures or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA	10.1.a. Monitoring program established - with TARPs - reviewed by IMP 10.1.b. Consideration of operational mining and environmental data to confirm predictions	D (Pb)	1 (E)	2 (L)	

Springvale Mine Groundwater Uncertainty Analysis 2018

Instructions
WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
	Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.					
13. Surface water users	There is a risk to Operations from ::: loss of surface water to groundwater causes impacts to surface water extractors and water dependent infrastructure/recreation ::: Caused by: Adaptive management mining changes less than adequate or Effect of geological structures or Model conceptualisation does not reflect natural system adequately or Monitoring and baseline data LTA or Over estimation of model parameters or Under estimation of model parameters Resulting in: Business impact or Environmental impact (eg GDEs, flora/fauna) or Legal non-compliance or Social impact.	13.1.a. Take from the Coxs River is neg 13.1.b. Wolgan river users are outside area of impact 13.1.c. Current surface water take insignificant to catchment runoff	D (Pb)	1 (F)	2 (L)	22. Review surface water users

Springvale Mine Groundwater Uncertainty Analysis 2018

Recommended Controls	Place(s) Used	Allocated To	Required By Date	Pulse User No.	PULSE Ref. No.
1. Conceptual model is being reviewed in consultation with the IMP	Events: 1.1, 2.1, 4.1, 5.1, 6.1, 8.1, 9.3	[redacted]	[redacted]	[redacted]	
2. Numerical model is being redeveloped in consutation with regulator, peers, IMP	Events: 1.1, 2.1, 5.1, 8.1	[redacted]	[redacted]	[redacted]	
3. Consideration of operational mining and environmental data to confirm predictions	Events: 1.1, 2.1, 4.1, 5.1, 6.1, 8.1, 9.3	[redacted]	[redacted]	[redacted]	
4. Level Uncertainity analysis will be increased	Events: 1.1, 2.1, 3.1, 4.1, 5.1, 6.1, 8.1, 9.3	[redacted]	[redacted]	[redacted]	
5. Increasing environmental monitoring as a result of IMP recommendations (soil moisture probs, ERT)	Events: 1.1, 5.1, 8.1	[redacted]	[redacted]	[redacted]	
6. Ongoing engagement with IMP	Events: 1.1, 2.1, 3.1, 5.1, 8.1	[redacted]	[redacted]	[redacted]	
7. Numerical model is being redeveloped in consutation with regulator, peers, IMP - Water balance from seepage faces are being further interograted	Events: 4.1, 6.1, 9.3	[redacted]	[redacted]	[redacted]	
8. Uncertainity considerations applied to hydrological model of shrub swamps	Events: 6.1, 9.3	[redacted]	[redacted]	[redacted]	
9. Revisit groundwater users as part of modelling process being reviewed	Events: 7.1, 7.2	[redacted]	[redacted]	[redacted]	
10. Administrative changes to WALs for multiple WSWAs	Events: 9.1	[redacted]	[redacted]	[redacted]	
11. Ongoing engagement with regulator	Events: 9.1	[redacted]	[redacted]	[redacted]	
12. Strategic planning of water take	Events: 9.2	[redacted]	[redacted]	[redacted]	
13. Refinement of numerical modelling methodology to calculate take of water	Events: 9.2	[redacted]	[redacted]	[redacted]	
14. Application for water sharing plan boundary modification	Events: 9.2	[redacted]	[redacted]	[redacted]	
15. Application for controlled allocation ongoing	Events: 9.1	[redacted]	[redacted]	[redacted]	
16. Review of existing licence applications/status (zero share licences) - Consideration of NET take	Events: 9.3	[redacted]	[redacted]	[redacted]	
17. Consider post mining investigation above LW420 (similar to SPR1101 investigation)	Events: 11.1	[redacted]	[redacted]	[redacted]	
18. Packer tests for geological boreholes forecast for southern blocks	Events: 11.1	[redacted]	[redacted]	[redacted]	
19. Increases environmental monitoring data	Events: 11.2	[redacted]	[redacted]	[redacted]	
20. Uncertainty assessment (type 3)	Events: 11.1	[redacted]	[redacted]	[redacted]	
21. Uncertainty assessment (type 3)	Events: 11.2, 12.1	[redacted]	[redacted]	[redacted]	
22. Review surface water users	Events: 13.1	[redacted]	[redacted]	[redacted]	
		[redacted]	[redacted]	[redacted]	

Springvale Mine Groundwater Uncertainty Analysis 2018

Recommended Controls

Recommended Controls	Place(s) Used	Allocated To	Required By Date	Pulse User No.	PULSE Ref. No.
23. Review of adjacent activities	Events: 14.1				
24. Update numerical model to cover revised Angus Place mine plan (2018)	Events: 14.2				

Springvale Mine Groundwater Uncertainty Analysis 2018

PULSE Ref. No.	Recommended Controls	Allocated To	Required By Date	Controls Completion Details: Action Completion Comments	Action Completed By	Completed Date
	1. Conceptual model is being reviewed in consultation with the IMP	[redacted]	[redacted]			
	2. Numerical model is being redeveloped in consutation with regulator, peers, IMP	[redacted]	[redacted]			
	3. Consideration of operational mining and environmental data to confirm predictions	[redacted]	[redacted]			
	4. Level Uncertainity analysis will be increased	[redacted]	[redacted]			
	5. Increasing environmental monitoring as a result of IMP recommendations (soil moisture probs, ERT)	[redacted]	[redacted]			
	6. Ongoing engagement with IMP	[redacted]	[redacted]			
	7. Numerical model is being redeveloped in consutation with regulator, peers, IMP - Water balance from seepage faces are being further interograted	[redacted]	[redacted]			
	8. Uncertainity considerations applied to hydrological model of shrub swamps	[redacted]	[redacted]			
	9. Revisit groundwater users as part of modelling process being reviewed	[redacted]	[redacted]			
	10. Administrative changes to WALs for multiple WSWAs	[redacted]	[redacted]			
	11. Ongoing engagement with regulator	[redacted]	[redacted]			
	12. Strategic planning of water take	[redacted]	[redacted]			
	13. Refinement of numerical modelling methodology to calculate take of water	[redacted]	[redacted]			
	14. Application for water sharing plan boundary modification	[redacted]	[redacted]			
	15. Application for controlled allocation ongoing	[redacted]	[redacted]			
	16. Review of existing licence applications/status (zero share licences) - Consideration of NET take	[redacted]	[redacted]			
	17. Consider post mining investigation	[redacted]	[redacted]			

Springvale Mine Groundwater Uncertainty Analysis 2018

PULSE Ref. No.	Recommended Controls	Allocated To	Required By Date	Controls Completion Details		
				Action Completion Comments	Action Completed By	Completed Date
	above LW420 (similar to SPR1101 investigation)	[redacted]	[redacted]			
	18. Packer tests for geological boreholes forecast for southern blocks	[redacted]	[redacted]			
	19. Increases environmental monitoring data	[redacted]	[redacted]			
	20. Uncertainty assessment (type 3)	[redacted]	[redacted]			
	21. Uncertainty assessment (type 3)	[redacted]	[redacted]			
	22. Review surface water users	[redacted]	[redacted]			
	23. Review of adjacent activities	[redacted]	[redacted]			
	24. Update numerical model to cover revised Angus Place mine plan (2018)	[redacted]	[redacted]			

Springvale Mine Groundwater Uncertainty Analysis 2018

Appendix B Approach to Variably Saturated Flow

B1. Variably Saturated Flow Equation

Variably saturated in MODFLOW was first implemented by HGL (1996) in their adaptation of MODFLOW, known as MODFLOW-Surfact.

From HGL (1996),

> The 3-D movement of water in a variably saturated system can be expressed as (Huyakorn et al., 1986):
>
> $$\frac{\partial}{\partial x}\left(K_{xx}k_{rw}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}k_{rw}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}k_{rw}\frac{\partial h}{\partial z}\right)-W=\phi\frac{\partial S_w}{\partial t}+S_wS_s\frac{\partial h}{\partial t} \quad (1)$$
>
> where:
>
> x, y, and z are Cartesian coordinates (L);
>
> K_{xx}, K_{yy}, and K_{zz} are the principal components of hydraulic conductivity along the x, y, and z axes, respectively (LT^{-1});
>
> k_{rw} is the relative permeability, which is a function of water saturation;
>
> h is the hydraulic head (L);
>
> W is a volumetric flux per unit volume and represents sources and/or sinks of water (T^{-1});
>
> ϕ is the drainable porosity taken to be equal to the specific yield, S_y;
>
> S_w is the degree of saturation of water, which is a function of the pressure head;
>
> S_s is the specific storage of the porous material (L^{-1}); and
>
> t is time (T).

[HGL, 1996, page 2-2]

As noted by HGL (1996), the variably saturated equation presented above reduces to the standard 3D groundwater flow equation in a fully saturated medium (S_w = 1.0),

> For a fully saturated medium (i.e., S_w = 1.0), the relative permeability is unity and equation (1) reduces to:
>
> $$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t} \quad (2)$$
>
> Equation (2) is the basic groundwater flow equation used in the development of MODFLOW (McDonald and Harbaugh, 1988). Hence, the variably saturated flow equation reduces to the conventional groundwater flow equation below the water table and in confined systems.

[HGL, 1996, page 2-2 and 2-3]

In MODFLOW-Surfact, the relationship between relative permeability and water saturation is represented by one of two formulations. The Brooks and Corey (1966) function or a relationship developed by van Genuchten (1977). It is noted that the Brooks and Corey (1966) function is the function available in MODFLOW-USG Transport.

The 3-D movement of water in a variably saturated subsurface system is expressed by equation (1). In order to solve the variably saturated flow problem, it is also necessary to specify the relationships of relative permeability versus water phase saturation, and pressure head versus water phase saturation. Two alternative functional expressions are used to describe the relationship of relative permeability versus water saturation. These functions are given by (Brooks and Corey, 1966):

$$k_{rw} = S_e^n \tag{4a}$$

and (van Genuchten, 1977):

$$k_{rw} = S_e^{1/2}\left[1 - \left(1 - S_e^{1/\gamma}\right)^{\gamma}\right]^2 \tag{4b}$$

when n and γ are empirical parameters and S_e is the effective water saturation defined as $S_e=(S_w-S_{wr})/(1-S_{wr})$ with S_{wr} being referred to as the residual water saturation. The Brooks-Corey expression produces a similar curve to the van Genuchten function when the parameter n is chosen such that $n = 1 + 2/\gamma$ (van Genuchten, 1980).

[HGL, 1996, page 2-3 and 2-4]

In MODFLOW-Surfact, the relationship between pressure head and water saturation is represented by the van Genuchten (1977, 1980) function. The van Genuchten (1980) relationship is the function available in MODFLOW-USG Transport.

The relationship of pressure head ($\psi = h$-z, where z = vertically upward coordinate) versus water saturation is described by the following function (van Genuchten, 1977, 1980):

$$S_e = \frac{S_w - S_{wr}}{1 - S_{wr}} = \begin{cases} \frac{1}{[1+(\alpha h_c)^{\beta}]^{\gamma}} & for\ \psi < 0 \\ 1 & for\ \psi \geq 0 \end{cases} \tag{6}$$

where α and β are empirical parameters, h_c is the capillary head defined as $(h_{ap}$-$\psi)$, where h_{ap}, the pressure head in air is taken as atmospheric (=0), and S_{wr} is the residual water phase saturation. The parameters β and γ are related by $\gamma = 1\text{-}1/\beta$. The Brooks-Corey and van Genuchten functions for the moisture retention and relative permeability characteristics can be measured in the laboratory for a given soil.

[HGL, 1996, page 2-4]

In summary, the variably saturated formulation developed in MODFLOW-Surfact is the same as that deployed in MODFLOW-USG Transport, having been developed by the primary author of MODFLOW-USG, Dr Sorab Panday, whilst at Hydrogeologic Inc.. For the purpose of reference, the MODFLOW-Surfact formulation index variable, IREALSL equals 2, is the formulation deployed in MODFLOW-USG Transport.

Parameterisation of the variably saturated formulation requires values for van Genucthen' α (VANALPHA) and β terms (VANBETA), as well as the residual saturation (SR). For the Brooks-Corey relative hydraulic conductivity function, the exponent of that function (BROOKS) is required. It is noted that the van Genuchten parameter, α, is length unit dependent.

It is highlighted that residual saturation (S_r or S_{wr}) is not the same as residual water content (θ_r). Residual saturation (S_r or S_{wr}) can be considered to be the saturation at which the effective permeability of the wetting phase is zero, or the point at which there is a switch between capillary flow and non-capillary flow. In practice, it is sometimes taken as the permanent wilting point, which is the saturation at an equivalent matrix suction of -1500kPa.

Brooks and Corey (1966), in their original paper, present experimental data from three consolidated samples. That experimental data formed the basis of their relative hydraulic conductivity function.

Brooks and Corey (1966) state that the Hygiene Sandstone sample had no visible bedding, however, contained a substantial amount of clay. Brooks and Corey (1966) explain that the Berea Sandstone sample was cut perpendicular to the bedding plans and in a fully saturated state that stratification was not visible, however, during the experiment, at average saturation, the finer-texted strata were still fully saturated and darker than the partially desaturated coarser-textured strata. Brooks and Corey (1966) note that the Fragmented Mixture sample was not a natural sample and instead prepared by mixing of aggregates created by crushing oven-dried clay and a consolidated sandstone with their volcanic sand sample.

Figure B.1 presents the experiment data of capillary pressure head as a function of saturation, as well as the Brooks and Corey (1966) model of relative permeability (wetting phase) versus capillary pressure head.

From **Figure B.1**, a noteworthy feature is that the sandstone samples remain at full saturation until a capillary pressure head of approximately 50cm, which was similar to the behaviour unconsolidated clay and quite dissimilar to the behaviour of unconsolidated sand, which starts to desaturate almost immediately.

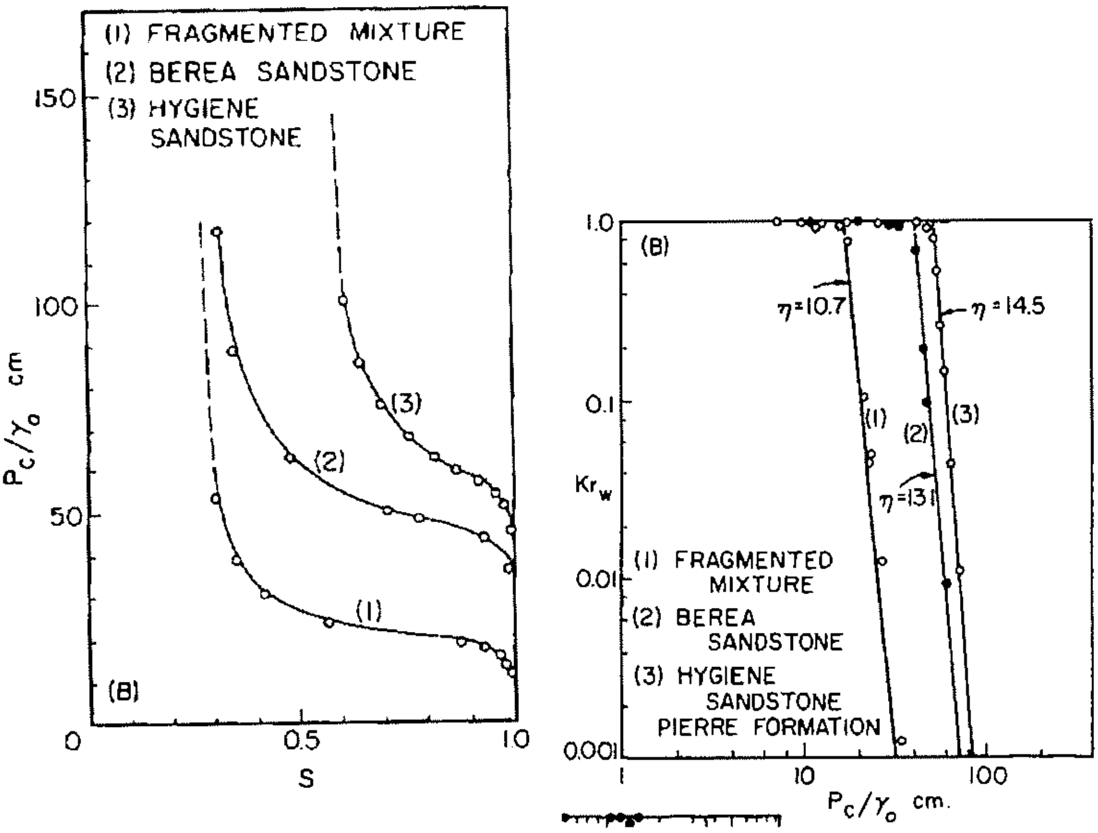


Figure B.1: Capillary Pressure Head as a function of Saturation and Predicted Wetting Phase Relative Permeability as a function of Capillary Pressure Head (after Figure 4 and Figure 10 of Brooks and Corey (1966))

Appendix C Mine Schedule

C1. Mine Schedule

Figure C.1 presents the mine schedule implemented in the numerical groundwater model. The schedule includes mining of Longwall 910N, on retreat, in 2038.

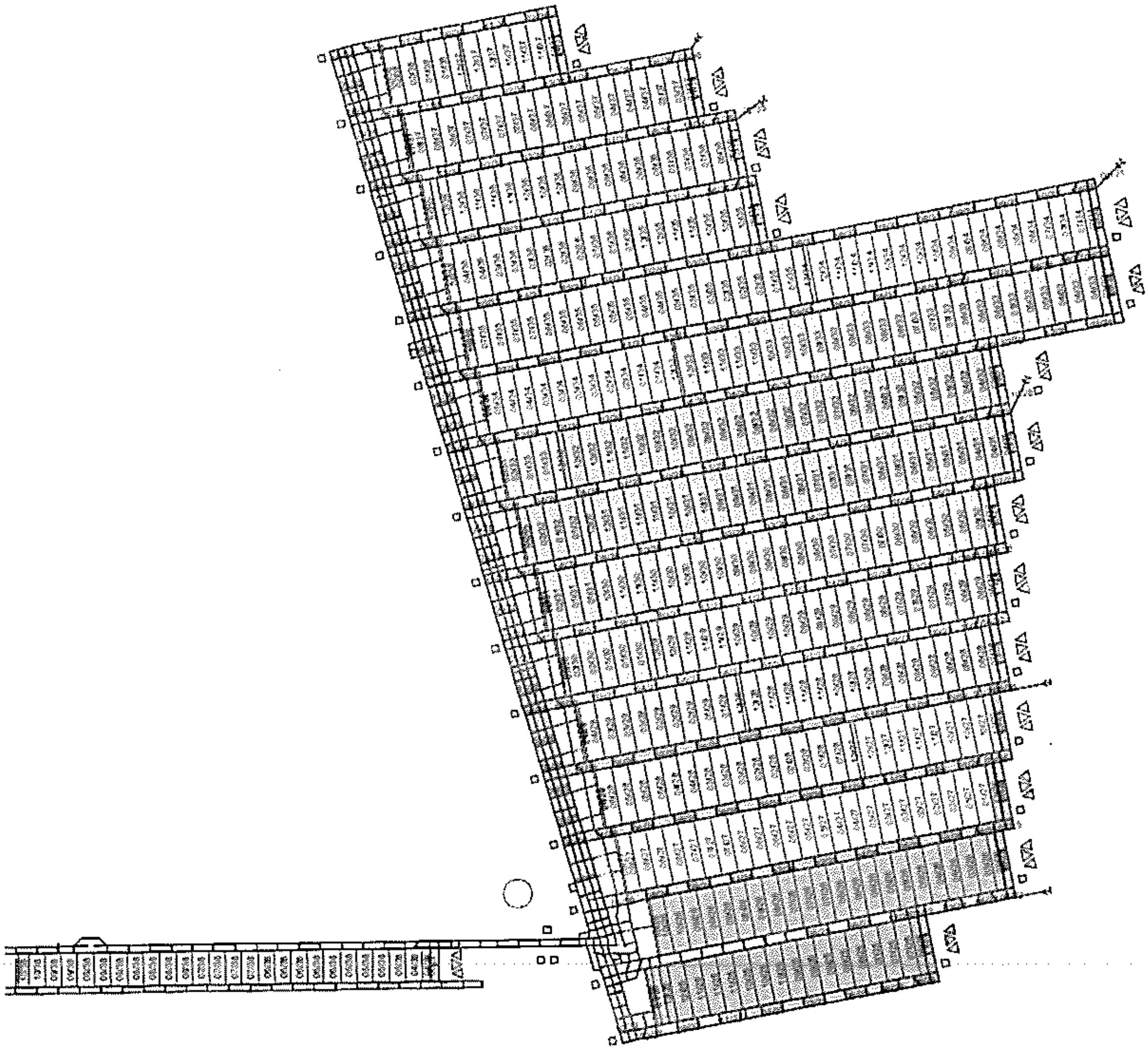


Figure C.1: Mine Schedule implemented in the Model

Table C.1 tabulates the information presented in **Figure C.1**.

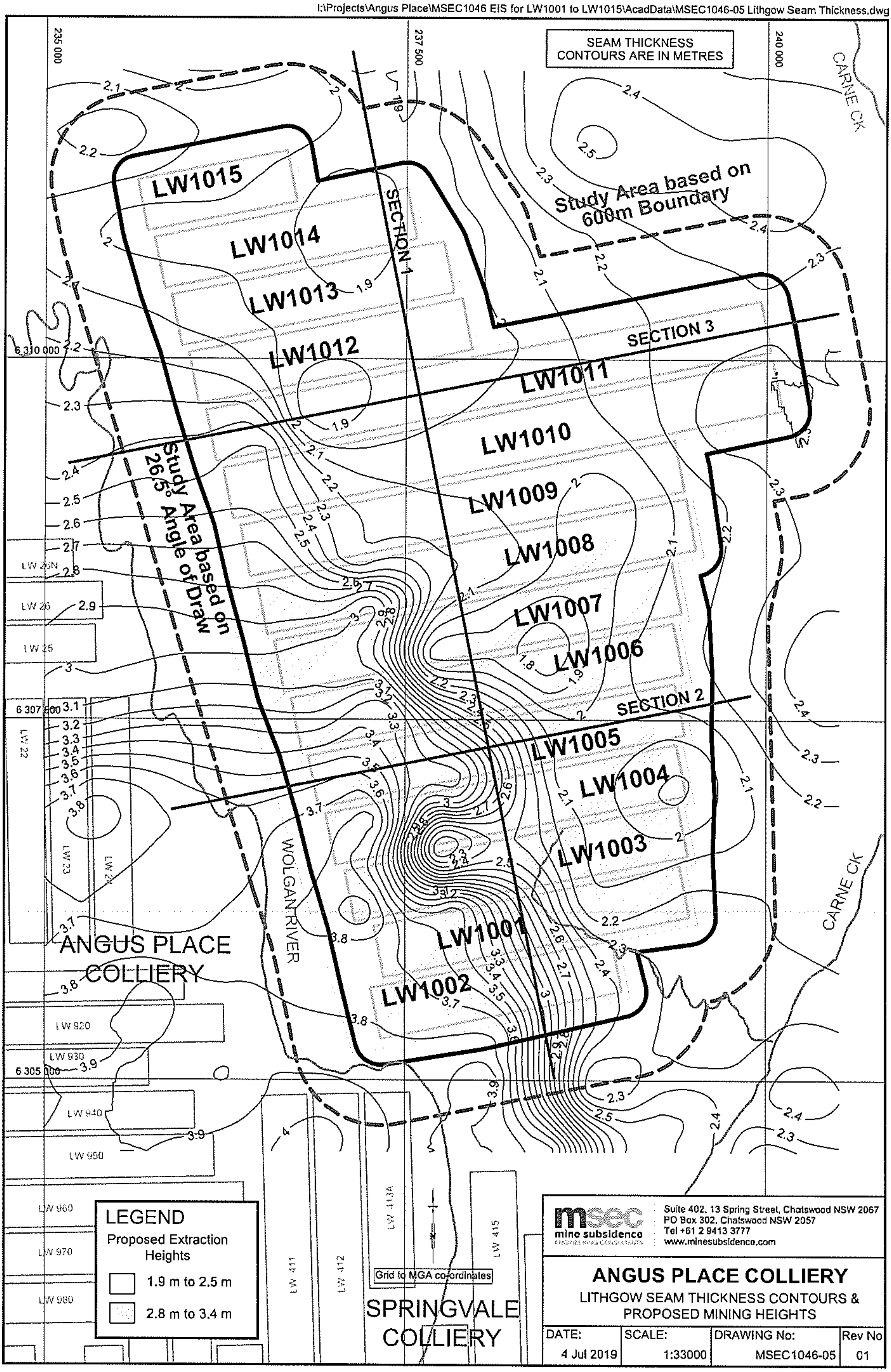
Table C.1: Mine Scheduled implemented in the Model

Longwall	Start Month	End Month
LW1002	July 2025	January 2026
LW1001	March 2026	September 2026
LW1003	January 2027	September 2027
LW1004	October 2027	June 2028
LW1005	August 2028	April 2029
LW1006	June 2029	February 2030
LW1007	May 2030	February 2031
LW1008	April 2031	February 2032
LW1009	April 2032	February 2033
LW1010	April 2033	May 2034
LW1011	July 2034	July 2035
LW1012	October 2035	April 2036
LW1013	June 2036	January 2037
LW1014	March 2037	August 2037
LW1015	October 2037	February 2038
LW910N	April 2038	October 2038

C2. Cutting Heights

The following figure presents the thickness contours of the Lithgow Seam as well as the proposed cutting heights.

I:\Projects\Angus Place\MSEC1046 EIS for LW1001 to LW1015\AcadData\MSEC1046-05 Lithgow Seam Thickness.dwg



Appendix D Subsidence Induced Change to Hydraulic Properties

D1. Example of Application of the Subsidence Model for Longwalls

Below is an example of how the implementation of information provided in **Table 4.7** has been considered in the model.

The lower right DRN cell in **Figure 4.12** is Node 661986 (Node 387141 with respect to 'Write Active Nodes Only' numbering).

The FORTRAN script reads the DRN cell inputs including Panel Width (in this case, 261m), Mining Height (in this case 3.4m), Height of Caved Zone (as a multiplier, in this case 10x), the Number of Bords (explained further **below**) as well as the Bottom Elevation.

The entry for Node 661986 is presented in **Figure D.1** below.

In **Figure D.1**, it is noted that units for delx, dely, PanelWidth and MiningHeight are m; units for area are m^2; and units for BotEl are mAHD (metres Australian Height Datum).

row	column	delx	dely	area	node	StartSP	EndSP	PanelWidt	MiningHeig	HeigthOfC	NumBords	BotEl
42	27	100	100	10000	661986	143	190	350.38	3.4	10	0	746.7711

Figure D.1: Example of DRN cell entry to the Subsidence-Induced Change to Hydraulic Property FORTRAN Script (Node 661986)

The FORTRAN script then calculates the height of Caved - Zone A Interface, A-B Interface, B-C Interface and C-D Interface. As noted above, if the elevation of these interfaces is such that they exceed ground surface, as is the case for Node 674909, then the profile is truncated.

The elevation of the interfaces is then applied in the calculation of the different zones in **Table 4.7**.

It is noted that the zonation in Table **4.7** was developed in an attempt to account for the dilation in the strata/gaps that develop at the interface between the various zones. i.e. a significant increase in relative hydraulic conductivity because of voids that can develop, albeit across a limited thickness.

The calculated elevation of the various zones for Node 661986 is presented in **Figure D.2**.

In **Figure D.2**, it is noted that units for Panel Width, Mining Height, Cover Depth, Effective Panel Width, Height of Fracturing_Zone A (HoF_A and HoF_A95), Height of Fracturing Zone B (HoF_B and HofF_B95) are m; units for Ground Surface, Zone_01 through Zone_13 are mAHD; and units for Cell Area are m^2.

Mine Laye	Orig Node	Start SP	End SP	Panel Widt	Mining Hei	HeightOfC	Layer 1 Or	Ground Su	Cover Dep	Effective F	WidthToH	Effective S	a	b	HoF_A	HoF_A95
24	661986	143	190	350.38	3.4	10	9867	1072.86	322.79	350.38	0	0	0	0	344.7	381.7

HoF_B	HoF_B95	Zone 01	Zone 02	Zone 03	Zone 04	Zone 05	Zone 06	Zone 07	Zone 08	Zone 09	Zone 10	Zone 11	Zone 12	Zone 13	NumBord:	Cell Area	B&P Scalir
391.5	417.6	1114.4	1114.4	1114.4	1114.4	1114.4	1114.4	1029.23	1024.23	1019.23	804.69	772.19	769.1	759.1	0	10000	1

Figure D.2: Example of summary output from the Subsidence-Induced Change to Hydraulic Property FORTRAN Script (Node 661986)

Based on the current values of parameters in **Table 4.7**, the subsidence profile for Node 661986 is calculated internally and presented in **Figure D.3**.

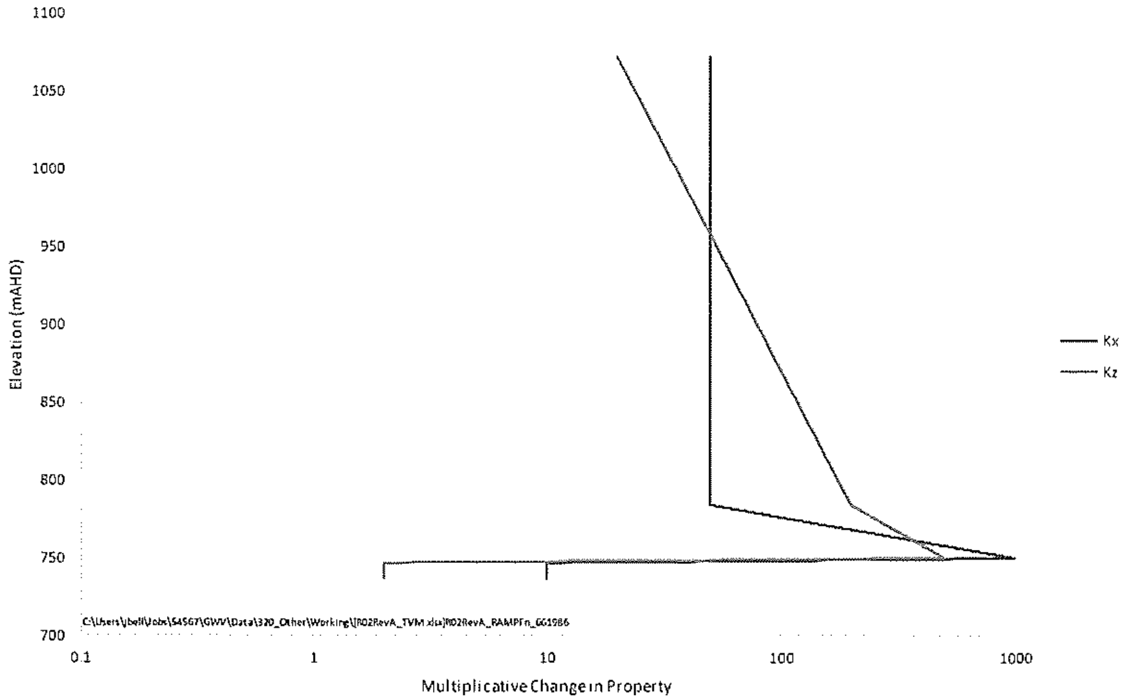


Figure D.3: Example of internally calculated Subsidence-Profile (Node 661968)

Note that the profile in **Figure D.3** is quite distinct from that presented in **Figure 4.13**. This is because, as indicated in **Figure D.2**, the subsidence profile is truncated as it exceeds ground surface. From **Figure D.2**, the cover depth at this location is 322.79m.

It is noted that, due to the high HoF_A from the Tammetta (2013) equation, most of the active mining DRN cells in the 1000 Panel Area resulted in a truncated subsidence profile.

Next is transposition of **Figure D.3** onto the relevant layers in the groundwater model. This is achieved through sampling of the log of elements in **Figure D.3**, and averaging for the relevant layer. **Figure D.4** presents the resultant profile and is what is written to the .TVM file, after multiplication by the existing value for hydraulic conductivity for the respective cell.

It is noted that due to using a 'Stacked Drain' approach, the factors presented in **Table 4.7** were not altered during model calibration, except for Kh and Kz multipliers in Zone 1 and the interface of Zone C and D. A Bord and Pillar adjustment factor, which is discussed below, was also adjusted but is noted to be not specifically listed in **Table 4.7**.

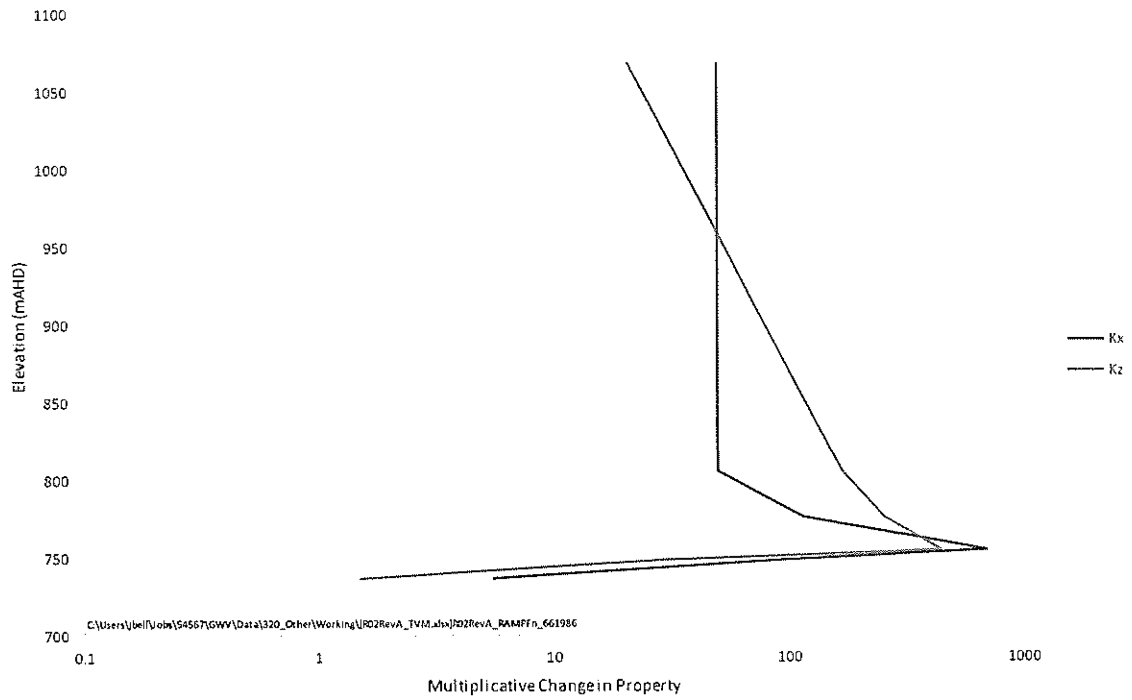


Figure D.4: Example of transposition of the Subsidence-Profile onto relevant model layers (Node 661968)

D2. Example of Application of the Subsidence Model to a Bord & Pillar Operation

Below is an example of how the subsidence model was implemented for a Bord & Pillar operation.

Node 661771 (386926) is located in the access road into Angus Place Colliery (refer **Figure D.5**) and is marked with a blue star.

Figure D.6 presents the entry for Node 661771 in the DRN file.

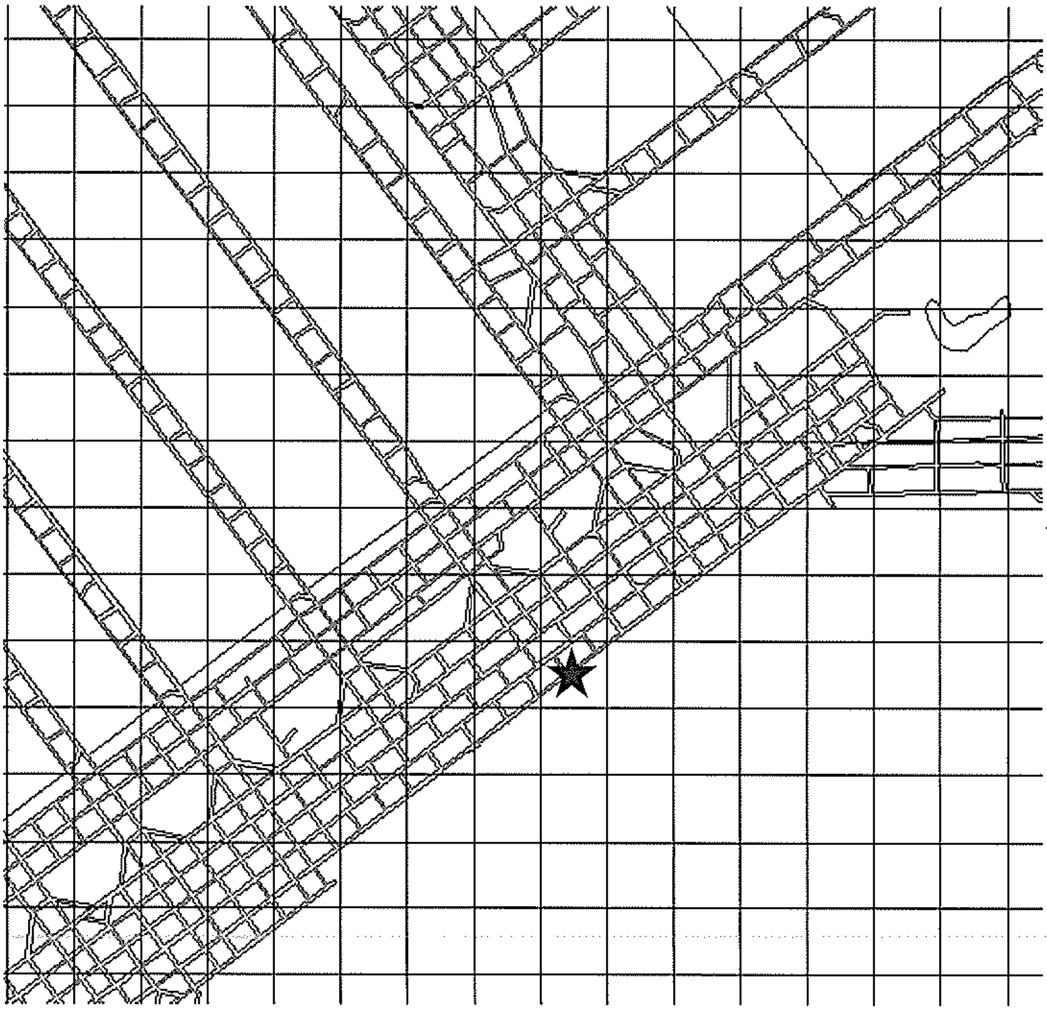


Figure D.5: Example of Bord & Pillar Cell (DRN) at Angus Place Colliery – Layer 24 (Lithgow Seam), SP143 (March 2029) (Node 661771)

From **Figure D.6**, the 'panel width' is 6m and the Height of Caved Zone Multiplier is 4, with the number of 'Bords' set at 4. As will be explained further below, the number of 'Bords' was used, together with the cell size to scale the resultant change in hydraulic properties.

In **Figure D.6**, it is noted that units for delx, dely, PanelWidth and MiningHeight are m; units for area are m^2; and units for BotEl are mAHD.

row	column	delx	dely	area	node	StartSP	EndSP	PanelWidt	MiningHei	HeightOfC	NumBords	BotEl
42	14	100	100	10000	661771	2	190	6	3.5371	4	4	805.8276

Figure D.6: Example of DRN cell entry to the Subsidence-Induced Change to Hydraulic Property FORTRAN Script (Node 661771)

The calculated elevation of the various zones for Node 661771 is presented in **Figure D.7**. The scaling factor in **Figure D.7** of 0.24, in the last column of **Figure D.7**, is based on 4 'Bords' * 6 m for each 'Bord' compared to a cell width of 100m.

In **Figure D.7**, it is noted that units for Panel Width, Mining Height, Cover Depth, Effective Panel Width, Height of Fracturing_Zone A (HoF_A and HoF_A95), Height of Fracturing Zone B (HoF_B and HofF_B95) are m; units for Ground Surface, Zone_01 through Zone_13 are mAHD; and units for Cell Area are m^2.

Mine Laye	Orig Node	Start SP	End SP	Panel Widt	Mining Hei	HeightOfC	Layer 1 Or	Ground Su	Cover Dep	Effective P	WidthToH	Effective S	a	b	HoF_A
24	661771	2	190	6	3.54	4	9652	1009.41	200.05	2.71	0.01	42	0.15	0.2	15.54

HoF_A95	HoF_B	HoF_B95	Zone 01	Zone 02	Zone 03	Zone 04	Zone 05	Zone 06	Zone 07	Zone 08	Zone 09	Zone 10	Zone 11	Zone 12	Zone 13	NumBords	Cell Area	B&P Scalin	Reach Nur
15.95	29.44	29.98	1009.41	1000.1	853.8	843.8	838.8	833.8	829.91	824.91	819.91	823.51	809.36	805.83	795.83	4	10000	0.24	204

Figure D.7: Example of summary output from the Subsidence-Induced Change to Hydraulic Property FORTRAN Script (Node 661771)

The internally calculated subsidence-profile is presented in **Figure D.8** and the transposition onto relevant model layers is presented in **Figure D.9**.

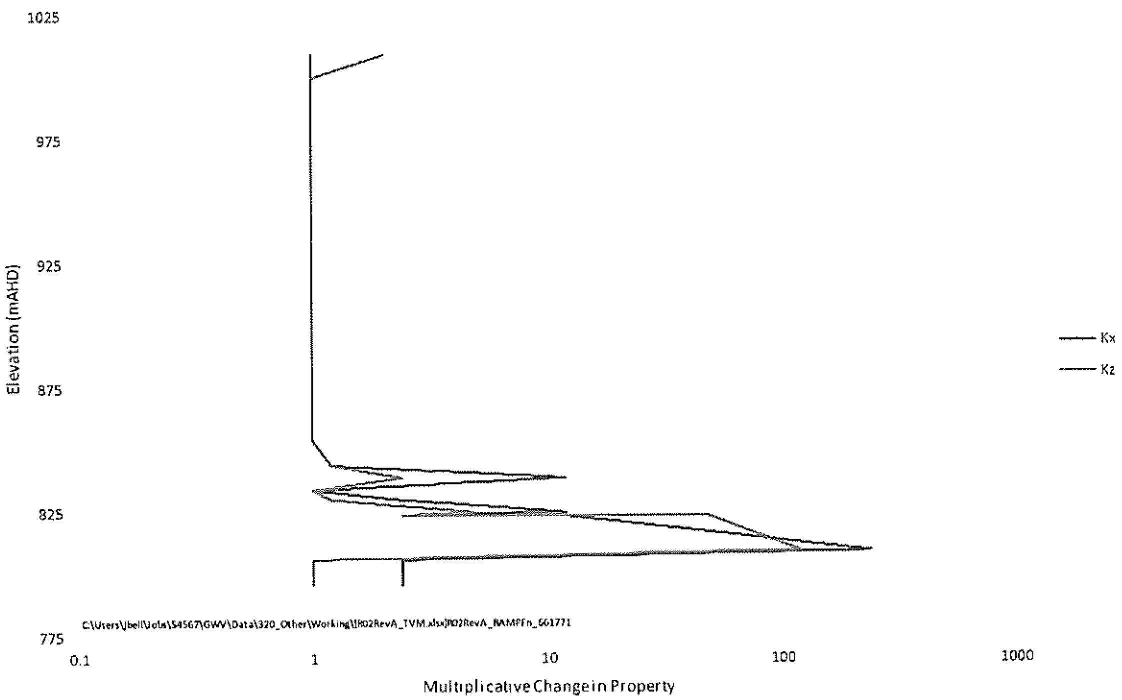


Figure D.8: Example of internally calculated Subsidence-Profile (Node 661771)

From **Figure D.9**, the magnitude of change to Kx and Kz is locally restricted to just above the roadway (limited to about 50m).

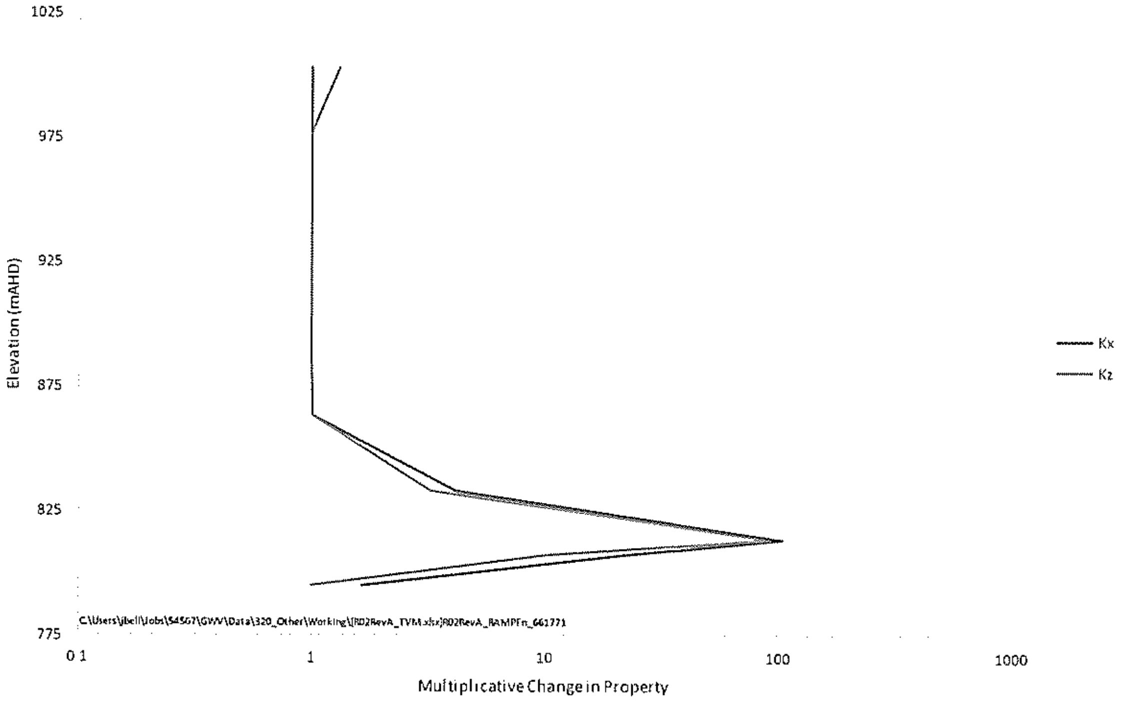
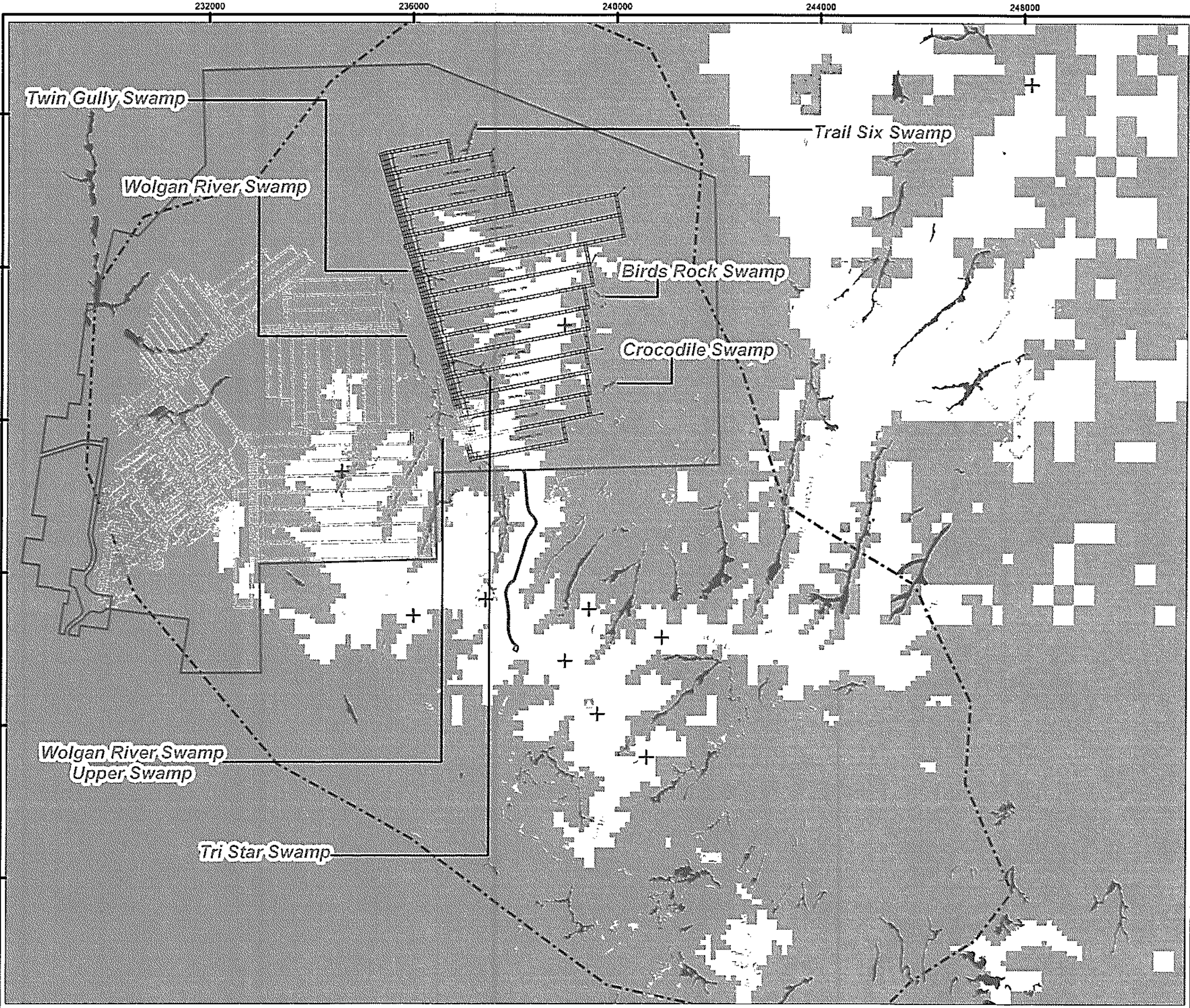


Figure D.9: Example of transposition of the Subsidence-Profile onto relevant model layers (Node 661771)

Appendix E Pilot Point Distribution and Spatial and Cumulative Distribution of Hydraulic Parameter Values

E1. Pilot Point Distribution

Figure 4.15 presents the distribution of Pilot Points in Layer 28 of the model. The location of Pilot Points in other model layers is presented in this appendix.



Legend:

- Pilot Points (Layer 3)
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- Pilot Point Region

RPS (2019):

- Shrub Swamps
- Hanging Swamps

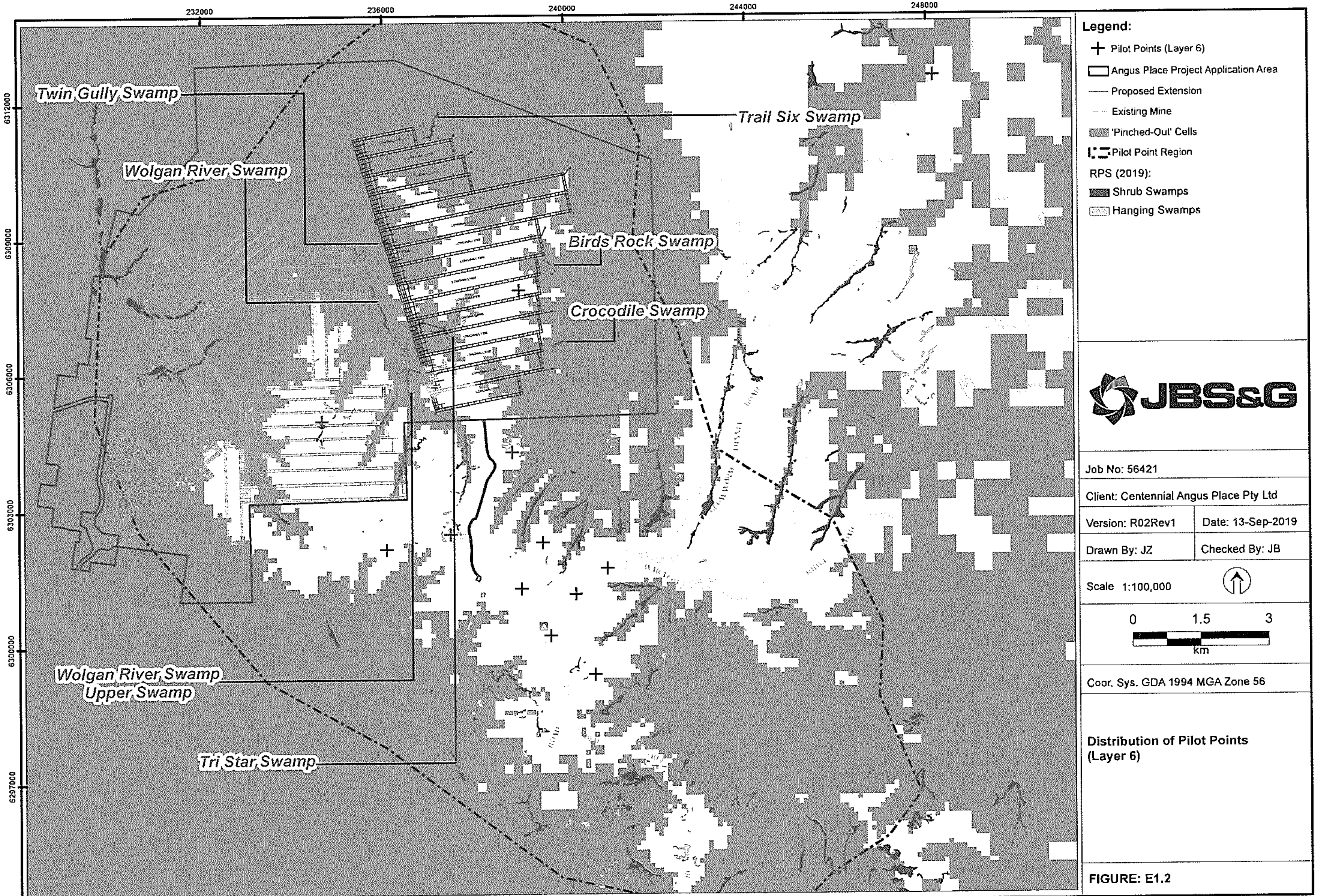
JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 13-Sep-2019
Drawn By: JZ	Checked By: JB
Scale 1:100,000	
0 1.5 3 km	
Coor. Sys. GDA 1994 MGA Zone 56	

Distribution of Pilot Points (Layer 3)

FIGURE: E1.1

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D036_PilotPoints_Layer03.mxd
Reference © Department of Finance Services & Innovation 2018



JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 13-Sep-2019
Drawn By: JZ	Checked By: JB

Scale 1:100,000

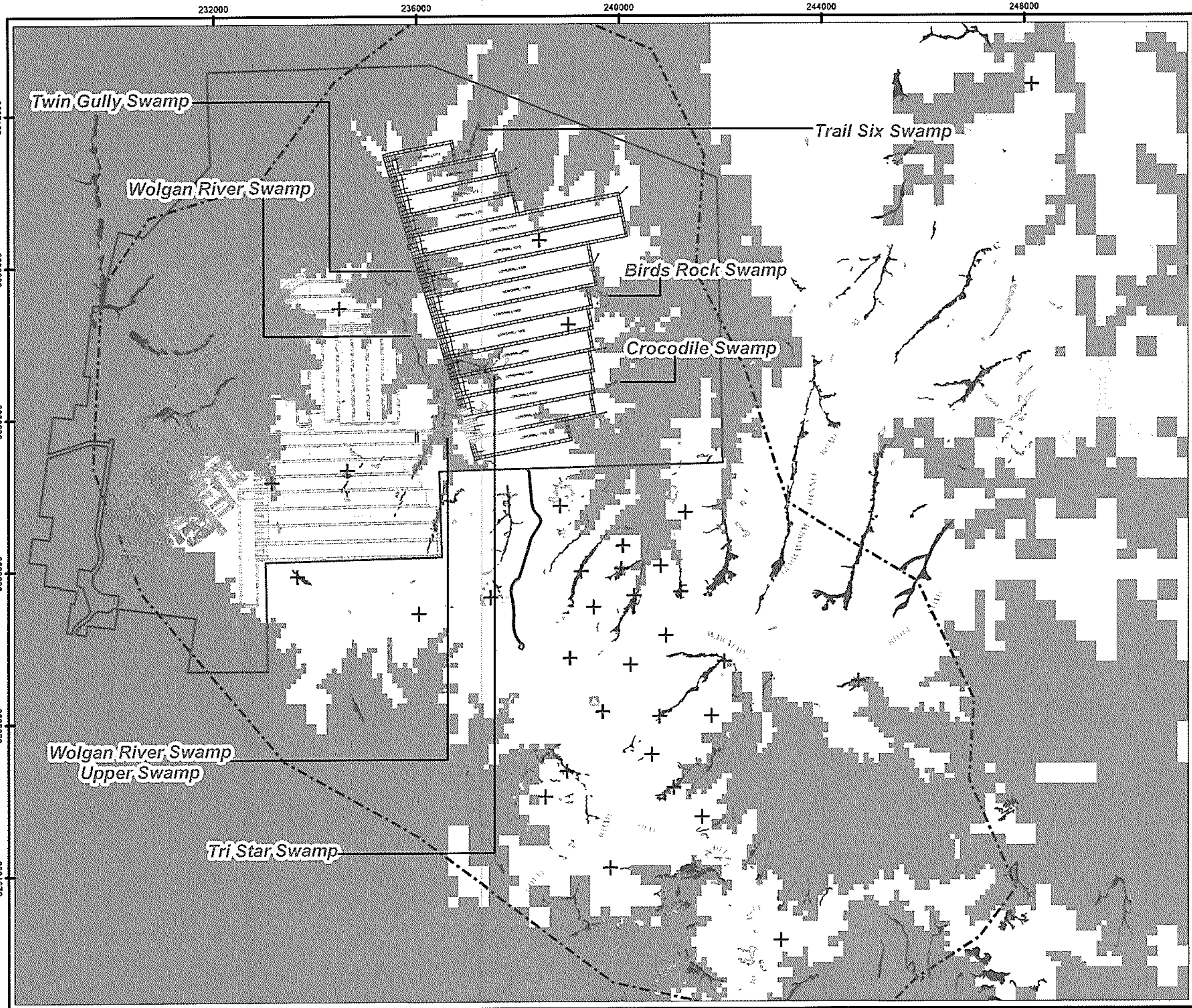
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Distribution of Pilot Points (Layer 6)

FIGURE: E1.2

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D037_PilotPoints_Layer06.mxd
Reference: © Department of Finance, Services & Innovation 2018



Legend:

- Pilot Points (Layer 9)
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- Pilot Point Region

RPS (2019):

- Shrub Swamps
- Hanging Swamps

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 13-Sep-2019
Drawn By: JZ	Checked By: JB
Scale 1:100,000	

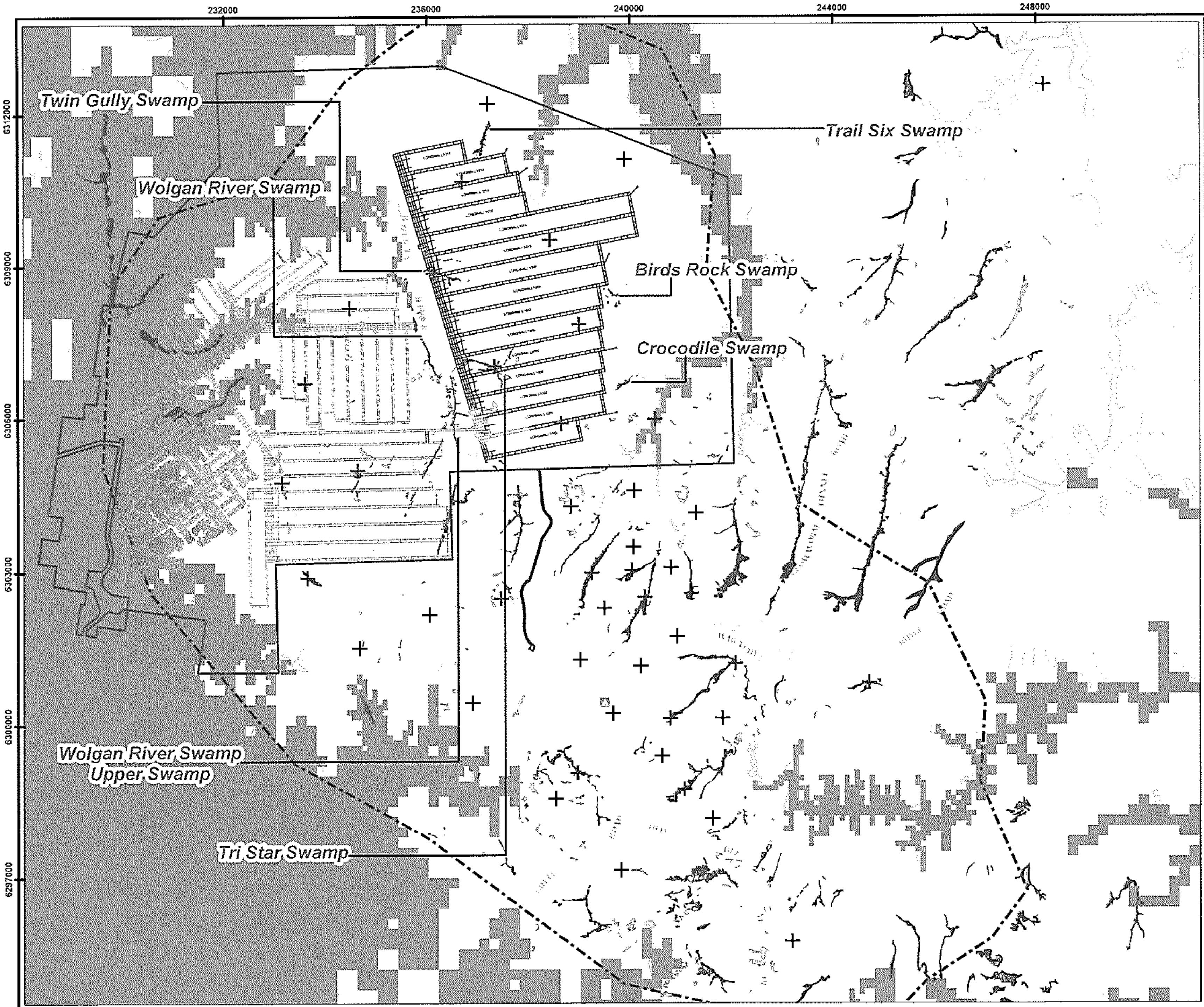
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Distribution of Pilot Points (Layer 9)

FIGURE: E1.3

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D038_PilotPoints_Layer09.mxd
Reference: © Department of Finance, Services & Innovation 2018



Legend:

- Pilot Points (Layer 13)
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- Pilot Point Region
- 'Pinched-Out' Cells

RPS (2019):

- Shrub Swamps
- Hanging Swamps

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 13-Sep-2019
Drawn By: JZ	Checked By: JB
Scale 1:100,000	

0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Distribution of Pilot Points (Layer 13)

FIGURE: E1.4

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D039_PilotPoints_Layer13.mxd
Reference © Department of Finance, Services & Innovation 2018

Legend:

- Pilot Points (Layer 18)
- Angus Place Project Application Area
- Proposed Extension
- Existing Mine
- Pilot Point Region
- 'Pinched-Out' Cells

RPS (2019):

- Shrub Swamps
- Hanging Swamps

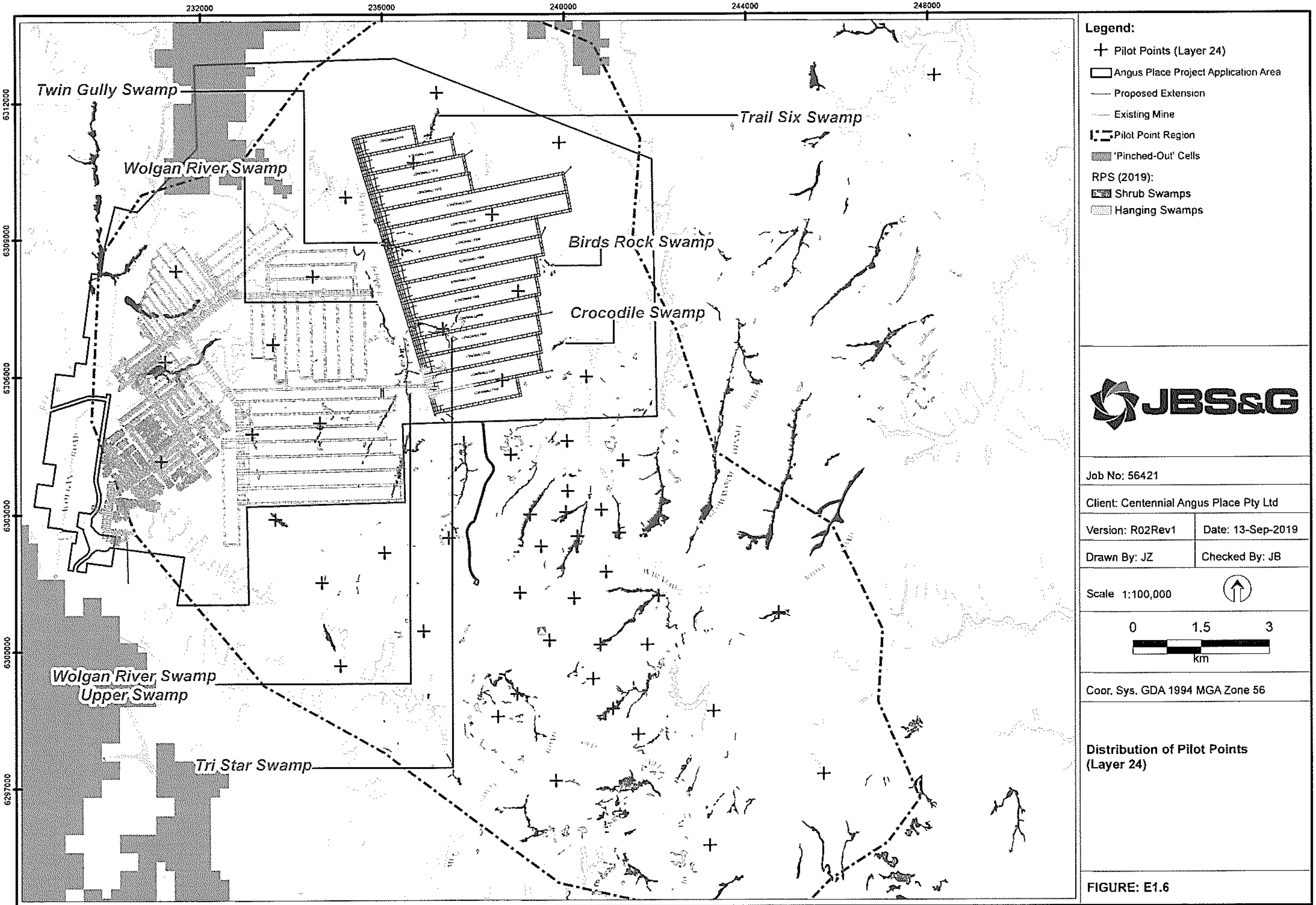
JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 13-Sep-2019
Drawn By: JZ	Checked By: JB
Scale 1:100,000	
0 1.5 3 km	
Coor. Sys. GDA 1994 MGA Zone 56	

Distribution of Pilot Points (Layer 18)

FIGURE: E1.5

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D040_PilotPoints_Layer18.mxd
Reference © Department of Finance, Services & Innovation 2018



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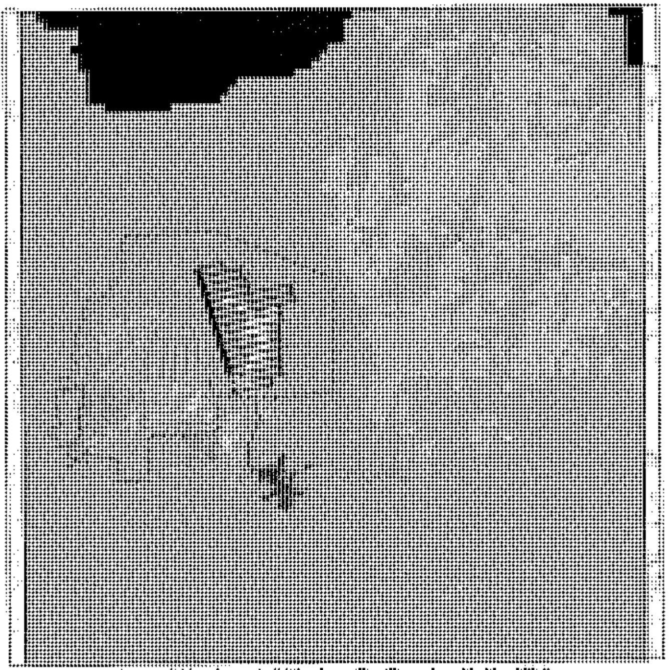
Reference: © Department of Finance, Services & Innovation 2018

E2. Spatial and Cumulative Distribution of Hydraulic Parameter Values

The calibrated hydraulic parameter distribution plots are presented in this appendix with respect to each model layer. As well, the cumulative distributions of parameter values are also presented.

K_h (m/d)

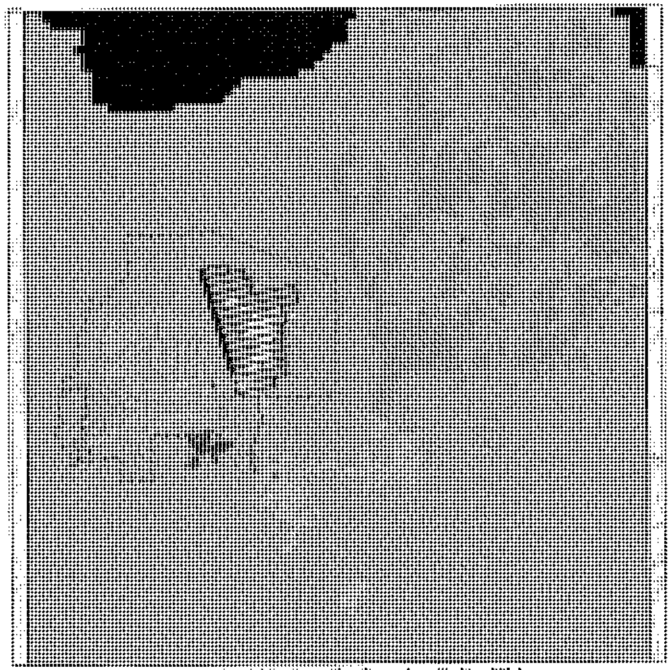
- 3.8e-02 - 4.9e-02
- 5.0e-02 - 5.6e-02
- 5.7e-02 - 7.6e-02
- 7.7e-02 - 1.1e-01
- 1.2e-01 - 1.7e-01



Distribution of Horizontal Hydraulic Conductivity (K_h)

K_Z (m/d)

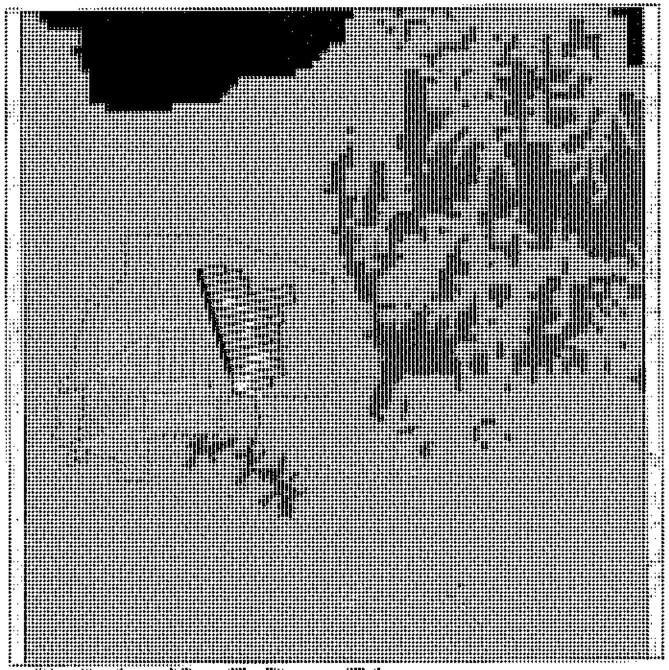
- 3.1e-04
- 3.2e-04 - 1.9e-03
- 2.0e-03 - 3.1e-03
- 3.2e-03 - 4.4e-03
- 4.5e-03 - 6.7e-03



Distribution of Vertical Hydraulic Conductivity (K_z)

S_S (/m)

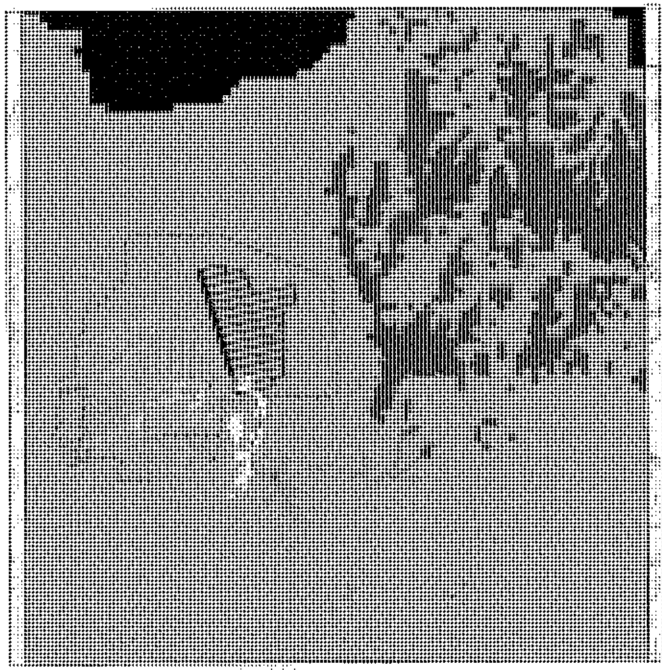
- 5.0e-06
- 5.1e-06 - 6.0e-06
- 6.1e-06 - 7.0e-06
- 7.1e-06 - 8.0e-06



Distribution of Specific Storage (S_s)

Φ

- 0.13 - 0.16
- 0.17 - 0.19
- 0.2 - 0.23
- 0.24 - 0.28



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 1)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	

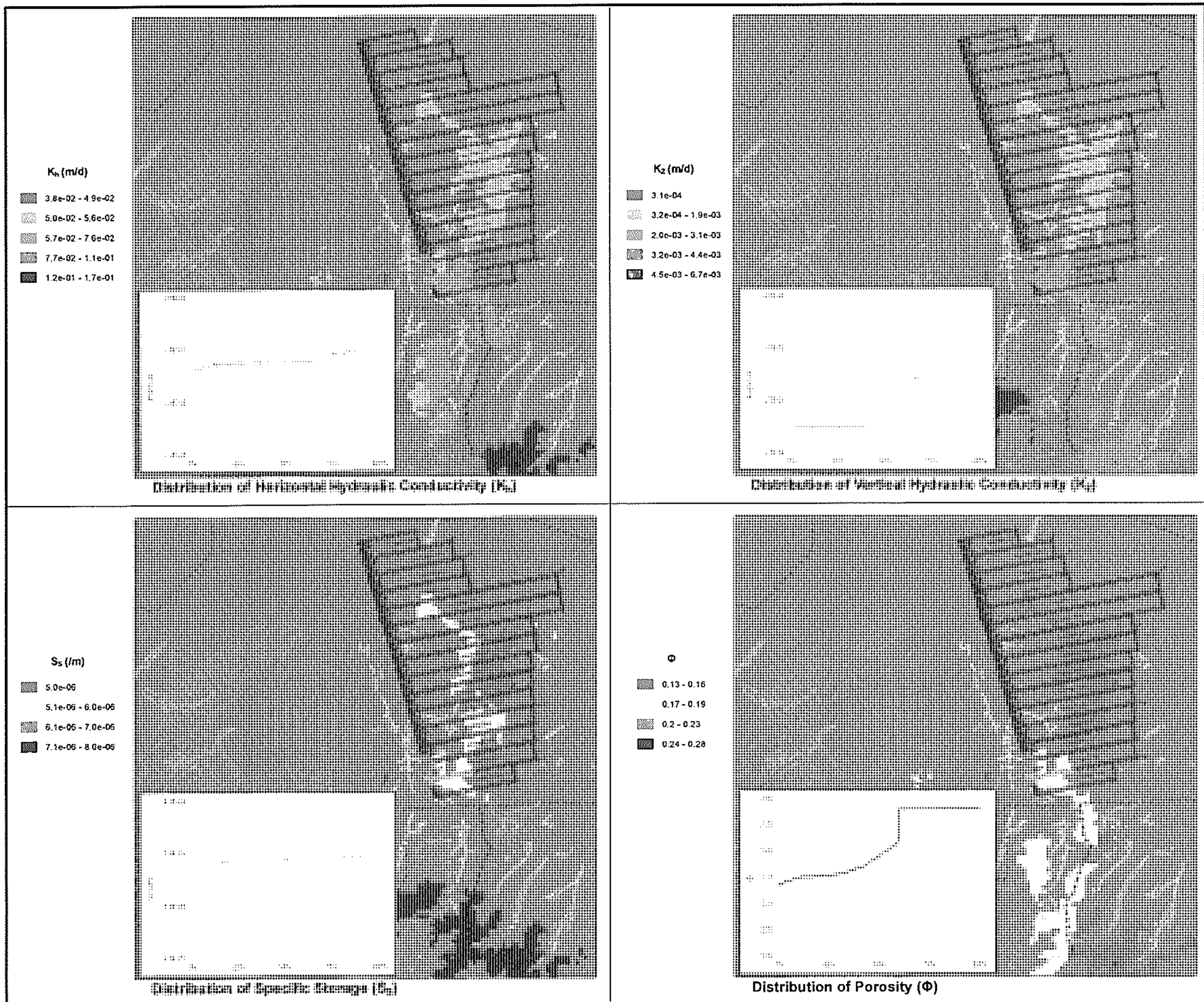
0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 1)

FIGURE: E.2.1a

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D077_DistributionOfAquiferProperties_L01.mxd
Reference © Department of Finance Services & Innovation 2018



Legend:

- × Pilot Points (Layer 1)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells
- RPS (2019):
  - Shrub Swamps
  - Hanging Swamps

Note: 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	

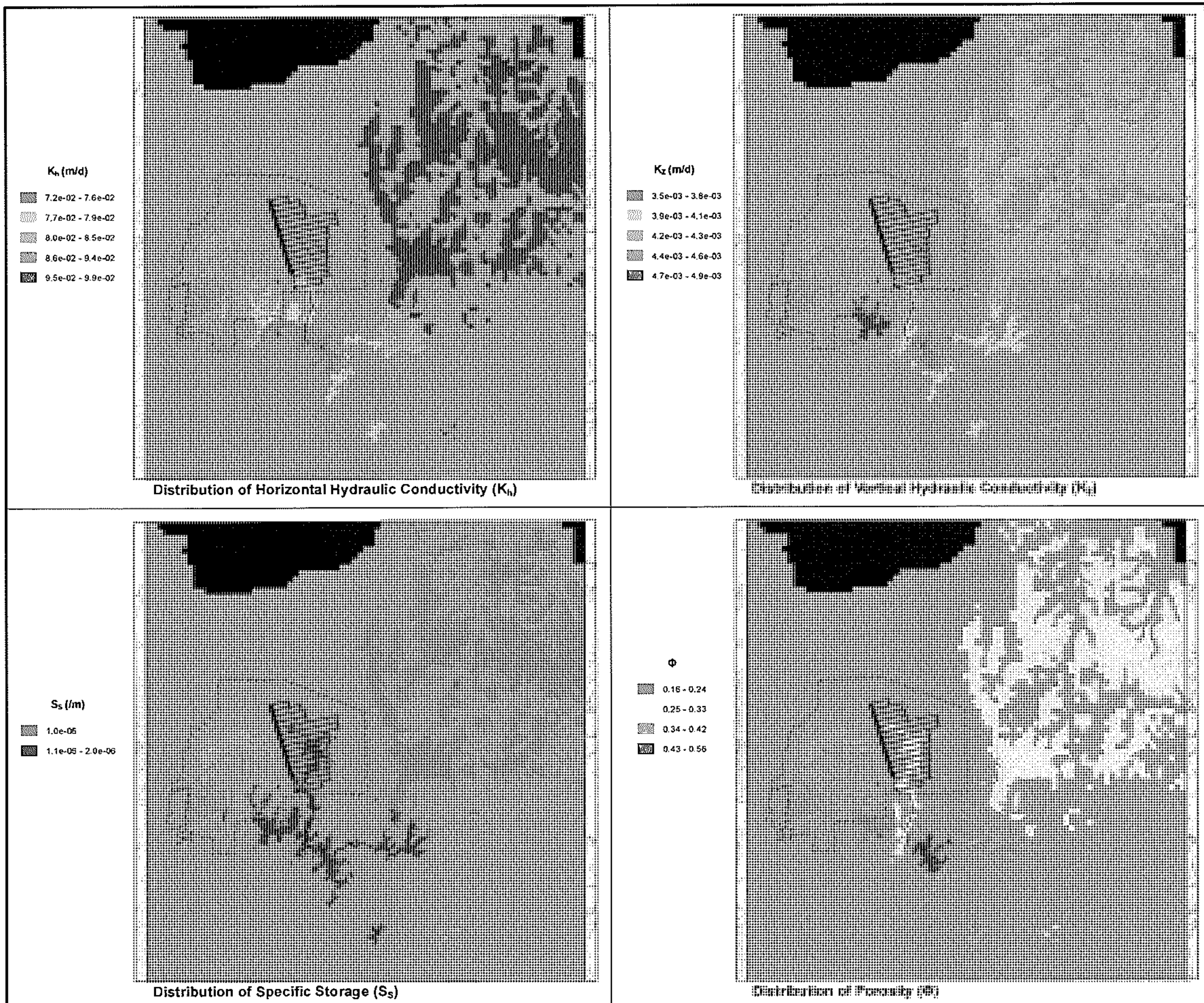
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 1) - Angus Place 1000 Panel Area

FIGURE: E.2.1b

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D077a_DistributionOfAquiferProperties_L01_Zoomed.mxd



Legend:

- × Pilot Points (Layer 2)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	

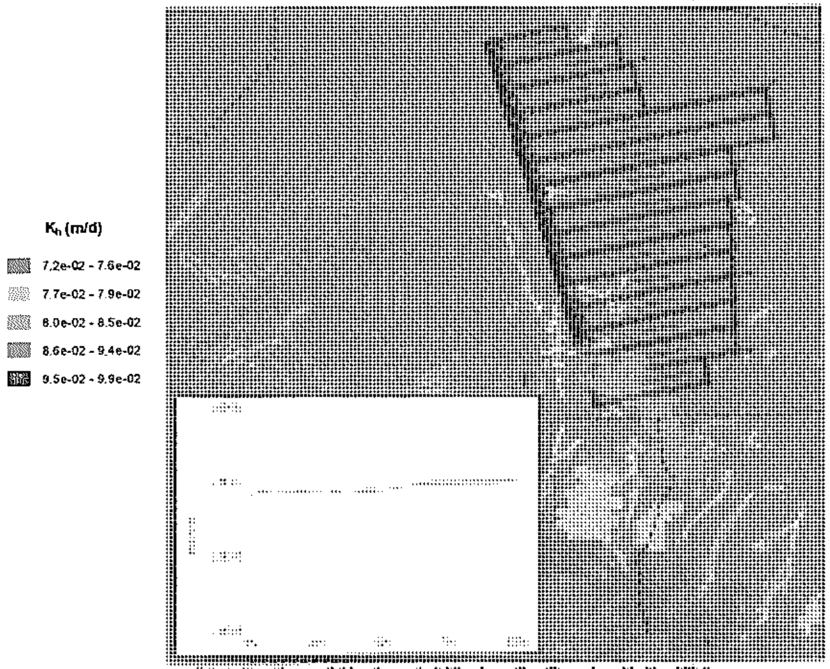
0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

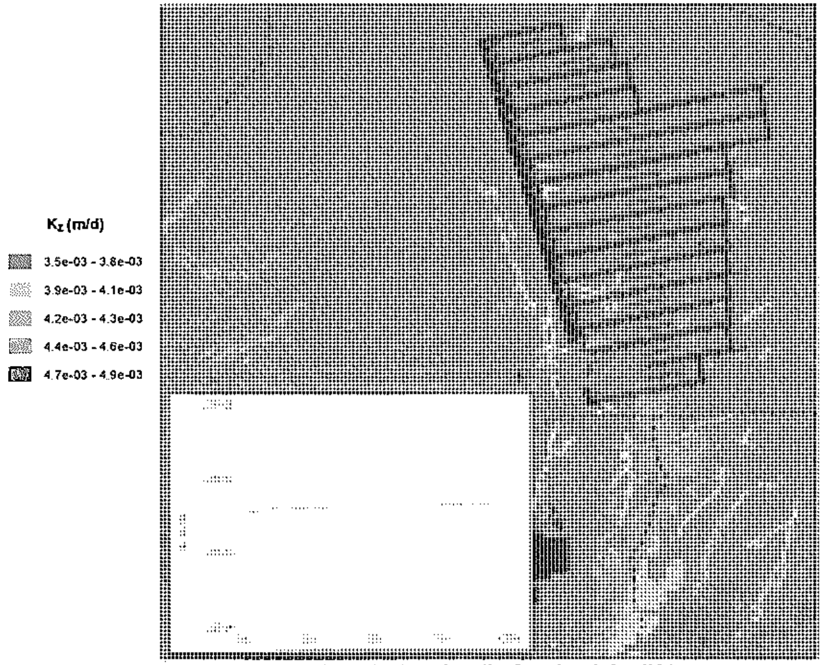
Calibrated Hydraulic Properties (Layer 2)

FIGURE: E.2.2a

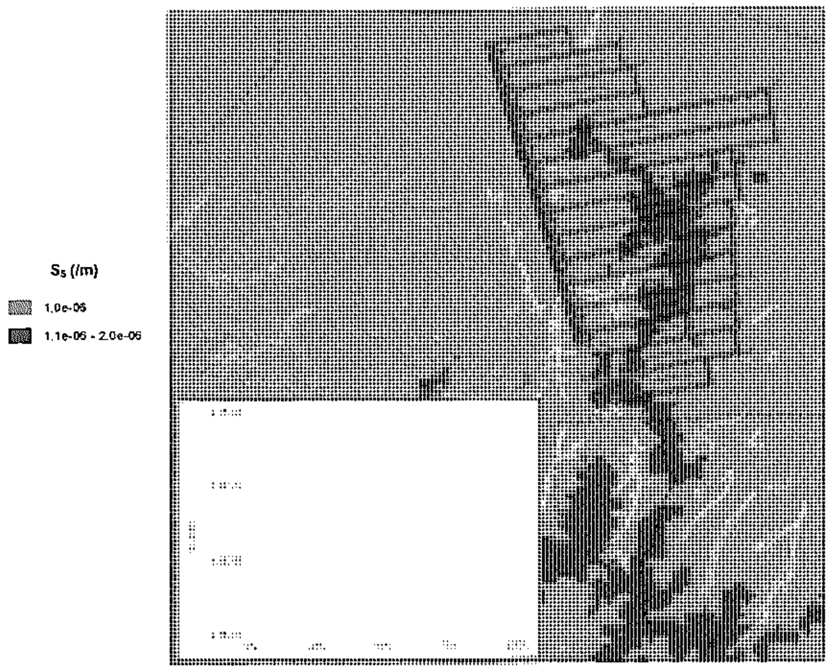
File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D076_DistributionOfAquiferProperties_L02.mxd
Reference © Department of Finance Services & Innovation 2018



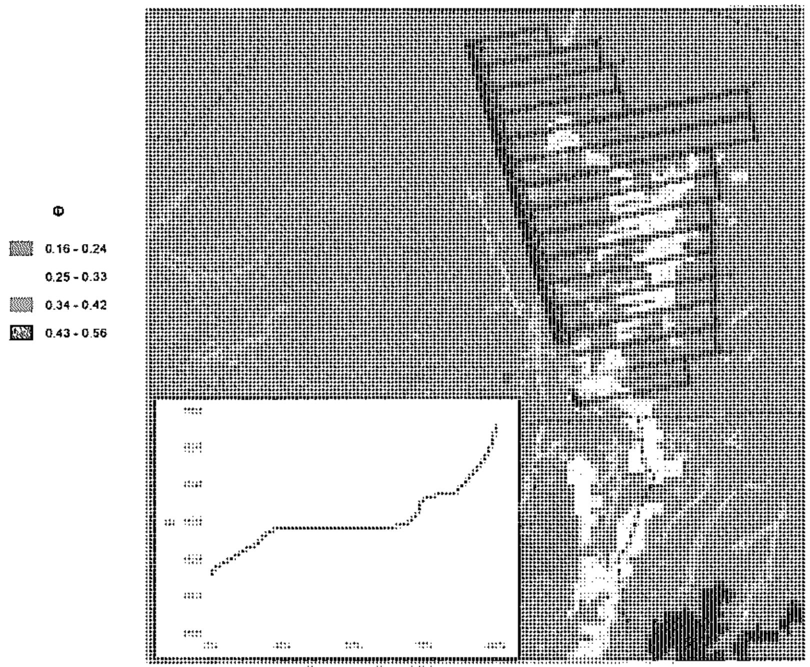
Distribution of Horizontal Hydraulic Conductivity (K_h)



Distribution of Vertical Hydraulic Conductivity (K_Z)



Distribution of Specific Storage (S_S)



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 2)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells
- RPS (2019):
  - Shrub Swamps
  - Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	
0 1.5 3 km	
Coor. Sys. GDA 1994 MGA Zone 56	

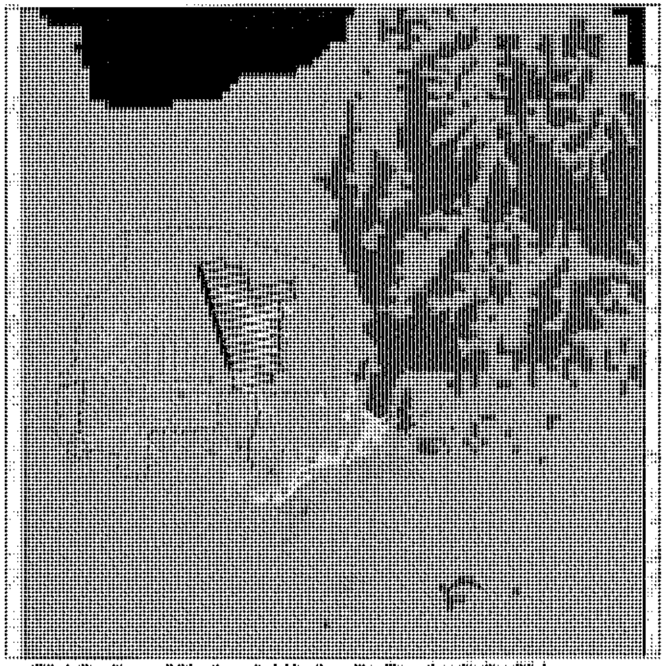
Calibrated Hydraulic Properties (Layer 2) - Angus Place 1000 Panel Area

FIGURE: E.2.2b

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D076a_DistributionOfAquiferProperties_L02_Zoomed.mxd
Reference © Department of Finance, Services & Innovation 2018

K_h (m/d)

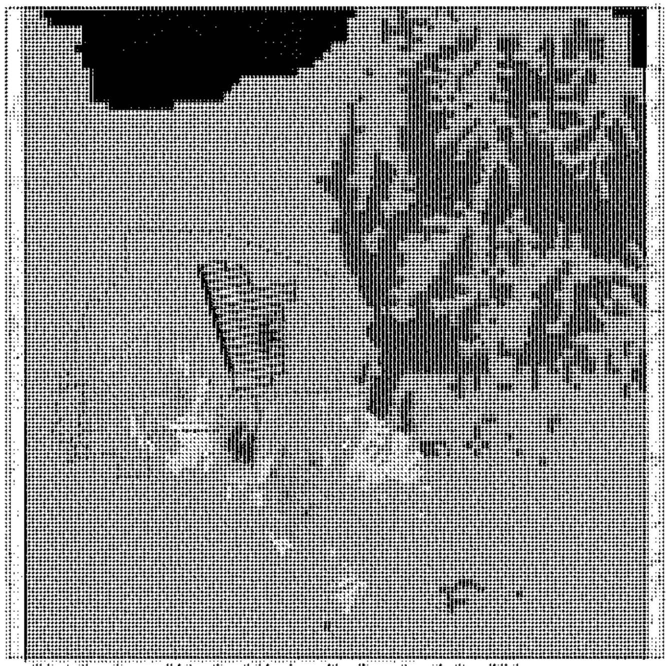
- 1.7e-03 - 1.5e-02
- 1.6e-02 - 2.4e-02
- 2.5e-02 - 3.1e-02
- 3.2e-02 - 4.8e-02
- 4.9e-02 - 6.6e-02



Distribution of Horizontal Hydraulic Conductivity (K_h)

K_z (m/d)

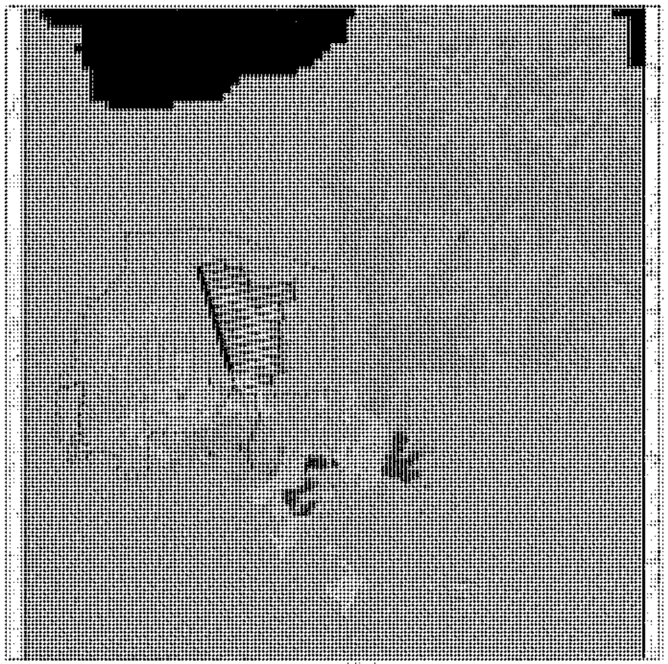
- 5.6e-03 - 6.4e-03
- 6.5e-03 - 7.0e-03
- 7.1e-03 - 7.8e-03
- 7.9e-03 - 8.4e-03
- 8.5e-03 - 1.1e-02



Distribution of Vertical Hydraulic Conductivity (K_z)

S_s (/m)

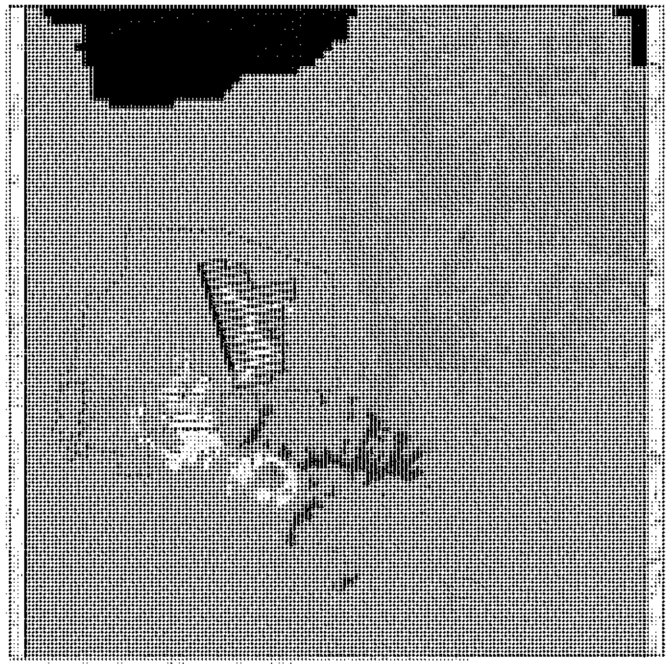
- 6.0e-06
- 6.1e-06 - 7.0e-06
- 7.1e-06 - 8.0e-06



Distribution of Specific Storage (S_s)

Φ

- 0.13 - 0.18
- 0.19 - 0.22
- 0.23 - 0.25
- 0.26 - 0.36



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 3)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

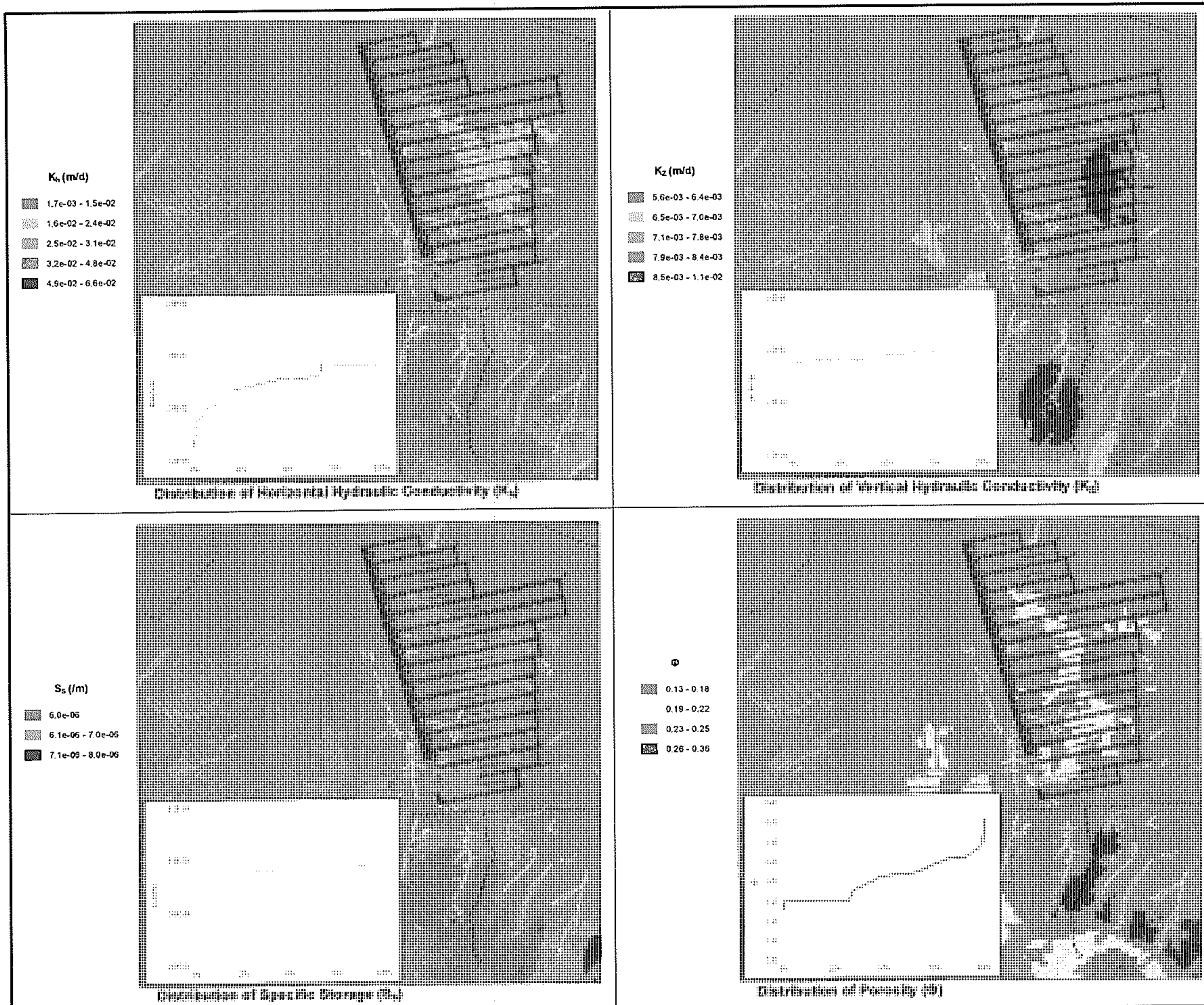
JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	
0 5 10 km	
Coor. Sys. GDA 1994 MGA Zone 56	

Calibrated Hydraulic Properties (Layer 3)

FIGURE: E.2.3a

File Name N:\Projects\Centennial\Coal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D075_DistributionOfAquiferProperties_L03.mxd
Reference © Department of Finance Services & Innovation 2018



Legend:

× Pilot Points (Layer 3)

Angus Place Project Application Area

Groundwater Model Domain

Proposed Extension

Existing Mine

'Pinched-Out' Cells

No Flow Boundary (NFB) Cells

RPS (2019):

Shrub Swamps

Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB

Scale 1:120,000

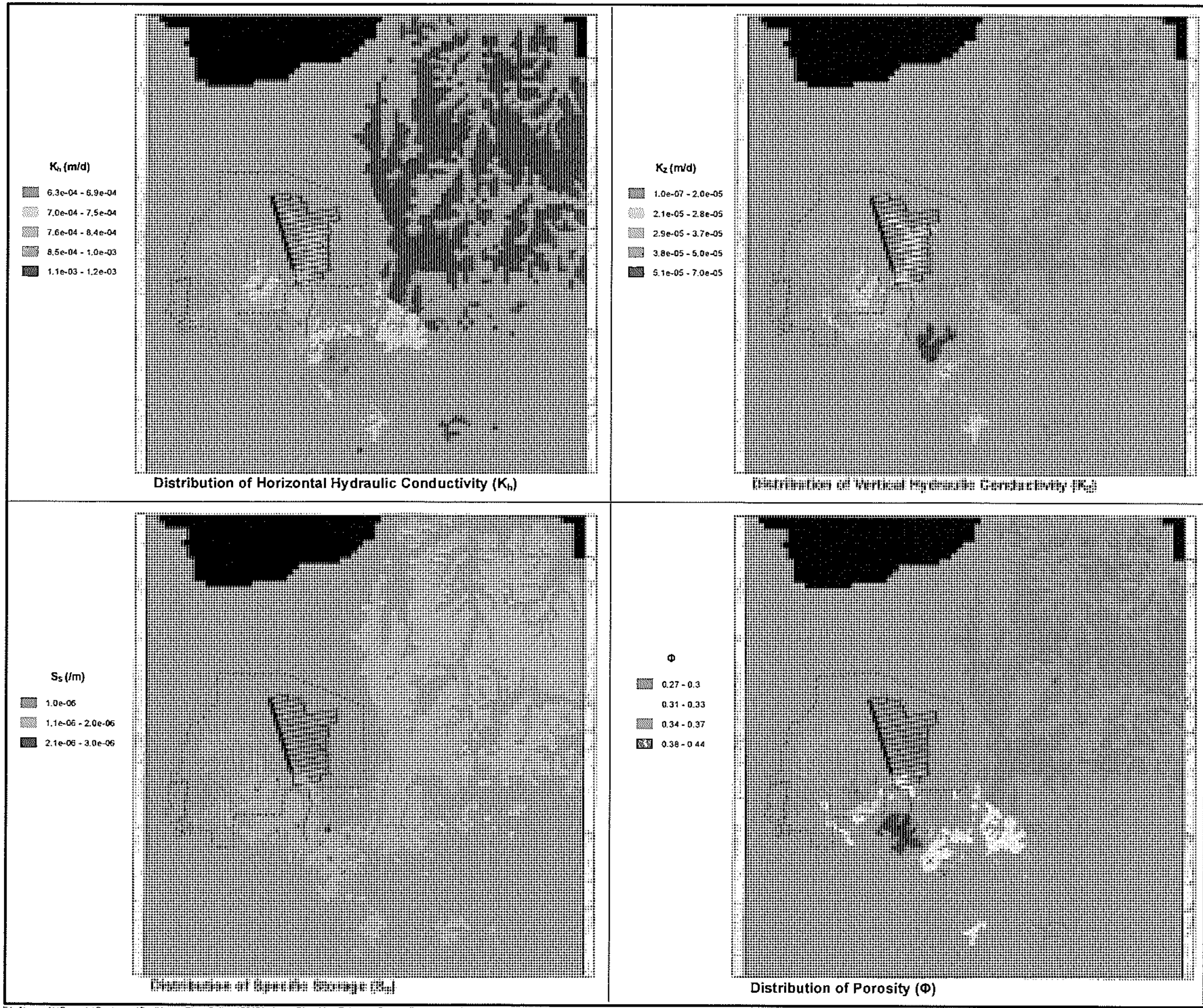
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 3) - Angus Place 1000 Panel Area

FIGURE: E.2.3b

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D075a_DistributionOfAquiferProperties_L03_Zoomed.mxd
Reference: © Department of Finance, Services & Innovation 2018



Legend:

- × Pilot Points (Layer 4)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	

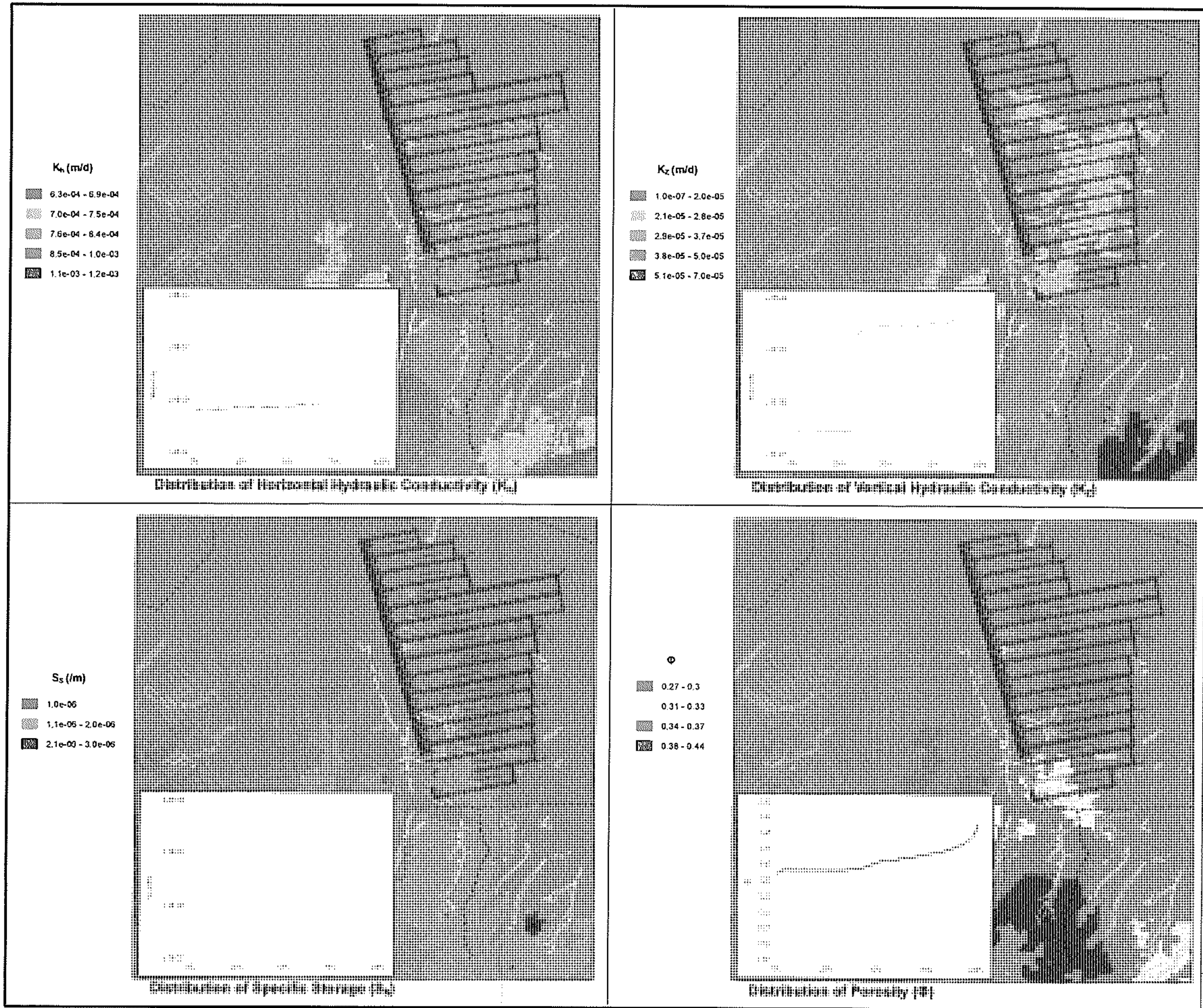
0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 4)

FIGURE: E.2.4a

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D074_DistributionOfAquiferProperties_L04.mxd
Reference © Department of Finance Services & Innovation 2018



Legend:

× Pilot Points (Layer 4)

Angus Place Project Application Area

Groundwater Model Domain

Proposed Extension

Existing Mine

'Pinched-Out' Cells

No Flow Boundary (NFB) Cells

RPS (2019):

Shrub Swamps

Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	

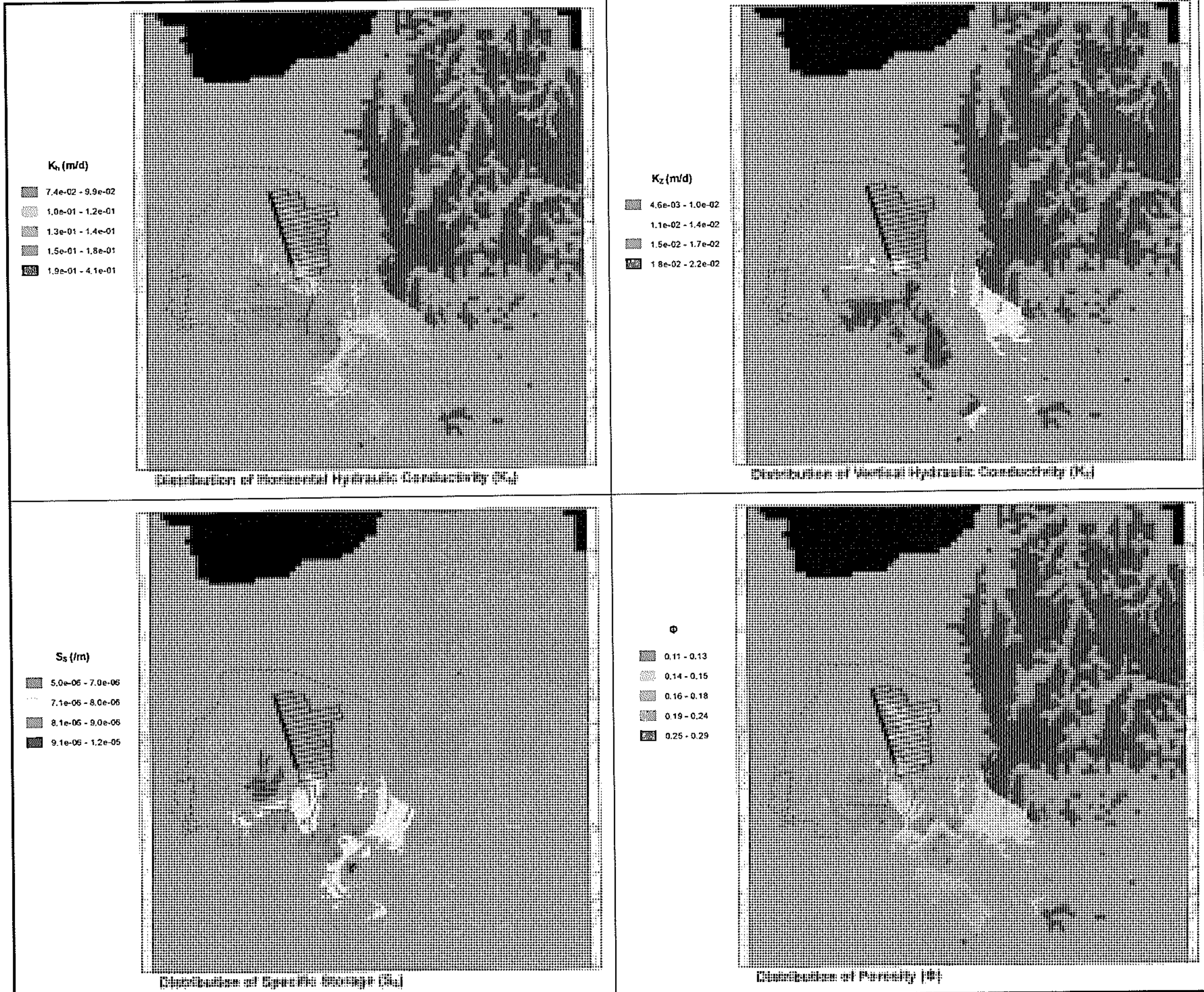
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 4) - Angus Place 1000 Panel Area

FIGURE: E.2.4b

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D074a_DistributionOfAquiferProperties_L04_Zoomed.mxd
Reference © Department of Finance Services & Innovation 2018



Legend:

- × Pilot Points (Layer 5)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB

Scale 1:350,000

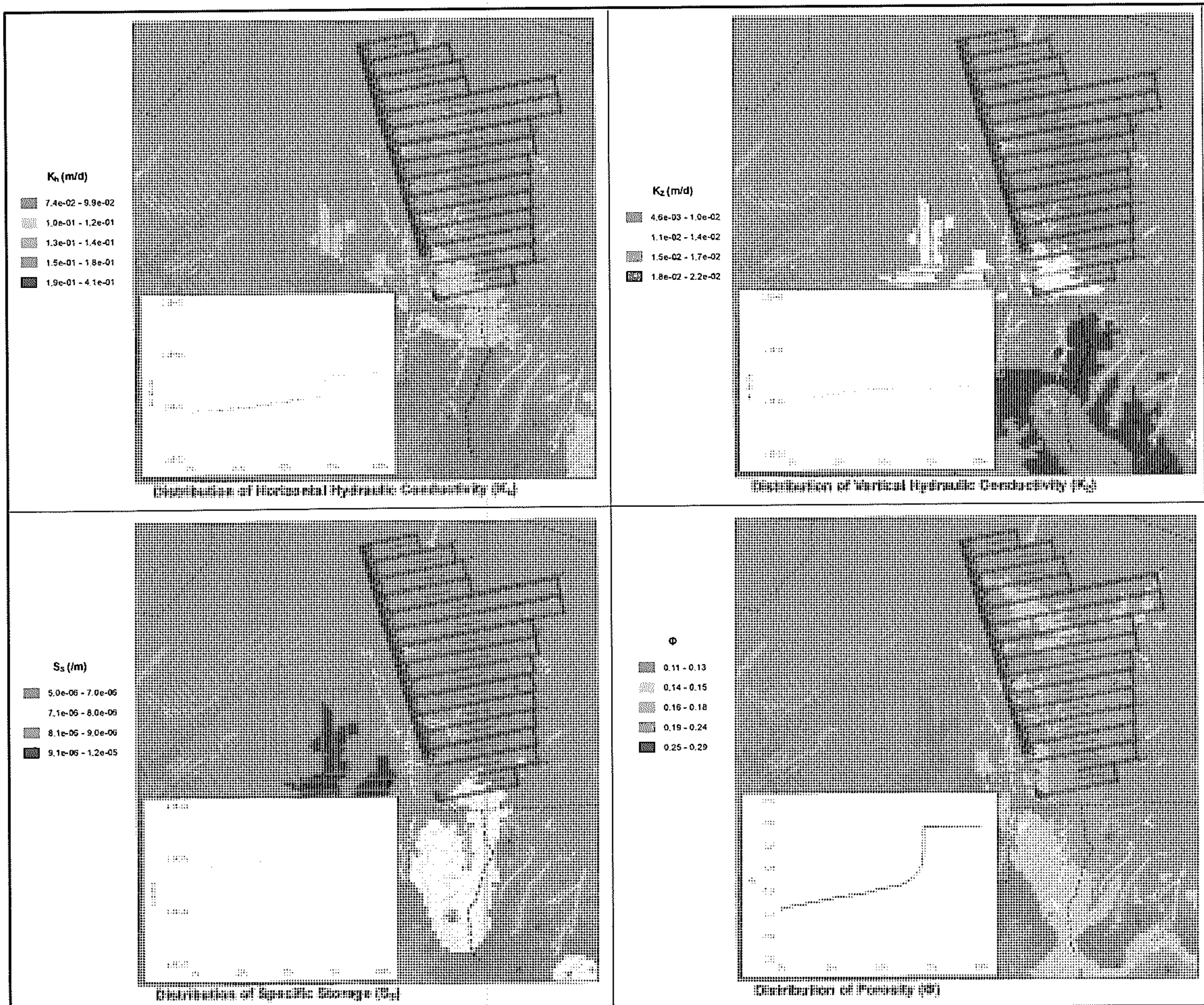
0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 5)

FIGURE: E.2.5a

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D073_DistributionOfAquiferProperties_L05.mxd
Reference © Department of Finance Services & Innovation 2018



Legend:

- × Pilot Points (Layer 5)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells
- RPS (2019):
  - Shrub Swamps
  - Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB

Scale 1:120,000

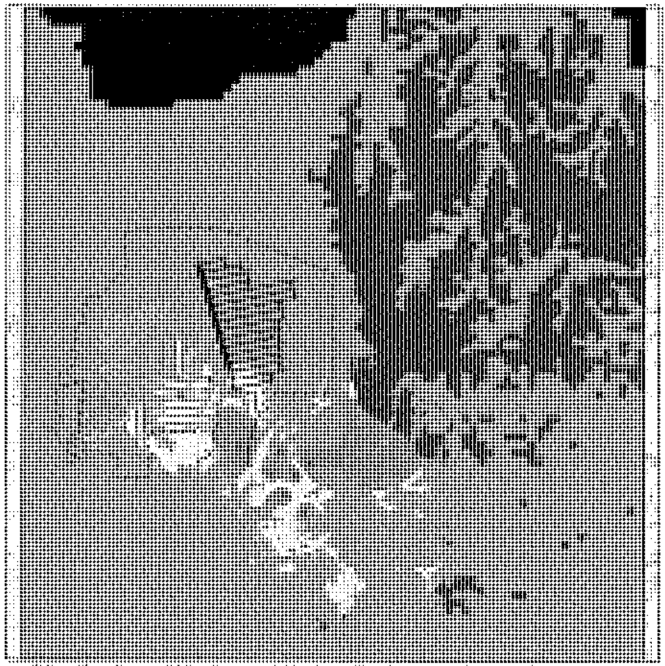
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

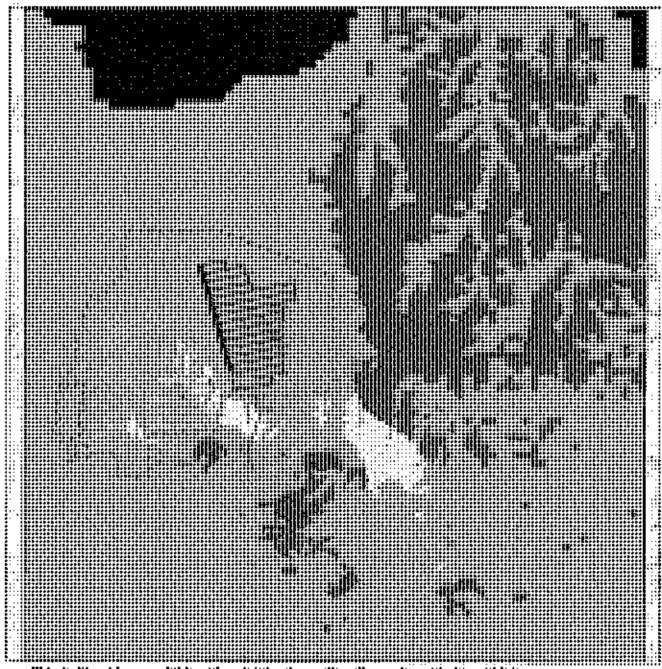
Calibrated Hydraulic Properties (Layer 5) - Angus Place 1000 Panel Area

FIGURE: E.2.5b

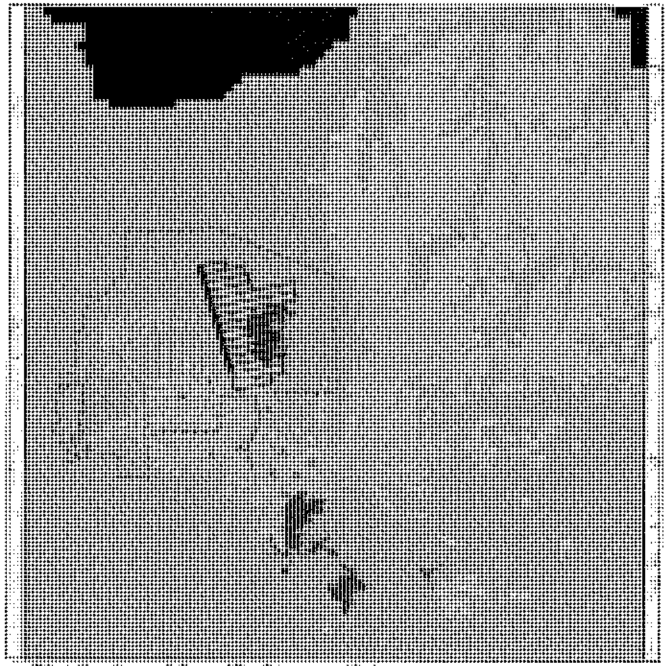
File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D073a_DistributionOfAquiferProperties_L05_Zoomed.mxd
Reference © Department of Finance Services & Innovation 2018



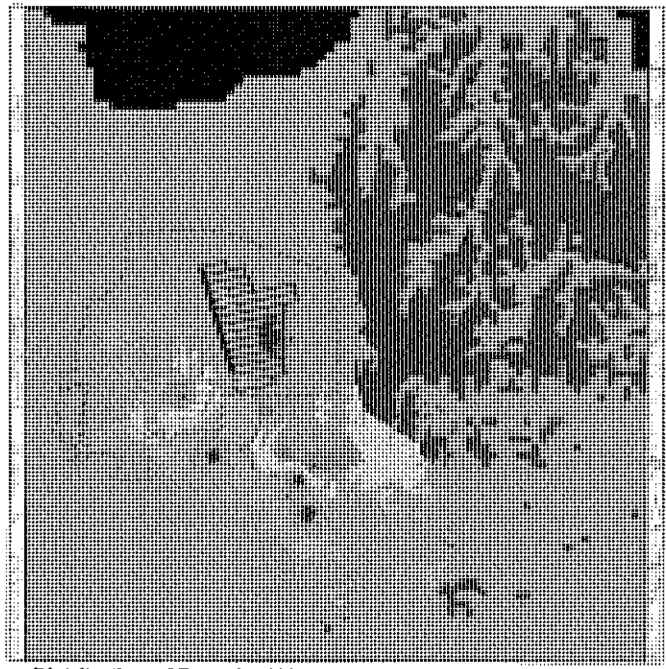
Distribution of Horizontal Hydraulic Conductivity (K_h)



Distribution of Vertical Hydraulic Conductivity (K_z)



Distribution of Specific Storage (S_s)



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 6)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	

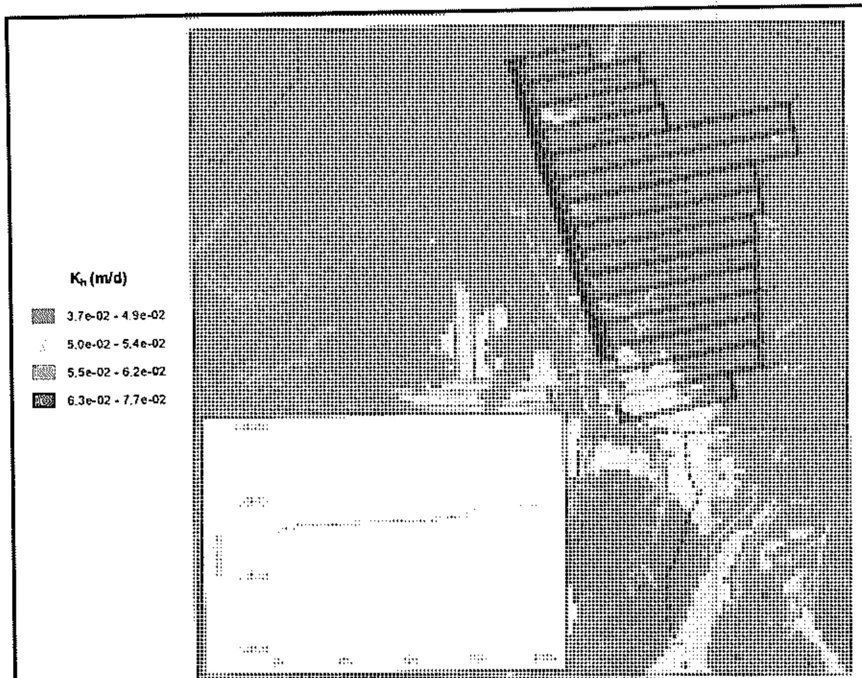
0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

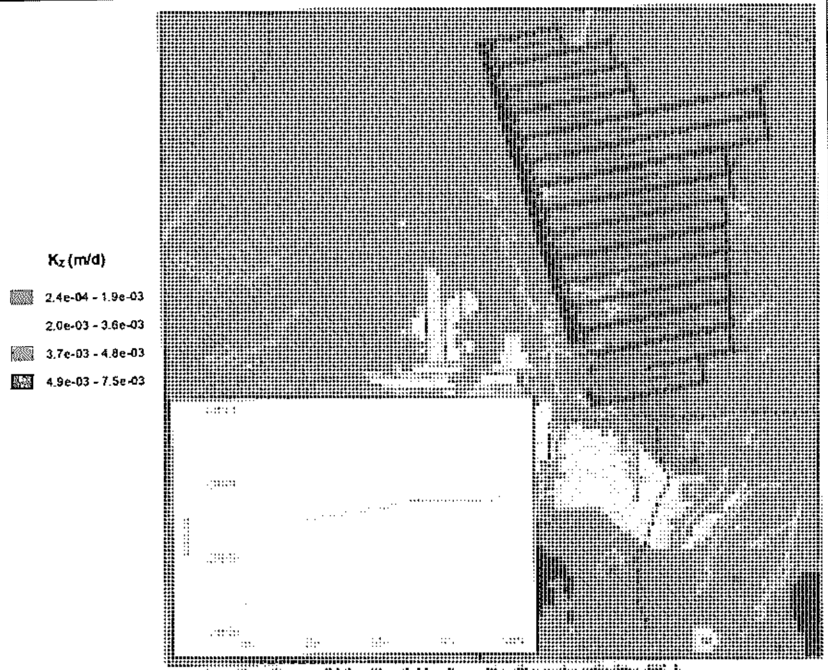
Calibrated Hydraulic Properties (Layer 6)

FIGURE: E.2.6a

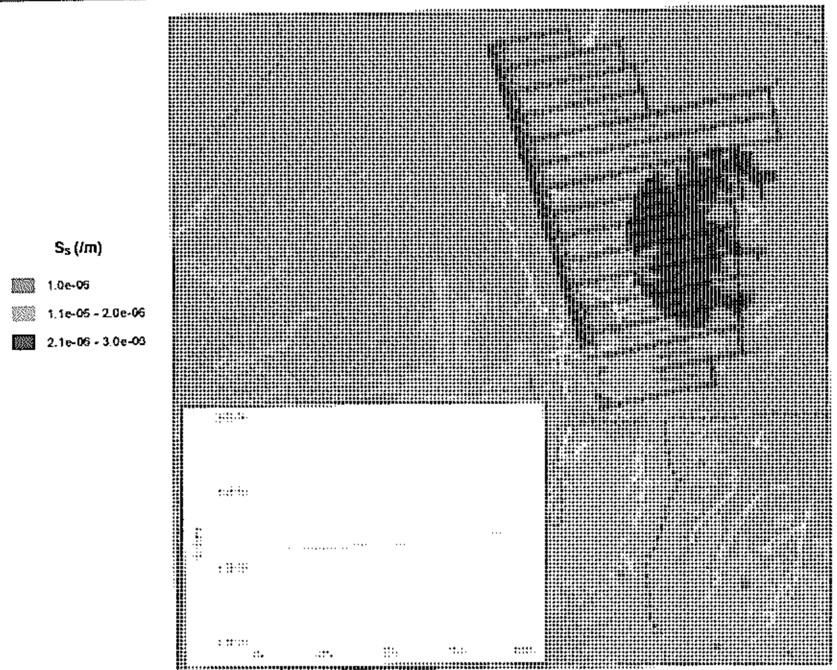
File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D072_DistributionOfAquiferProperties_L06.mxd
Reference © Department of Finance Services & Innovation 2018



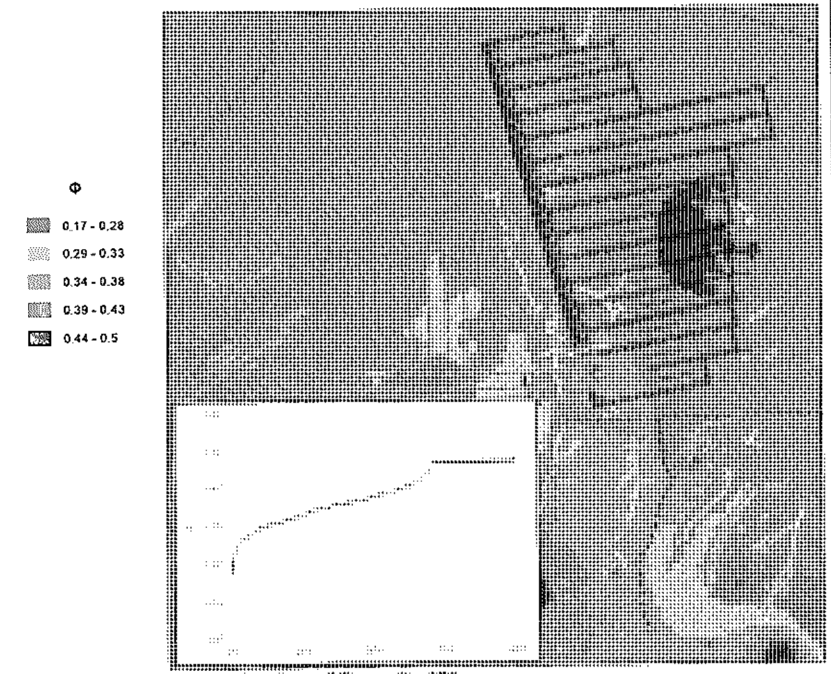
Distribution of Horizontal Hydraulic Conductivity (K_h)



Distribution of Vertical Hydraulic Conductivity (K_z)



Distribution of Specific Storage (S_s)



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 6)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

RPS (2019):

- Shrub Swamps
- Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

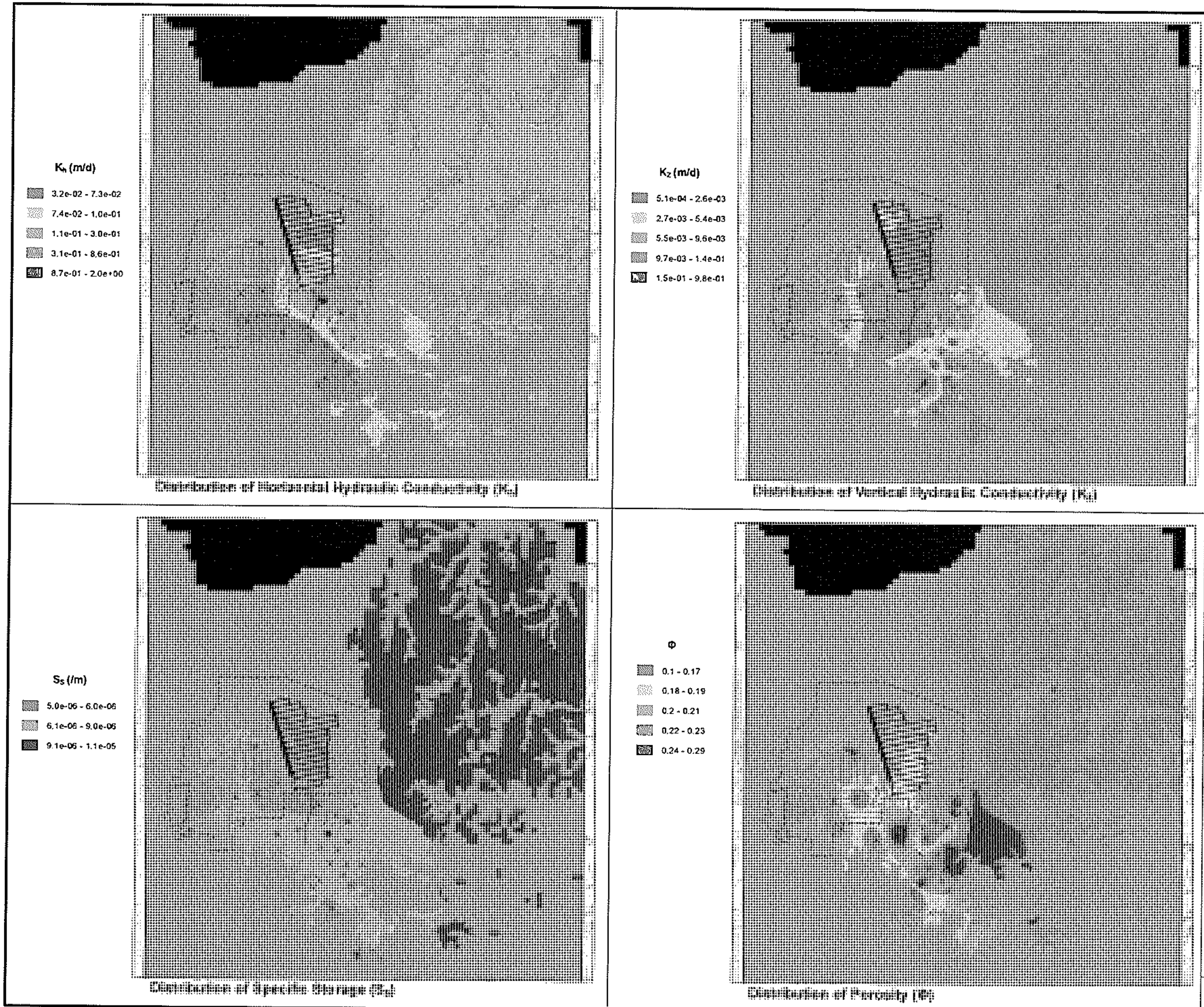
JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	
0 1.5 3 km	
Coor. Sys. GDA 1994 MGA Zone 56	

Calibrated Hydraulic Properties (Layer 6) - Angus Place 1000 Panel Area

FIGURE: E.2.6b

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D072a_DistributionOfAquiferProperties_L06_Zoomed.mxd
Reference © Department of Finance Services & Innovation 2018



Legend:

- × Pilot Points (Layer 7)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	

0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

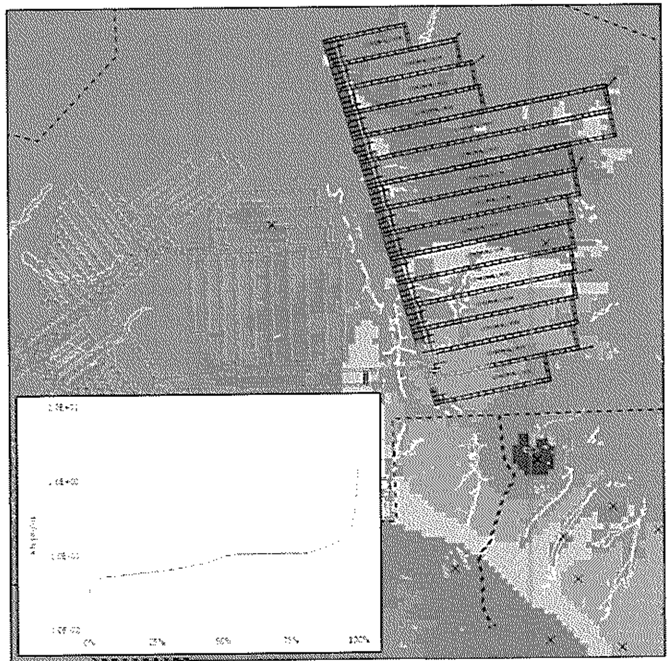
Calibrated Hydraulic Properties (Layer 7)

FIGURE: E.2.7a

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D071_DistributionOfAquiferProperties_L07.mxd
Reference © Department of Finance Services & Innovation 2018

K_h (m/d)

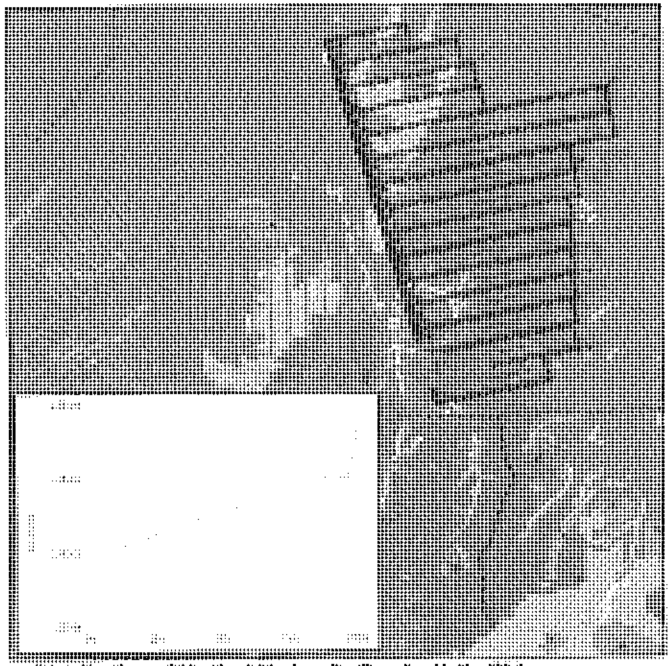
- 3.2e-02 - 7.3e-02
- 7.4e-02 - 1.0e-01
- 1.1e-01 - 3.0e-01
- 3.1e-01 - 8.6e-01
- 8.7e-01 - 2.0e+00



Distribution of Horizontal Hydraulic Conductivity (K_h)

K_z (m/d)

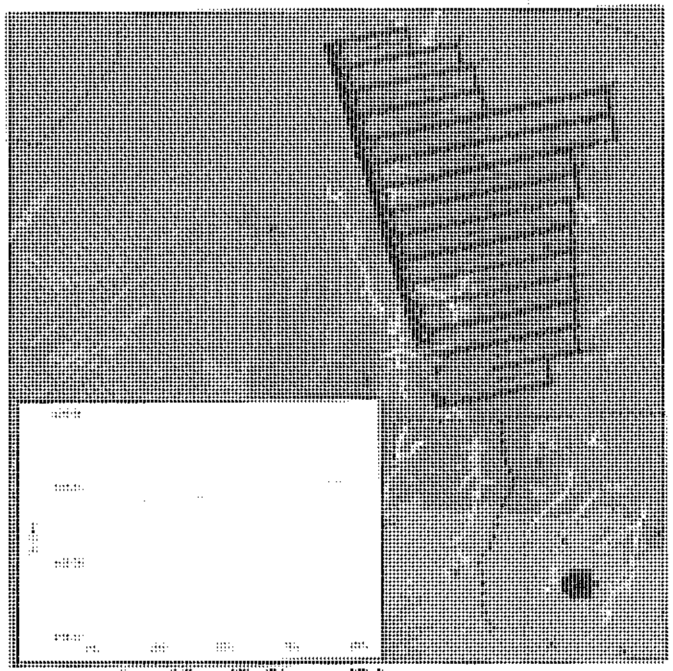
- 5.1e-04 - 2.6e-03
- 2.7e-03 - 5.4e-03
- 5.5e-03 - 9.6e-03
- 9.7e-03 - 1.4e-01
- 1.5e-01 - 9.8e-01



Distribution of Vertical Hydraulic Conductivity (K_z)

S_s (/m)

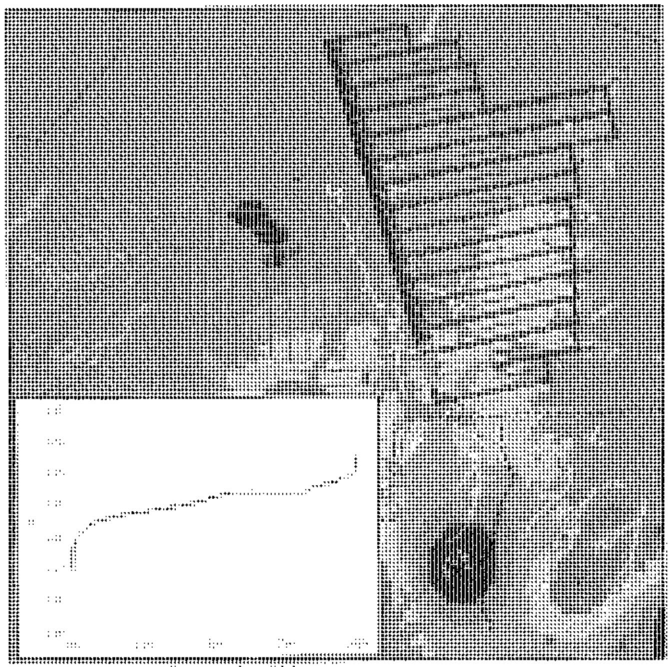
- 5.0e-06 - 6.0e-06
- 6.1e-06 - 9.0e-06
- 9.1e-06 - 1.1e-05



Distribution of Specific Storage (S_s)

Φ

- 0.1 - 0.17
- 0.18 - 0.19
- 0.2 - 0.21
- 0.22 - 0.23
- 0.24 - 0.29



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 7)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

RPS (2019):

- Shrub Swamps
- Hanging Swamps

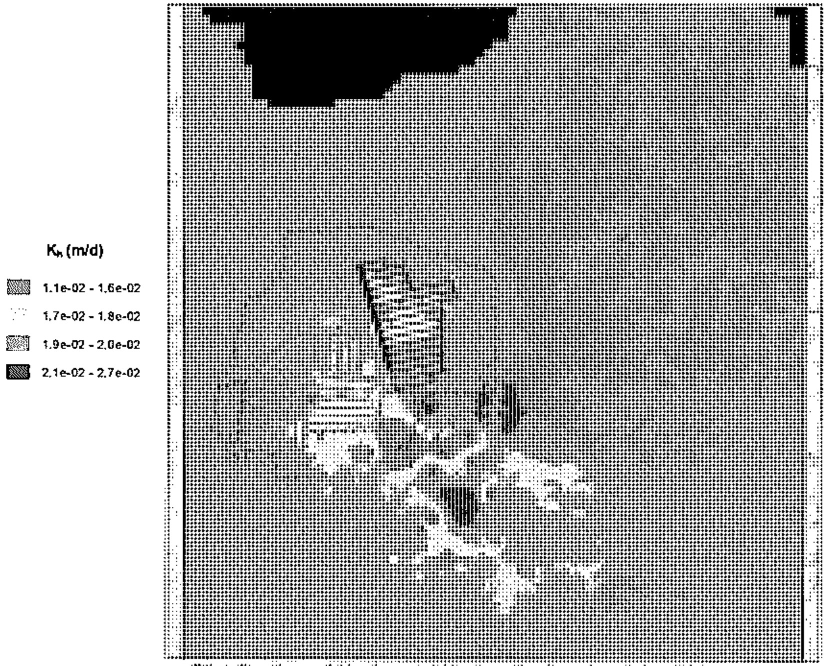
Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

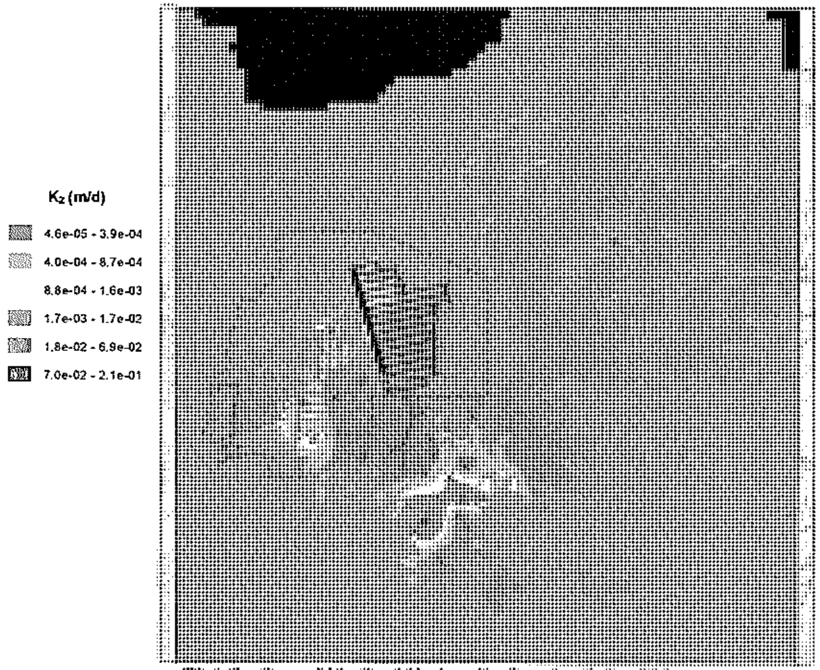
Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	
0 1.5 3 km	
Coor. Sys. GDA 1994 MGA Zone 56	

Calibrated Hydraulic Properties (Layer 7) - Angus Place 1000 Panel Area

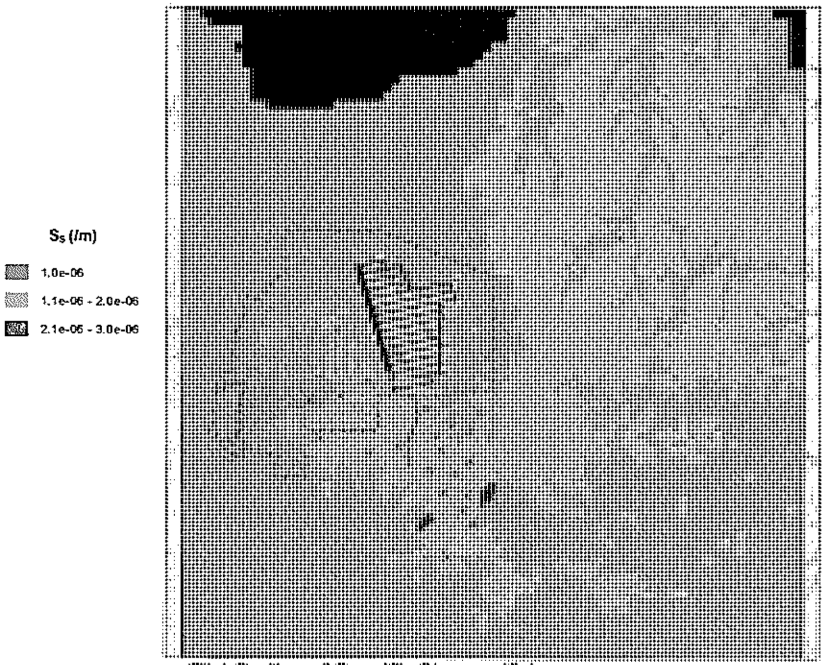
FIGURE: E.2.7b



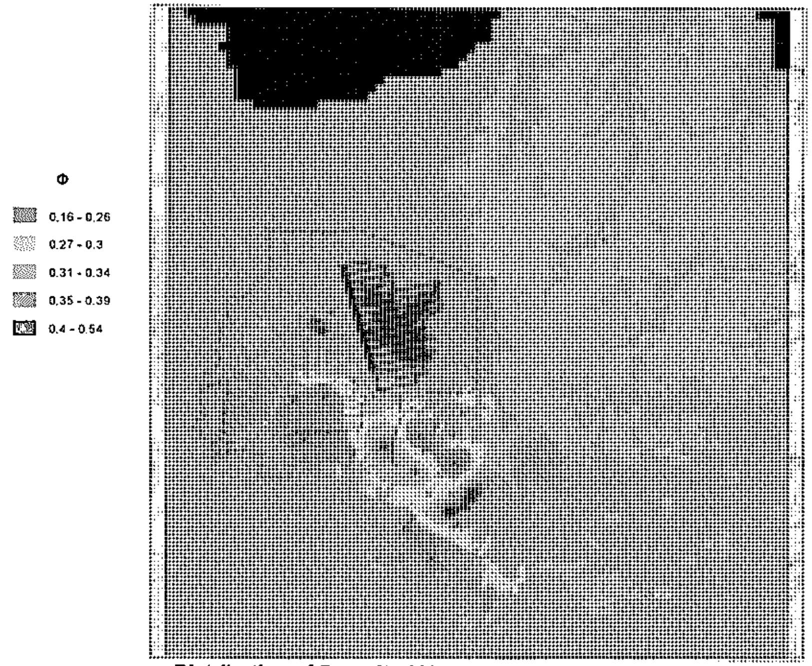
Distribution of Horizontal Hydraulic Conductivity (K_h)



Distribution of Vertical Hydraulic Conductivity (K_z)



Distribution of Specific Storage (S_s)



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 8)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	

0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

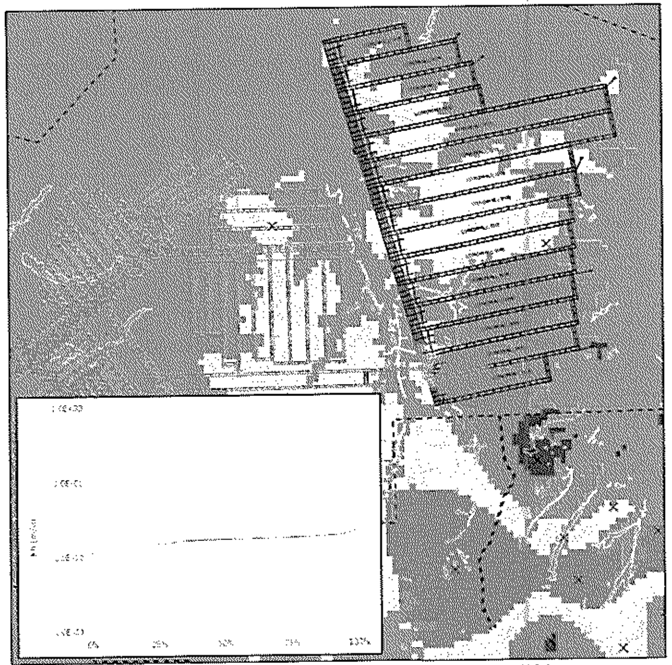
Calibrated Hydraulic Properties (Layer 8)

FIGURE: E.2.8a

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D070_DistributionOfAquiferProperties_L08.mxd
Reference © Department of Finance Services & Innovation 2018

K_h (m/d)

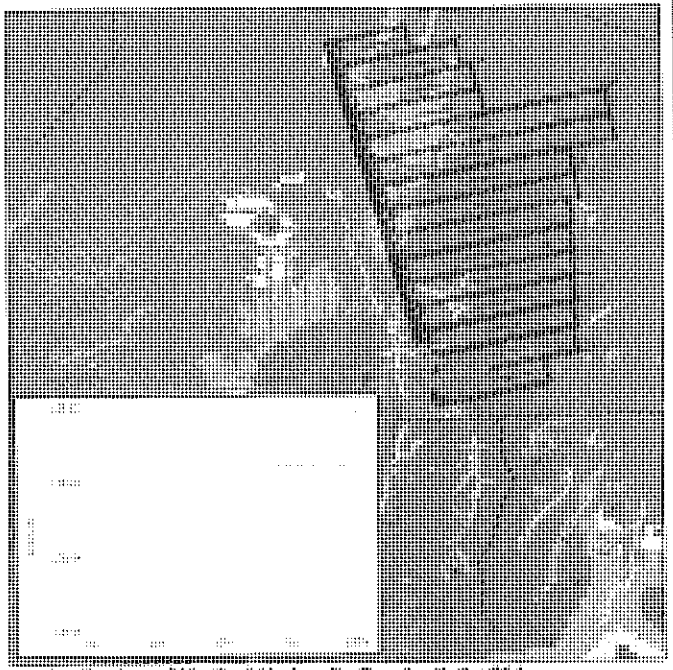
- 1.1e-02 - 1.6e-02
- 1.7e-02 - 1.8e-02
- 1.9e-02 - 2.0e-02
- 2.1e-02 - 2.7e-02



Distribution of Horizontal Hydraulic Conductivity (K_h)

K_z (m/d)

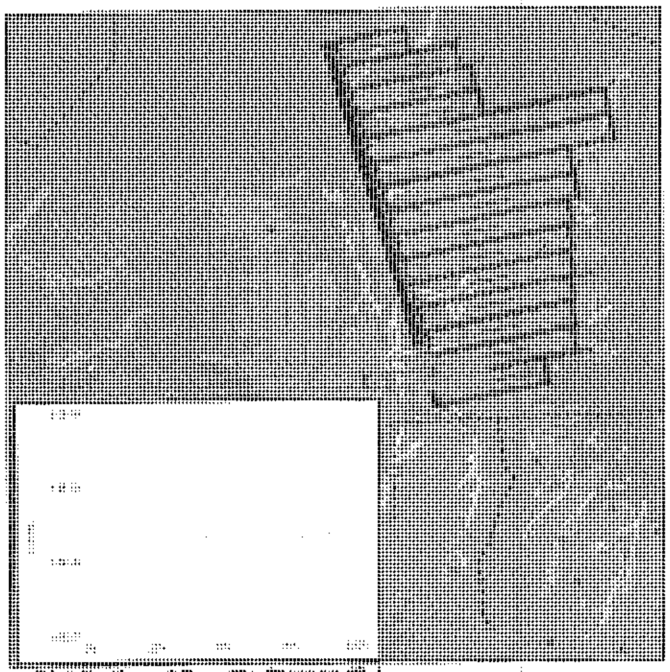
- 4.6e-05 - 3.9e-04
- 4.0e-04 - 8.7e-04
- 8.8e-04 - 1.6e-03
- 1.7e-03 - 1.7e-02
- 1.8e-02 - 6.9e-02
- 7.0e-02 - 2.1e-01



Distribution of Vertical Hydraulic Conductivity (K_z)

S_s (/m)

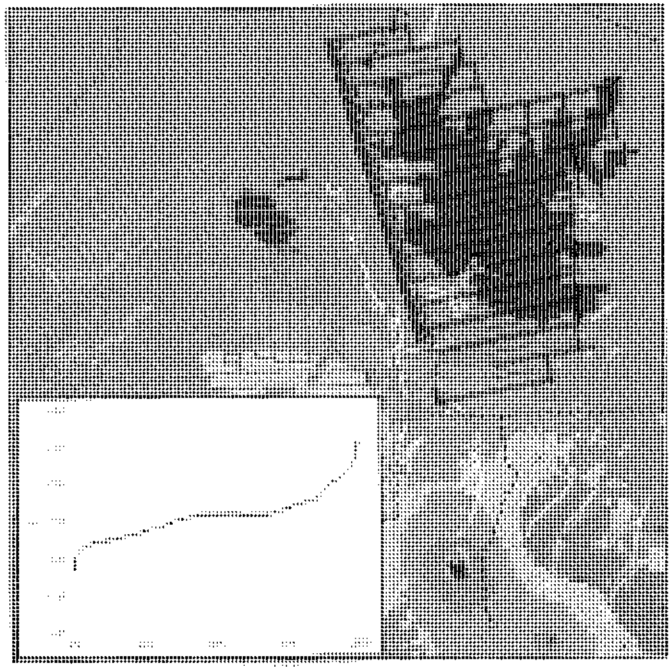
- 1.0e-06
- 1.1e-06 - 2.0e-06
- 2.1e-06 - 3.0e-06



Distribution of Specific Storage (S_s)

Φ

- 0.16 - 0.26
- 0.27 - 0.3
- 0.31 - 0.34
- 0.35 - 0.39
- 0.4 - 0.54



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 8)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

RPS (2019):

- Shrub Swamps
- Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1 | Date: 18-Oct-2019

Drawn By: JZ | Checked By: JB

Scale 1:120,000

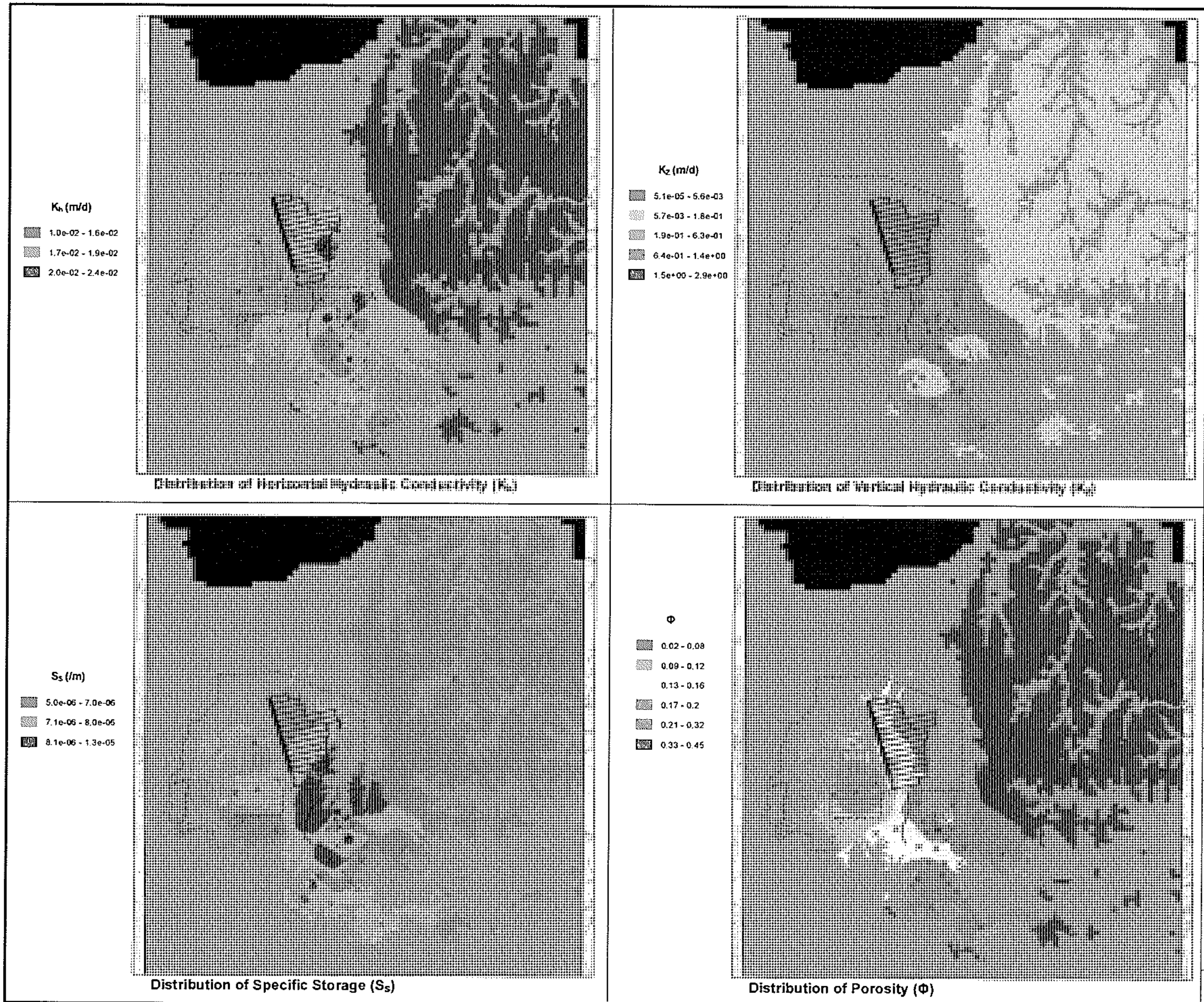
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 8) - Angus Place 1000 Panel Area

FIGURE: E.2.8b

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D070a_DistributionOfAquiferProperties_L08_Zoomed.mxd
Reference © Department of Finance, Services & Innovation 2018



Legend:

- × Pilot Points (Layer 9)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	

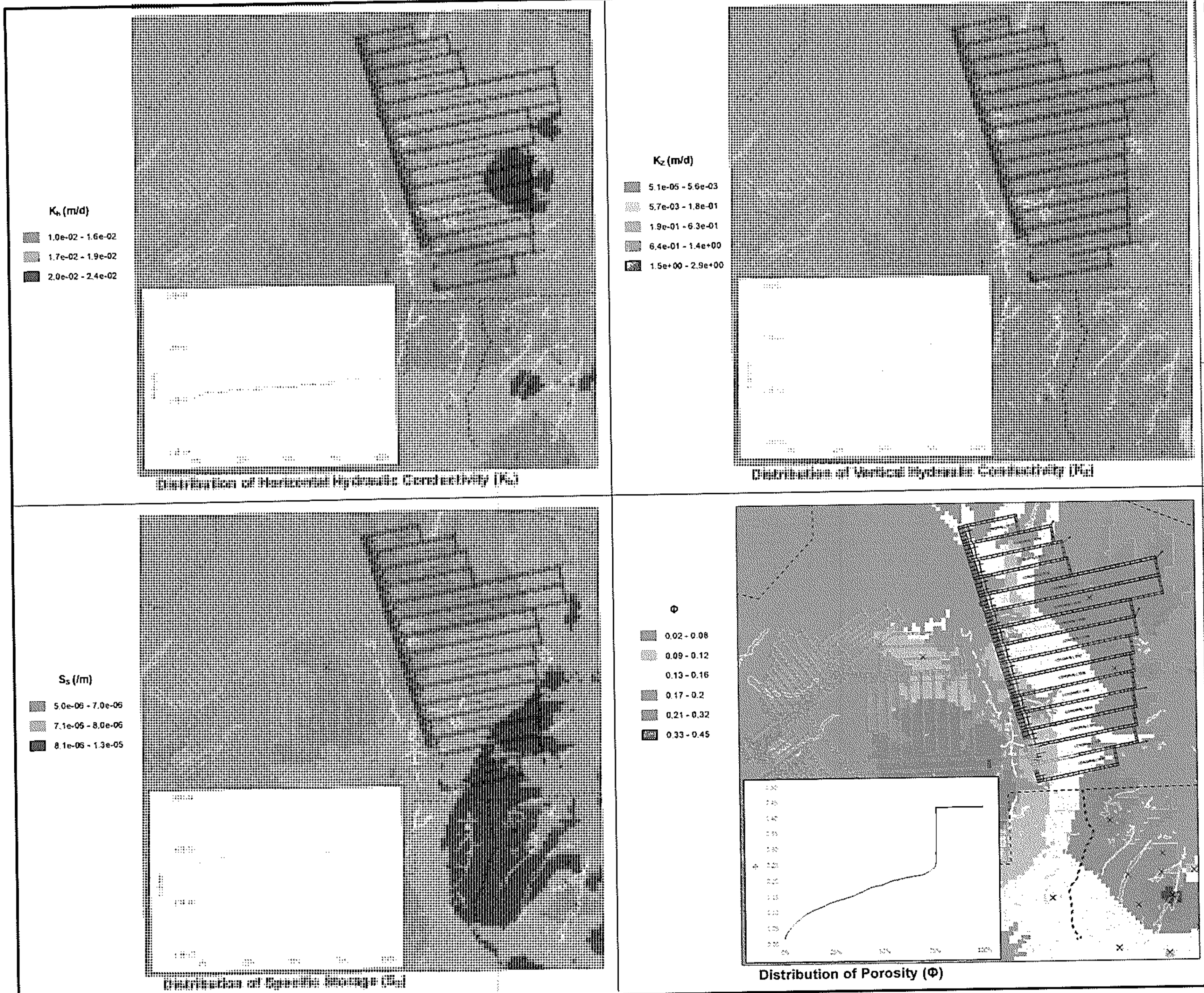
0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 9)

FIGURE: E.2.9a

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D069_DistributionOfAquiferProperties_L09.mxd
Reference © Department of Finance, Services & Innovation 2018



Legend:

× Pilot Points (Layer 9)
Angus Place Project Application Area
Groundwater Model Domain
Proposed Extension
Existing Mine
'Pinched-Out' Cells
No Flow Boundary (NFB) Cells
RPS (2019):
Shrub Swamps
Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

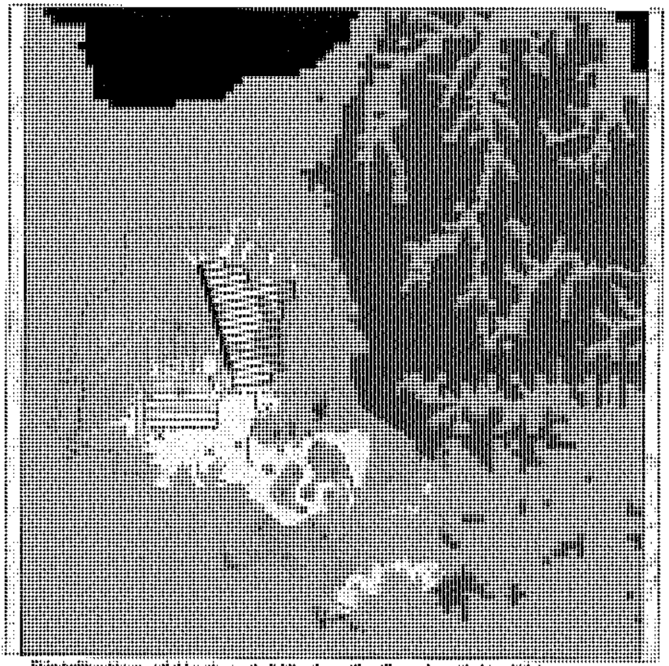
JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	
0 1.5 3 km	
Coor. Sys. GDA 1994 MGA Zone 56	

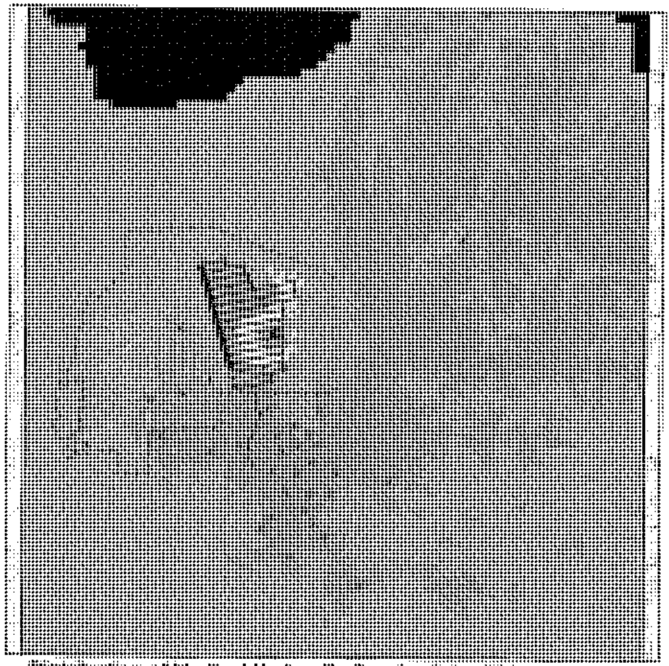
Calibrated Hydraulic Properties (Layer 9) - Angus Place 1000 Panel Area

FIGURE: E.2.9b

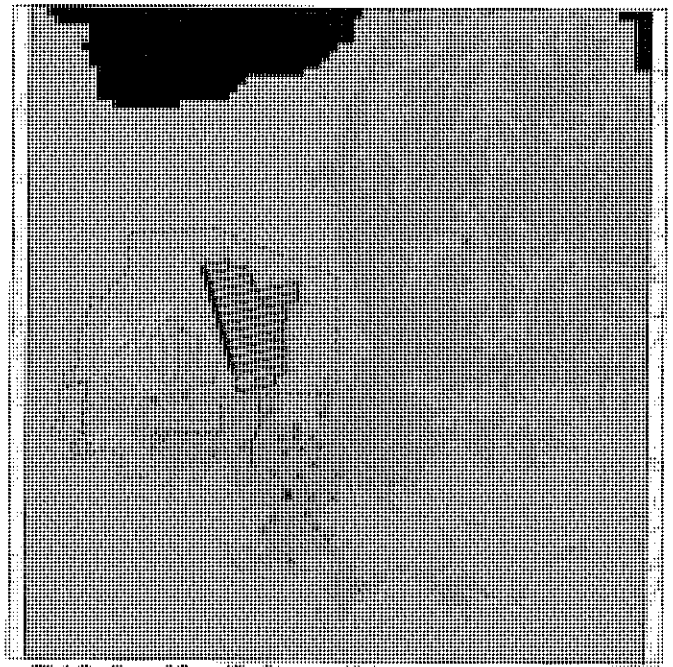
File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D069a_DistributionOfAquiferProperties_L09_Zoomed.mxd
Reference: © Department of Finance, Services & Innovation 2016



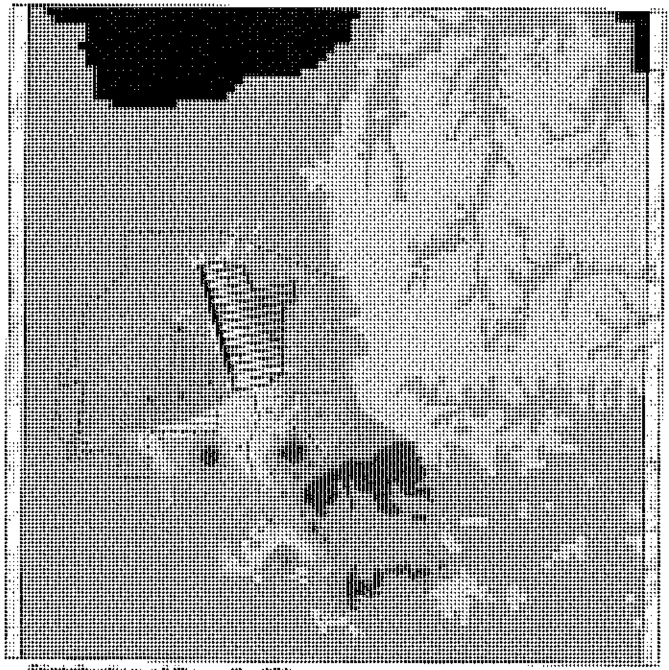
Distribution of Horizontal Hydraulic Conductivity (K_h)



Distribution of Vertical Hydraulic Conductivity (K_z)



Distribution of Specific Storage (S_s)



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 10)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB

Scale 1:350,000

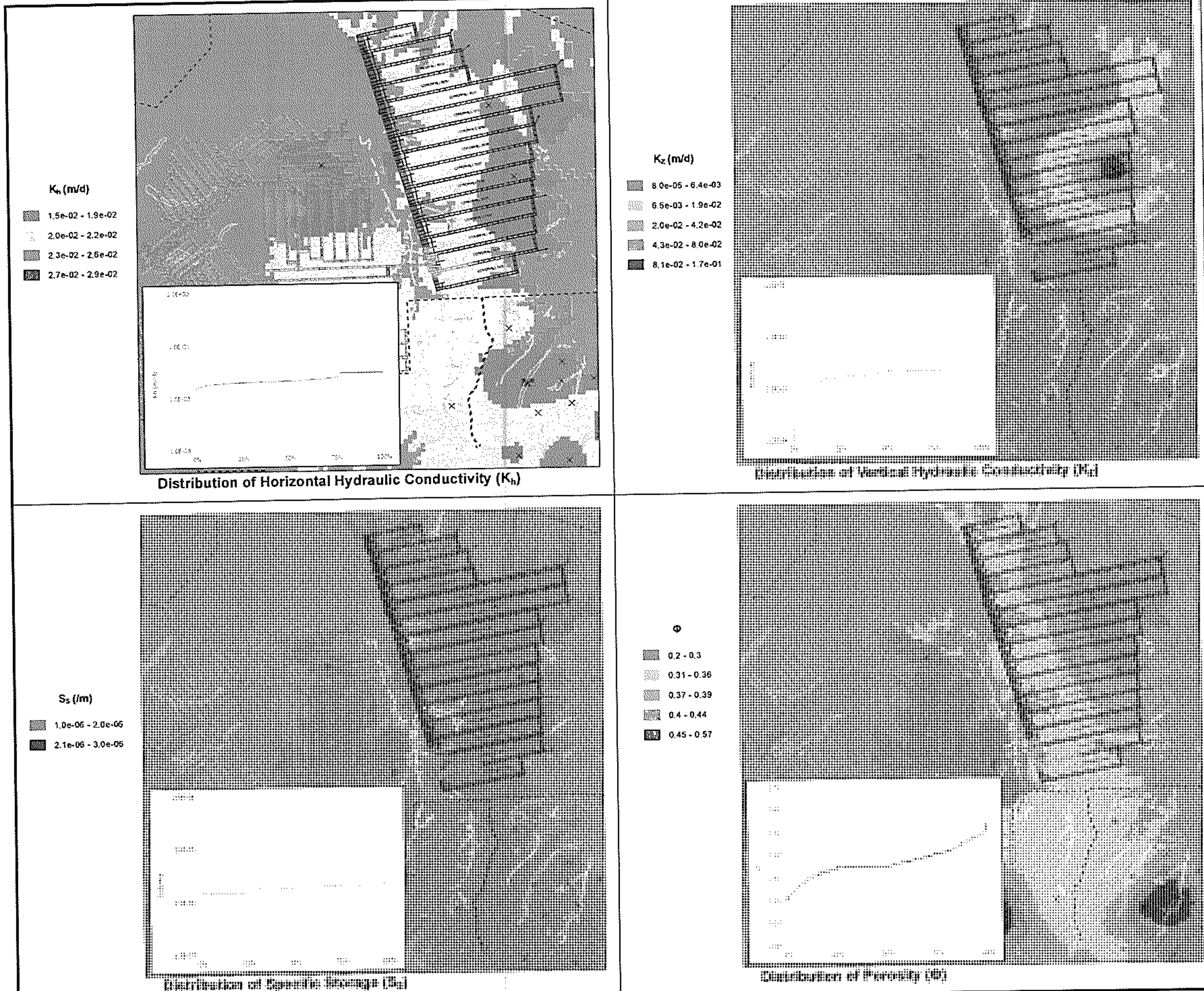
0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 10)

FIGURE: E.2.10a

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D068_DistributionOfAquiferProperties_L10.mxd
Reference © Department of Finance Services & Innovation 2016



Legend:

× Pilot Points (Layer 10)
Angus Place Project Application Area
Groundwater Model Domain
Proposed Extension
Existing Mine
'Pinched-Out' Cells
No Flow Boundary (NFB) Cells
RPS (2019):
Shrub Swamps
Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB

Scale 1:120,000

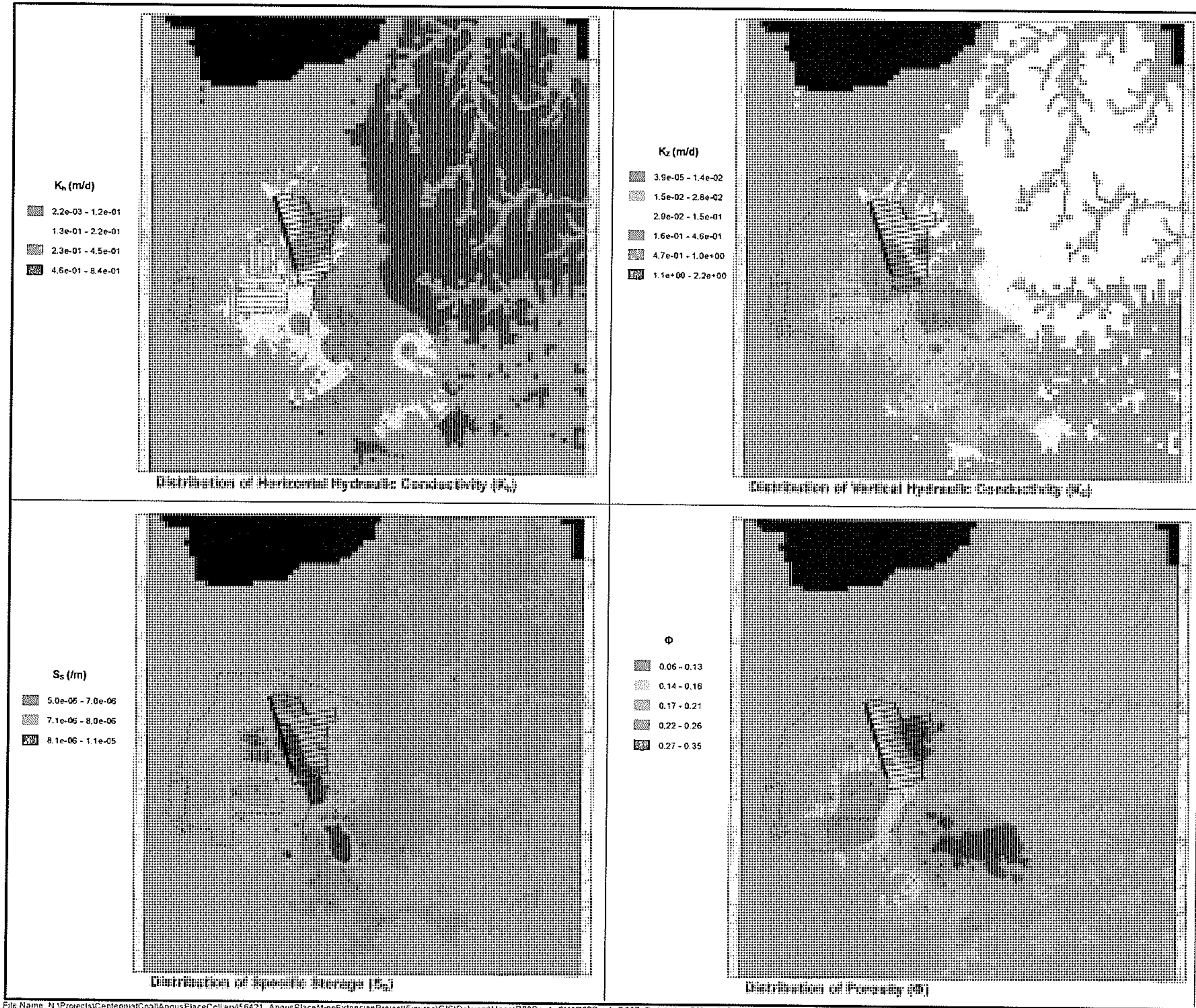
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 10) - Angus Place 1000 Panel Area

FIGURE: E.2.10b

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D068a_DistributionOfAquiferProperties_L10_Zoomed.mxd
Reference © Department of Finance, Services & Innovation 2018



Legend:

- × Pilot Points (Layer 11)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB

Scale 1:350,000

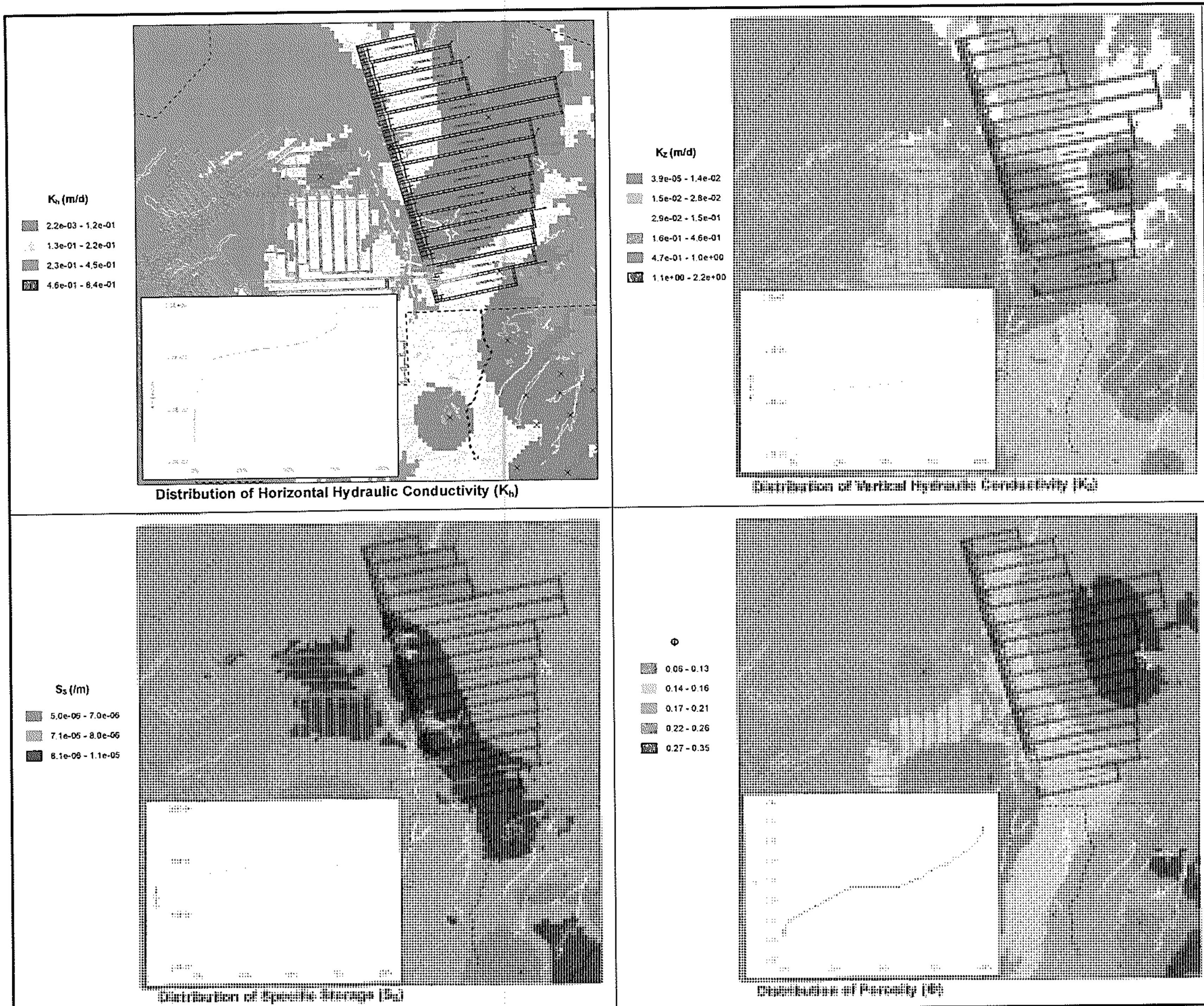
0 5 10 km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 11)

FIGURE: E.2.11a

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D067_DistributionOfAquiferProperties_L11.mxd
Reference © Department of Finance Services & Innovation 2016



Legend:

- × Pilot Points (Layer 11)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

RPS (2019):
- Shrub Swamps
- Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer

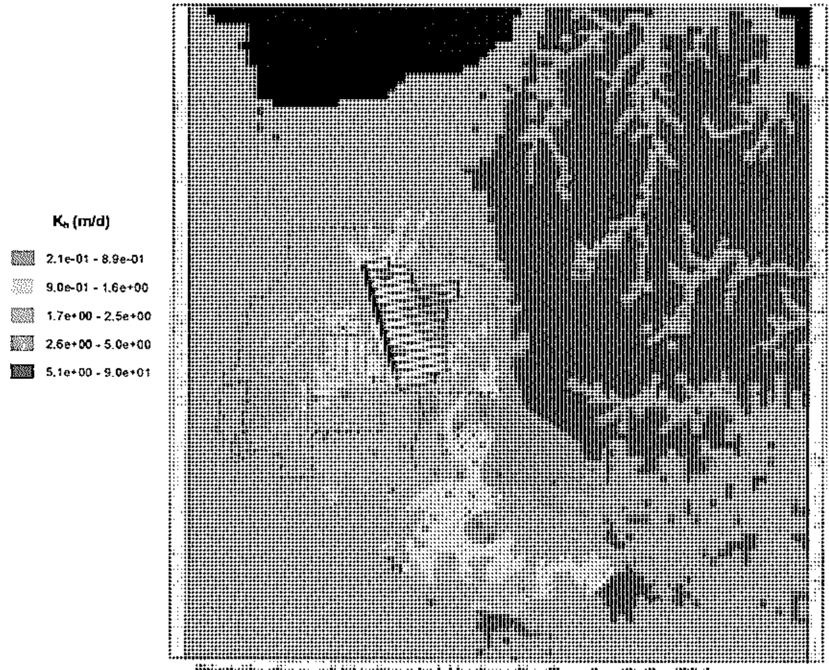
JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	
0 1.5 3 km	
Coor. Sys. GDA 1994 MGA Zone 56	

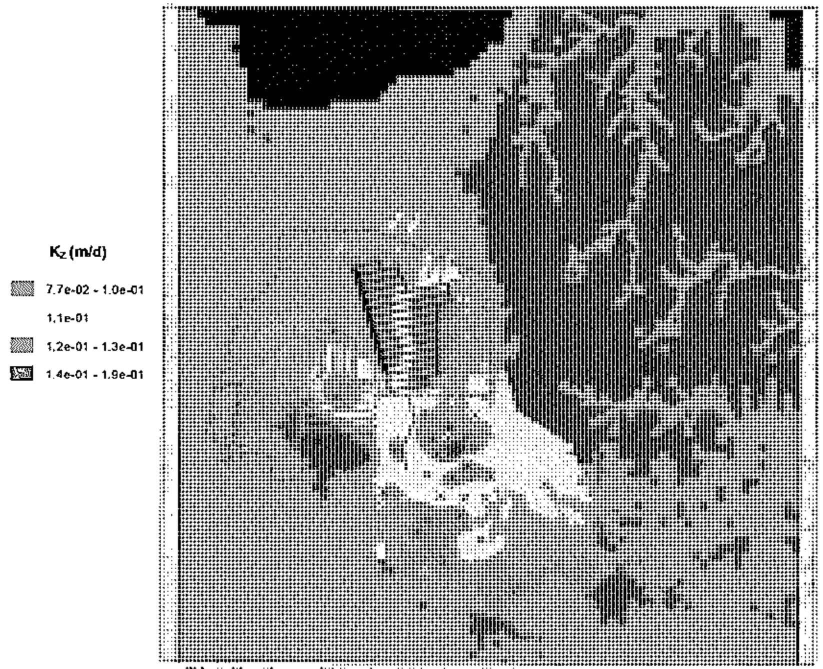
Calibrated Hydraulic Properties (Layer 11) - Angus Place 1000 Panel Area

FIGURE: E.2.11b

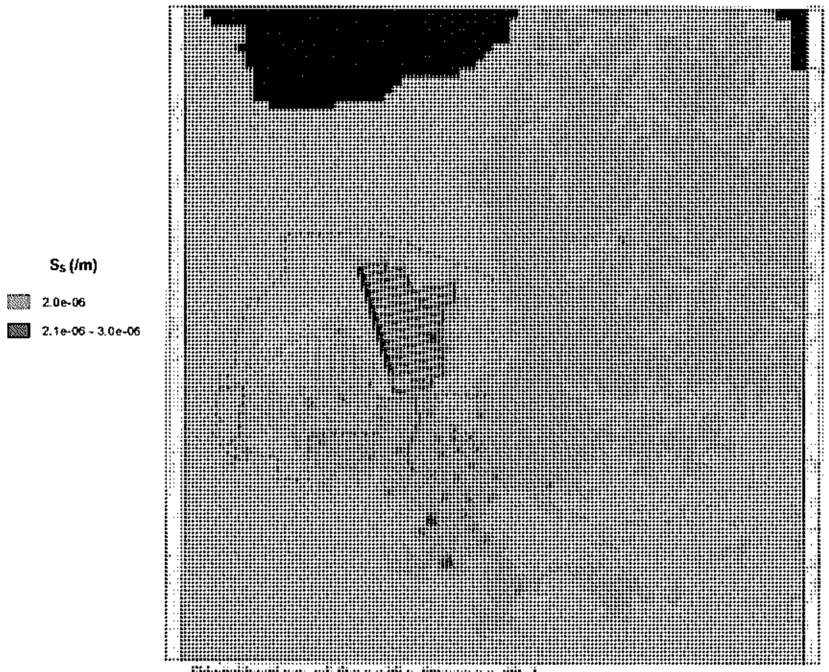
File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D067a_DistributionOfAquiferProperties_L11_Zoomed.mxd



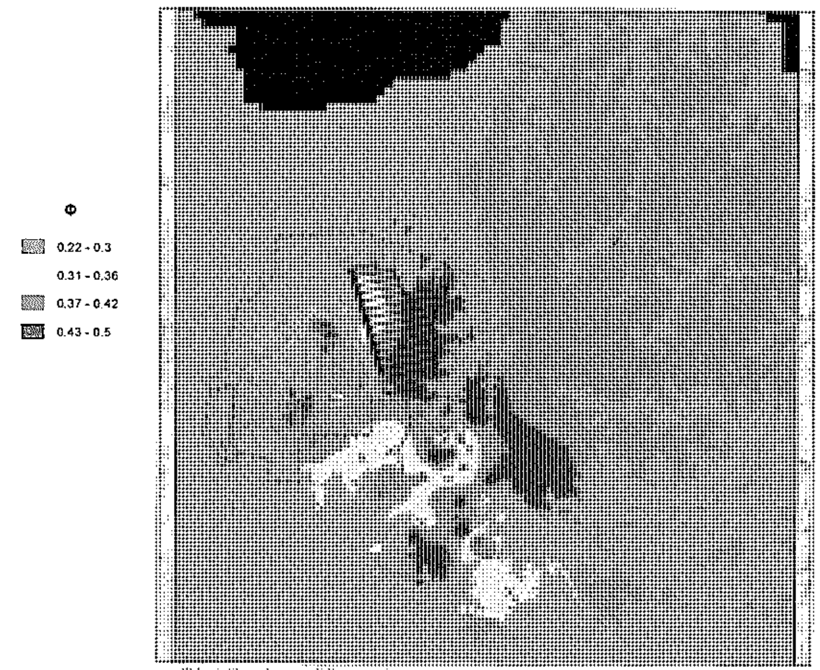
Distribution of Horizontal Hydraulic Conductivity (K_h)



Distribution of Vertical Hydraulic Conductivity (K_z)



Distribution of Specific Storage (S_s)



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 12)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	

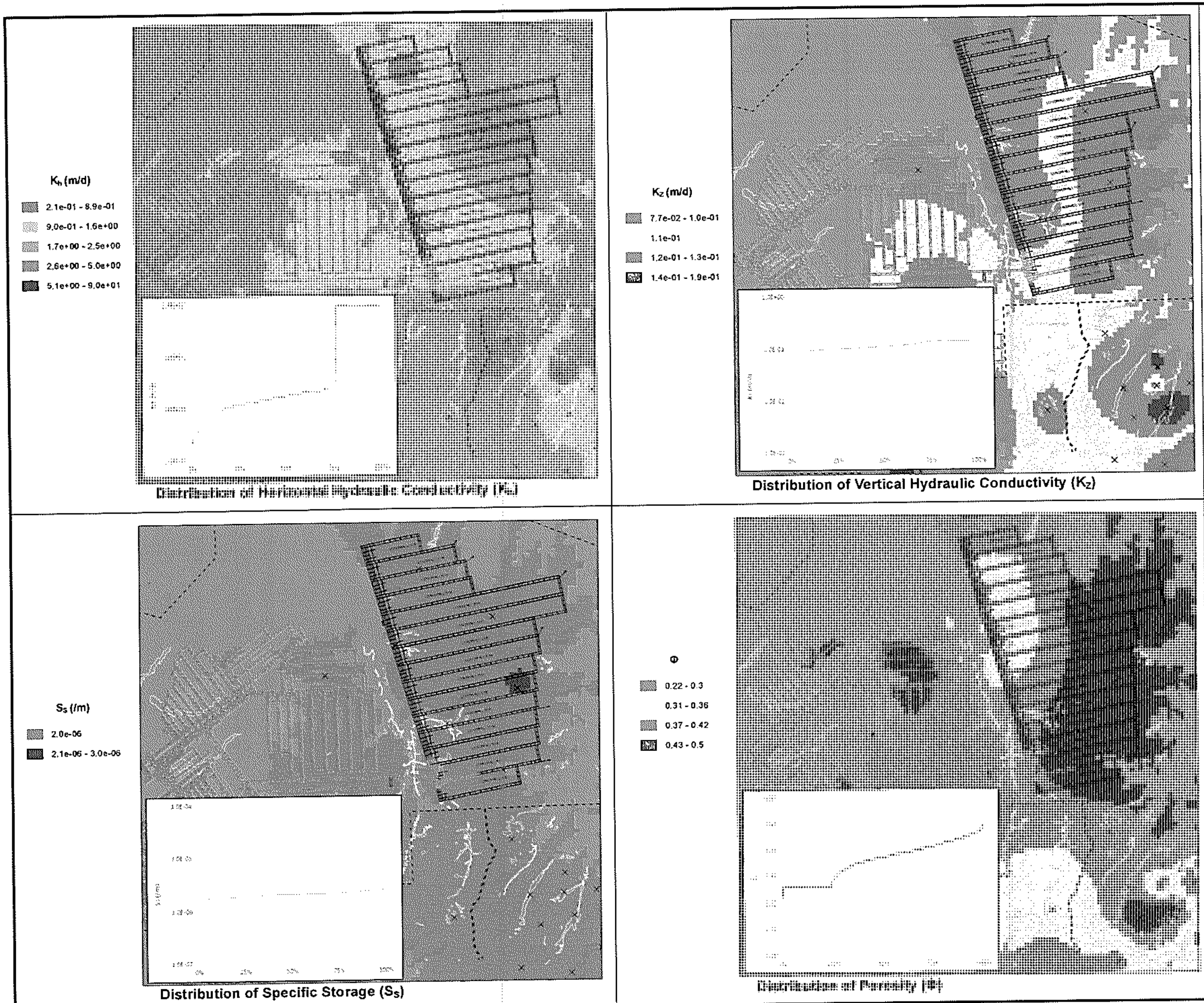
0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 12)

FIGURE: E.2.12a

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D066_DistributionOfAquiferProperties_L12.mxd
Reference © Department of Finance, Services & Innovation 2018



Legend:

- × Pilot Points (Layer 12)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

RPS (2019):

- Shrub Swamps
- Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	

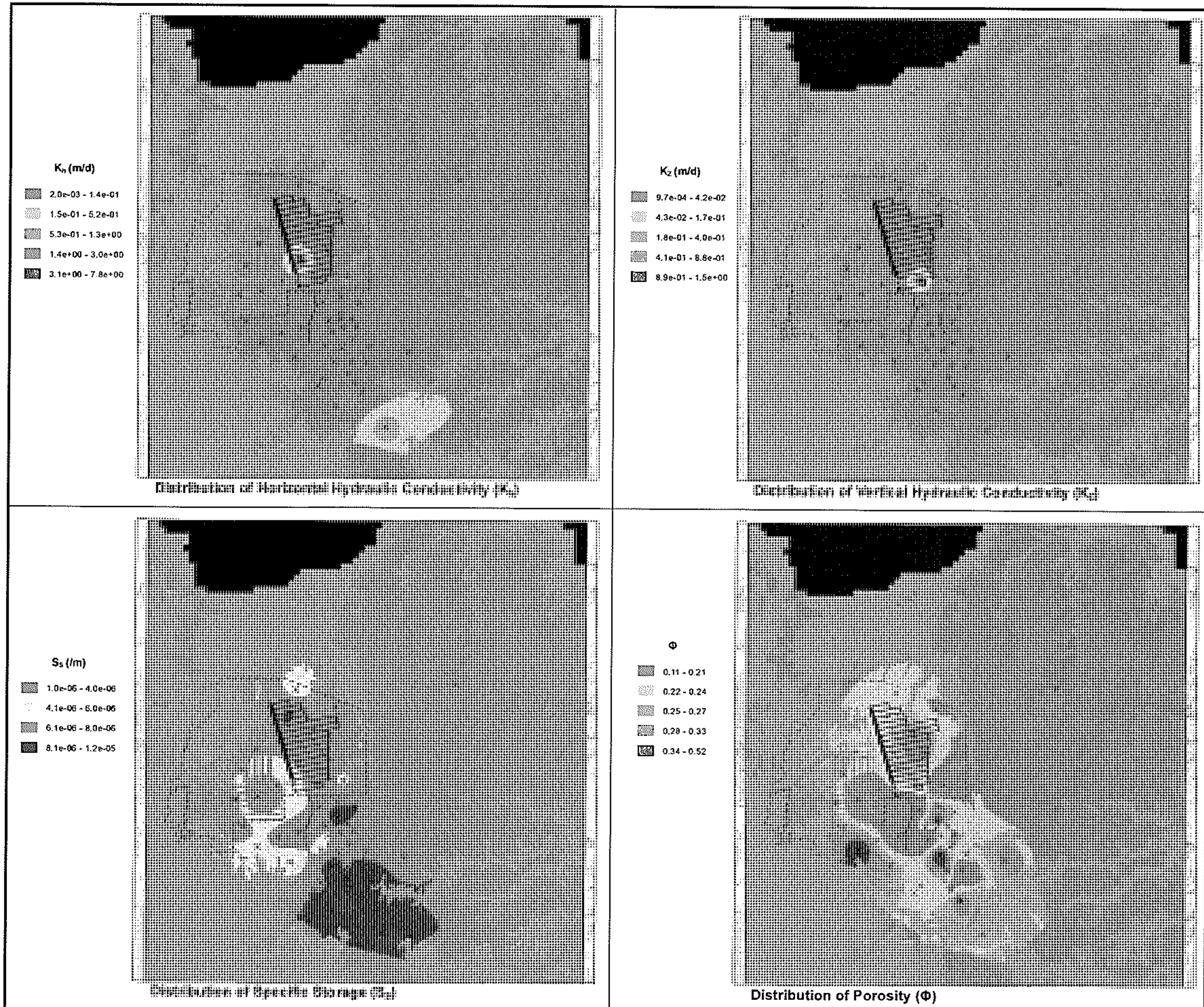
0 1.5 3 km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 12) - Angus Place 1000 Panel Area

FIGURE: E.2.12b

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D066a_DistributionOfAquiferProperties_L12_Zoomed.mxd
Reference © Department of Finance Services & Innovation 2018



Legend:

- × Pilot Points (Layer 13)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	

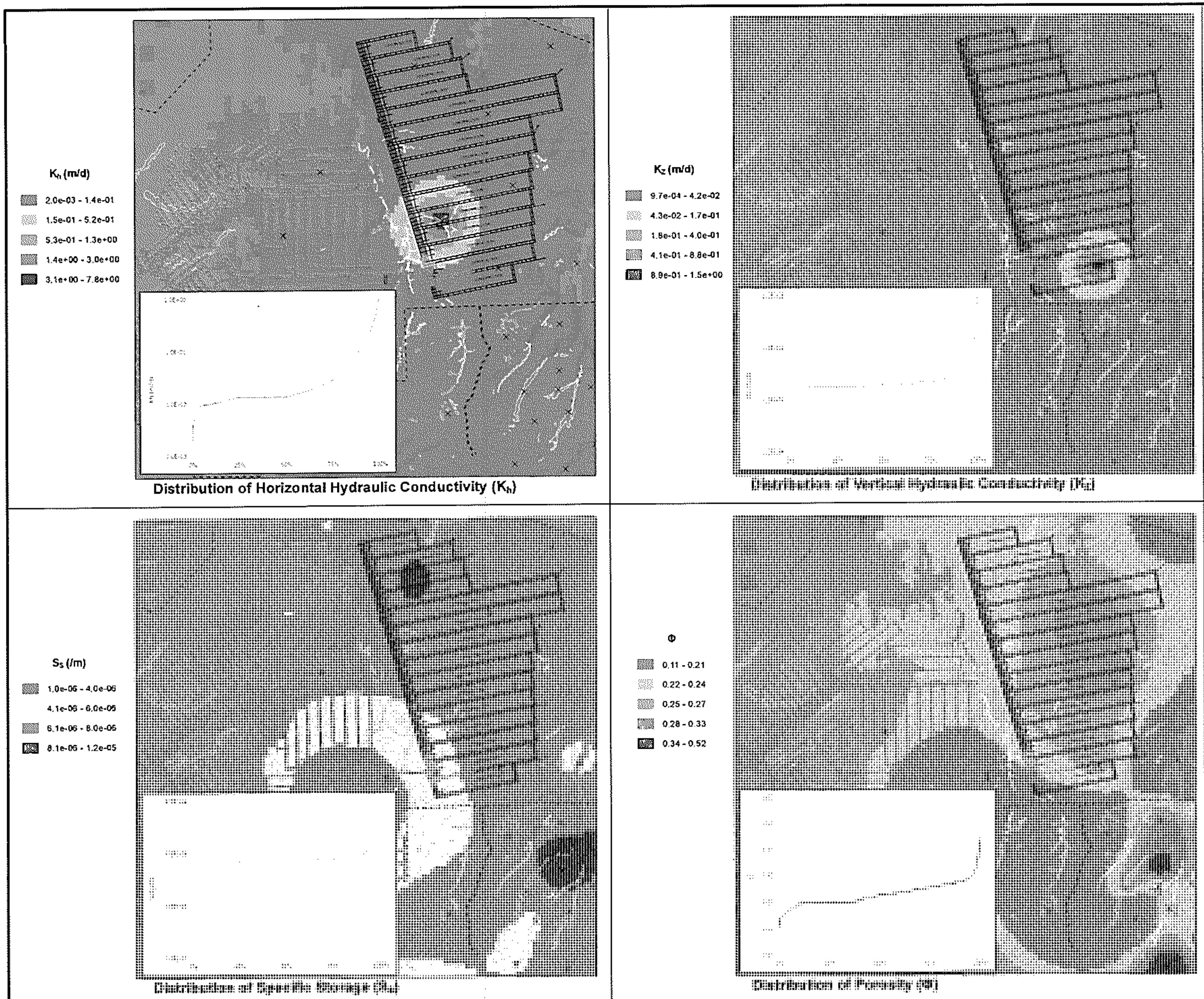
0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 13)

FIGURE: E.2.13a

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D065_DistributionOfAquiferProperties_L13.mxd
Reference © Department of Finance Services & Innovation 2018



Legend:

- × Pilot Points (Layer 13)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells
- RPS (2019):
  - Shrub Swamps
  - Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	
0 1.5 3 km	
Coor. Sys. GDA 1994 MGA Zone 56	

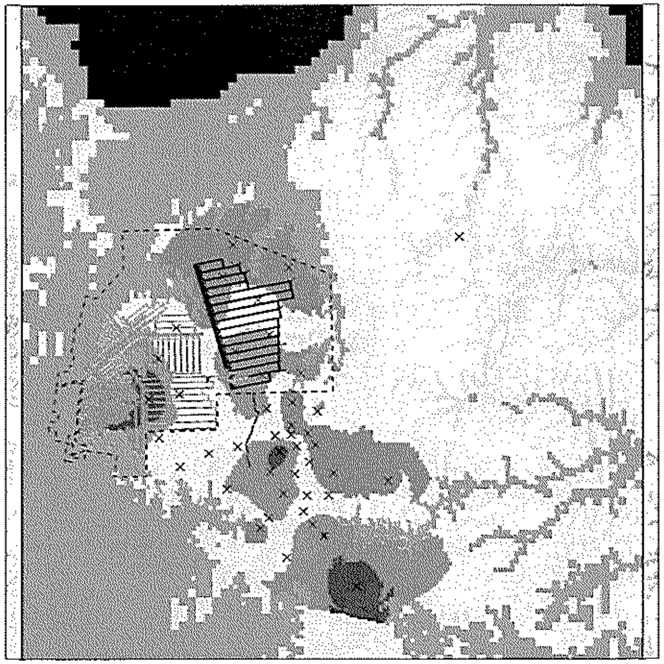
Calibrated Hydraulic Properties (Layer 13) - Angus Place 1000 Panel Area

FIGURE: E.2.13b

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D065a_DistributionOfAquiferProperties_L13_Zoomed.mxd
Reference © Department of Finance Services & Innovation 2018

K_h (m/d)

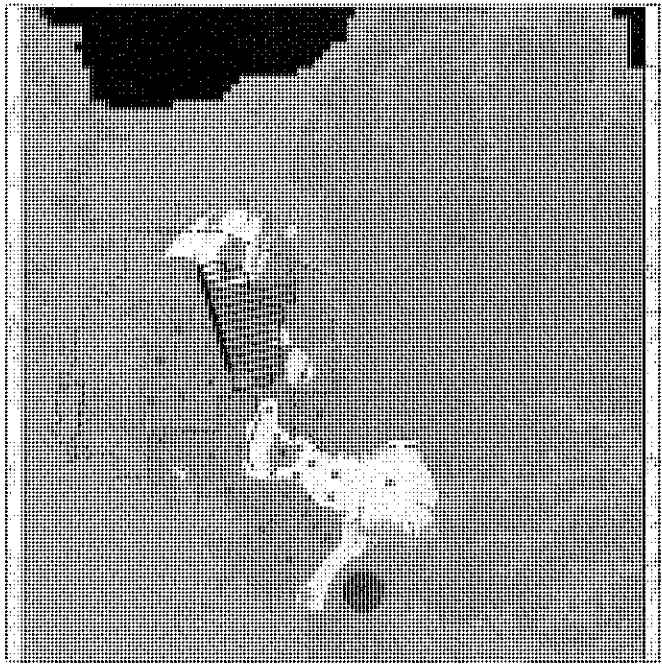
- 5.6e-04 - 8.2e-04
- 8.4e-04 - 9.6e-04
- 9.7e-04 - 1.1e-03
- 1.2e-03 - 1.8e-03



Distribution of Horizontal Hydraulic Conductivity (K_h)

K_Z (m/d)

- 1.1e-05 - 1.9e-04
- 2.0e-04 - 3.1e-04
- 3.2e-04 - 5.4e-04
- 5.5e-04 - 1.0e-03



Distribution of Vertical Hydraulic Conductivity (K_Z)

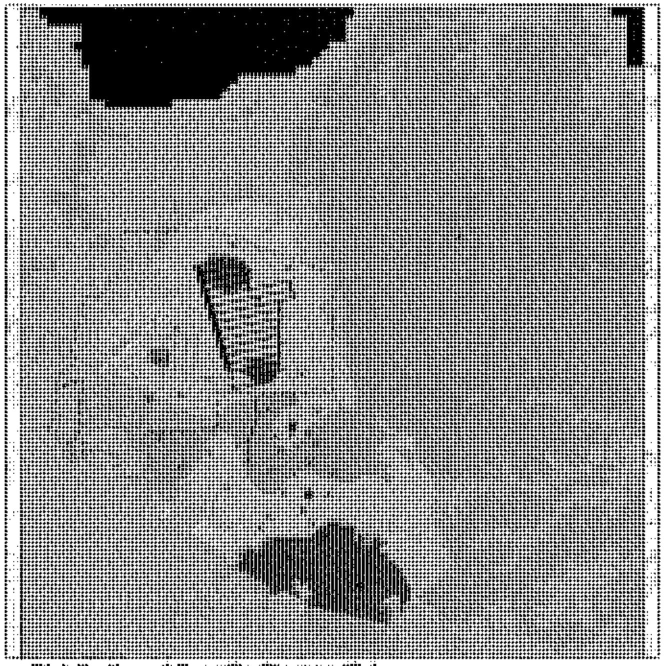
Legend:

- × Pilot Points (Layer 14)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

S_S (/m)

- 5.0e-06 - 7.0e-06
- 7.1e-06 - 9.0e-06
- 9.1e-06 - 1.2e-05



Distribution of Specific Storage (S_S)

Φ

- 0.12 - 0.18
- 0.19 - 0.22
- 0.23 - 0.25
- 0.26 - 0.3
- 0.31 - 0.54

Distribution of Porosity (Φ)

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	

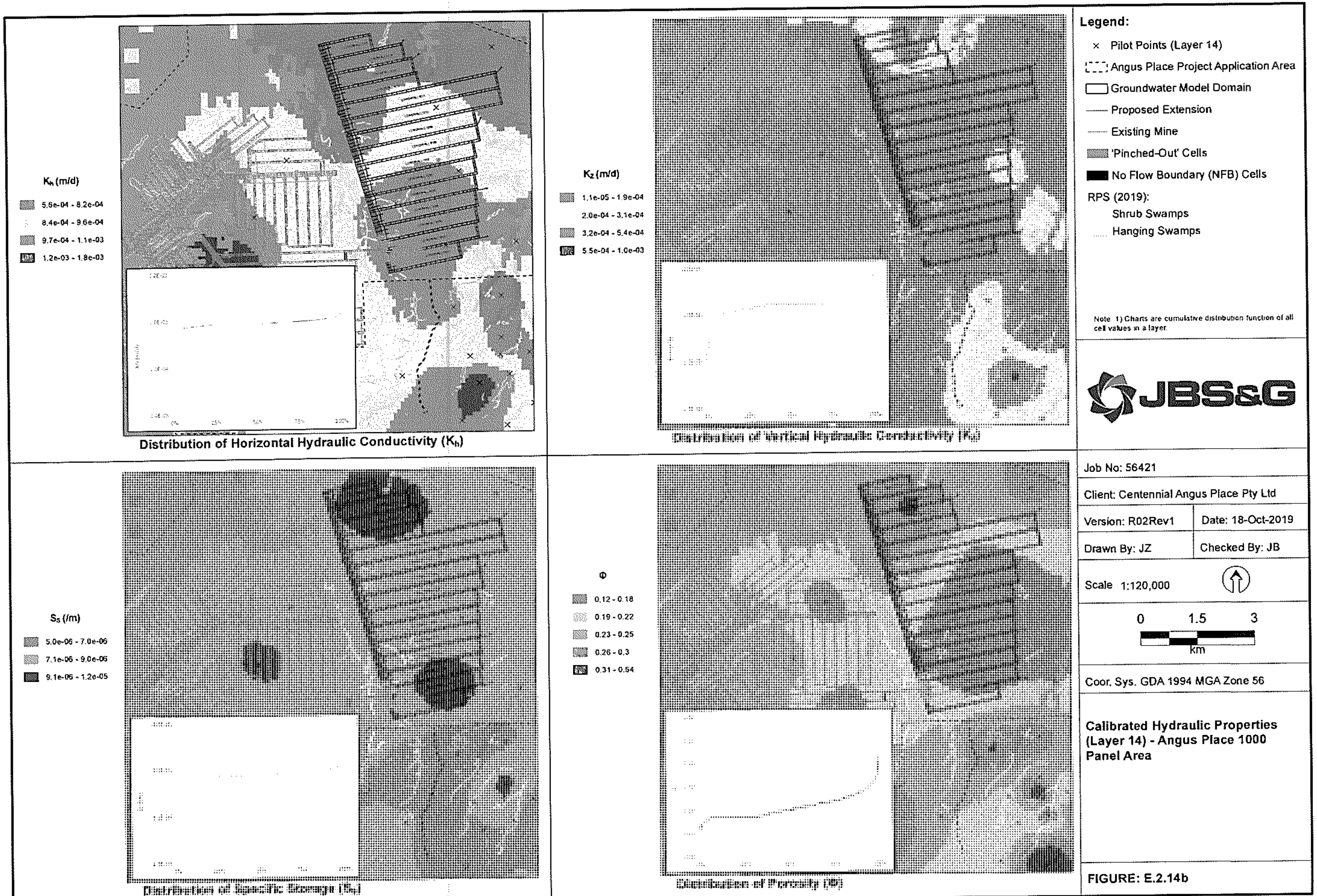
0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 14)

FIGURE: E.2.14a

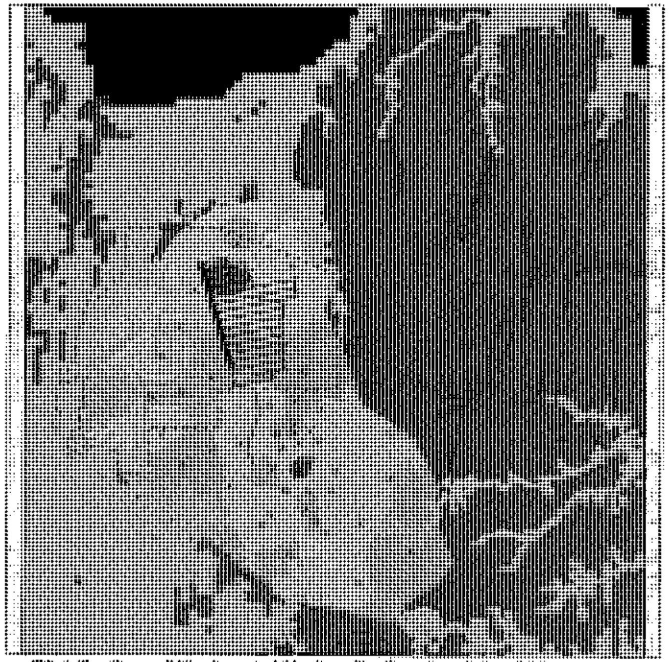
File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D064_DistributionOfAquiferProperties_L14.mxd
Reference © Department of Finance Services & Innovation 2018



File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D064a_DistributionOfAquiferProperties_L14_Zoomed.mxd
Reference: © Department of Finance, Services & Innovation 2018

K_h (m/d)

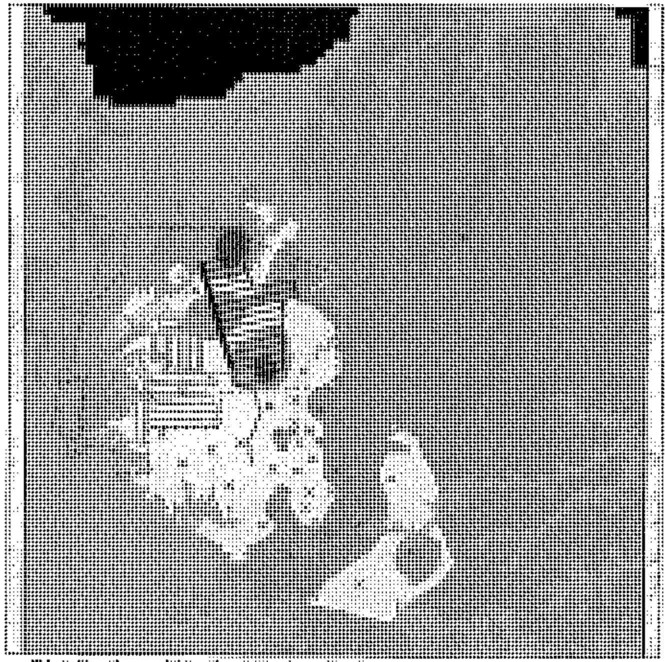
- 2.2e-04 - 3.7e-04
- 3.8e-04 - 5.2e-04
- 5.3e-04 - 7.9e-04



Distribution of Horizontal Hydraulic Conductivity (K_h)

K_z (m/d)

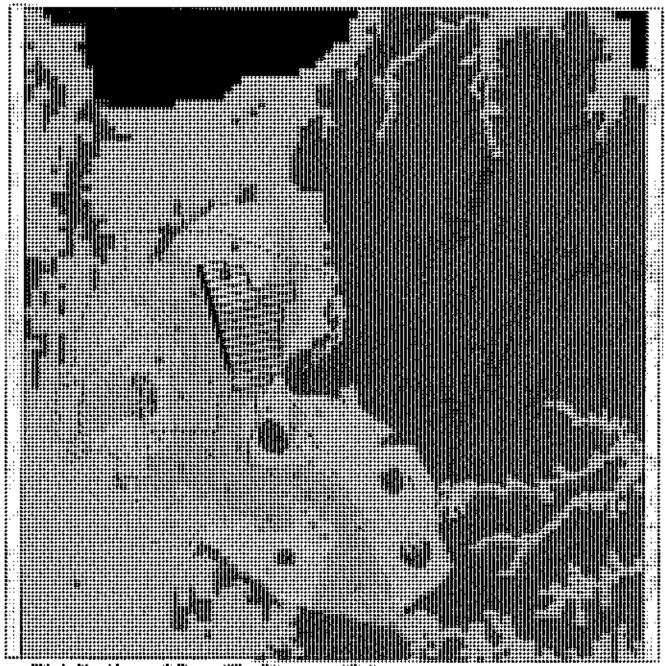
- 3.0e-06 - 1.9e-05
- 2.0e-05 - 4.4e-05
- 4.5e-05 - 8.4e-05
- 8.5e-05 - 2.1e-04



Distribution of Vertical Hydraulic Conductivity (K_z)

S_s (/m)

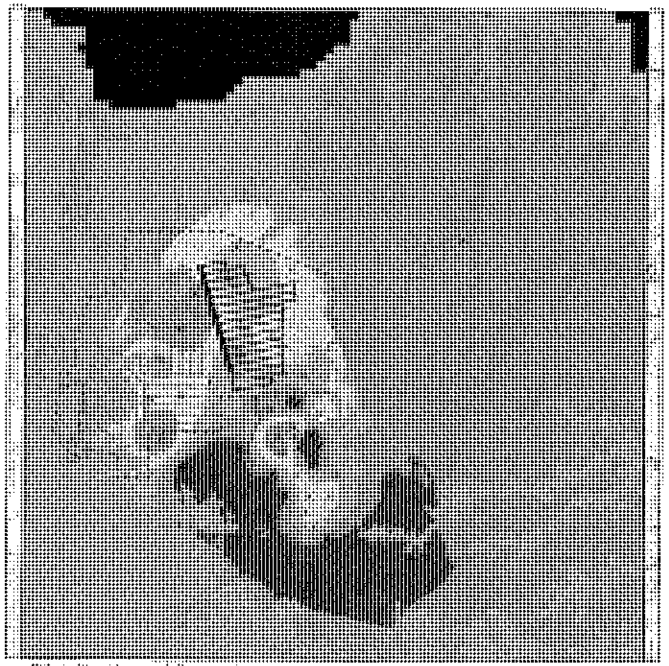
- 4.0e-06 - 5.0e-06
- 5.1e-06 - 6.0e-06
- 6.1e-06 - 1.0e-05



Distribution of Specific Storage (S_s)

Φ

- 0.23 - 0.34
- 0.35 - 0.39
- 0.4 - 0.43
- 0.44 - 0.48
- 0.49 - 0.58



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 15)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB

Scale 1:350,000

0 5 10

km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 15)

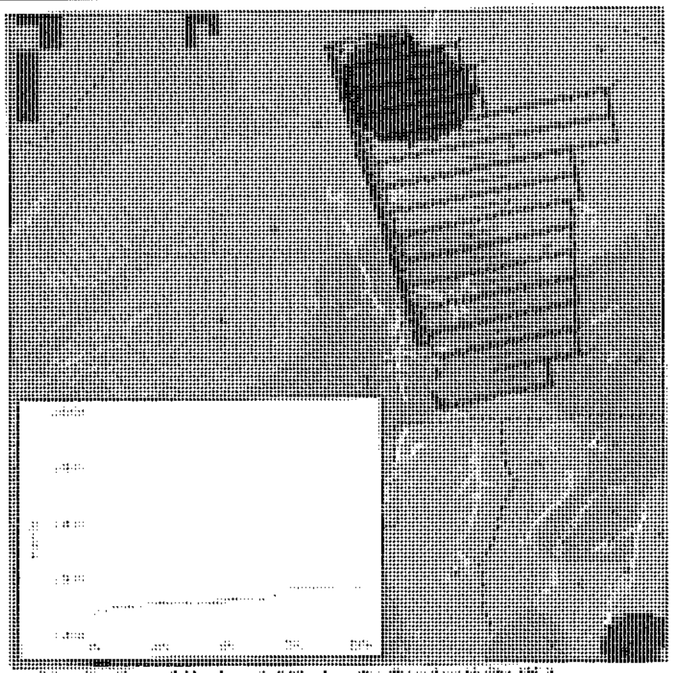
FIGURE: E.2.15a

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_0063_DistributionOfAquiferProperties_L15.mxd

Reference © Department of Finance Services & Innovation 2018

K_h (m/d)

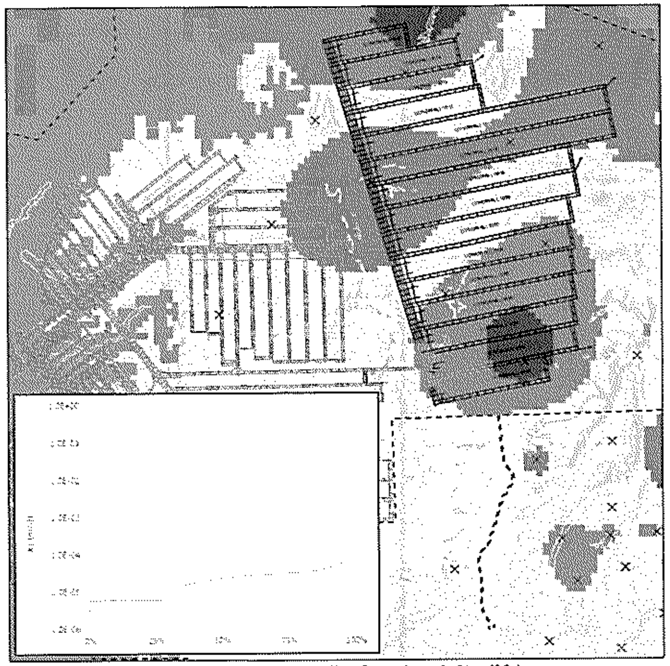
- 2.2e-04 - 3.7e-04
- 3.8e-04 - 5.2e-04
- 5.3e-04 - 7.9e-04



Distribution of Horizontal Hydraulic Conductivity (K_h)

K_z (m/d)

- 3.0e-06 - 1.9e-05
- 2.0e-05 - 4.4e-05
- 4.5e-05 - 8.4e-05
- 8.5e-05 - 2.1e-04



Distribution of Vertical Hydraulic Conductivity (K_z)

Legend:

- × Pilot Points (Layer 15)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

RPS (2019):

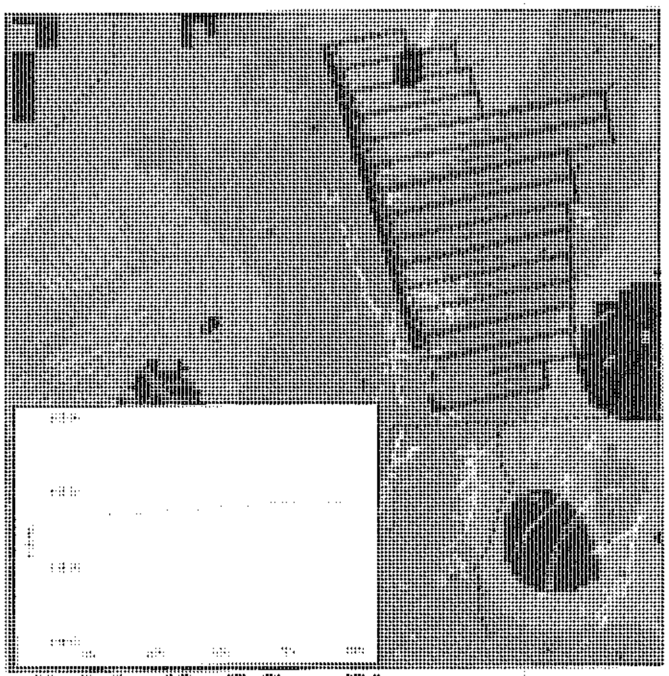
- Shrub Swamps
- Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

S_s (/m)

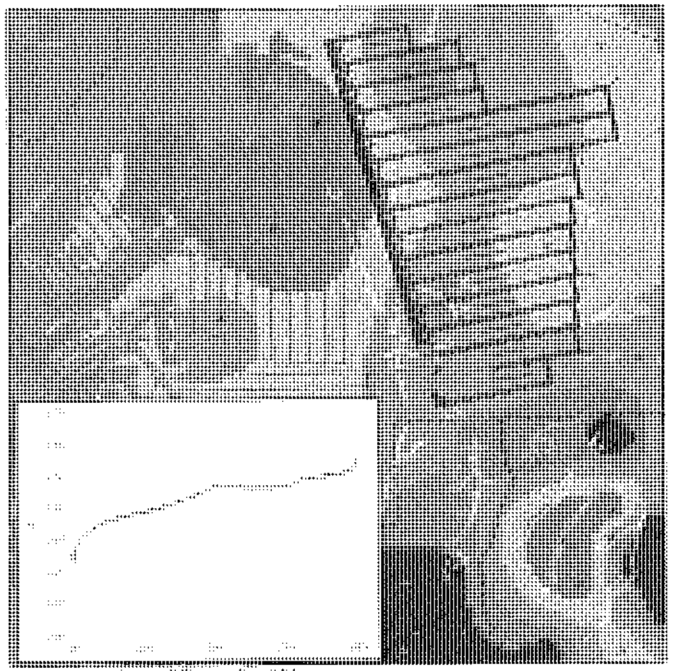
- 4.0e-06 - 5.0e-06
- 5.1e-06 - 6.0e-06
- 6.1e-06 - 1.0e-05



Distribution of Specific Storage (S_s)

Φ

- 0.23 - 0.34
- 0.35 - 0.39
- 0.4 - 0.43
- 0.44 - 0.48
- 0.49 - 0.58



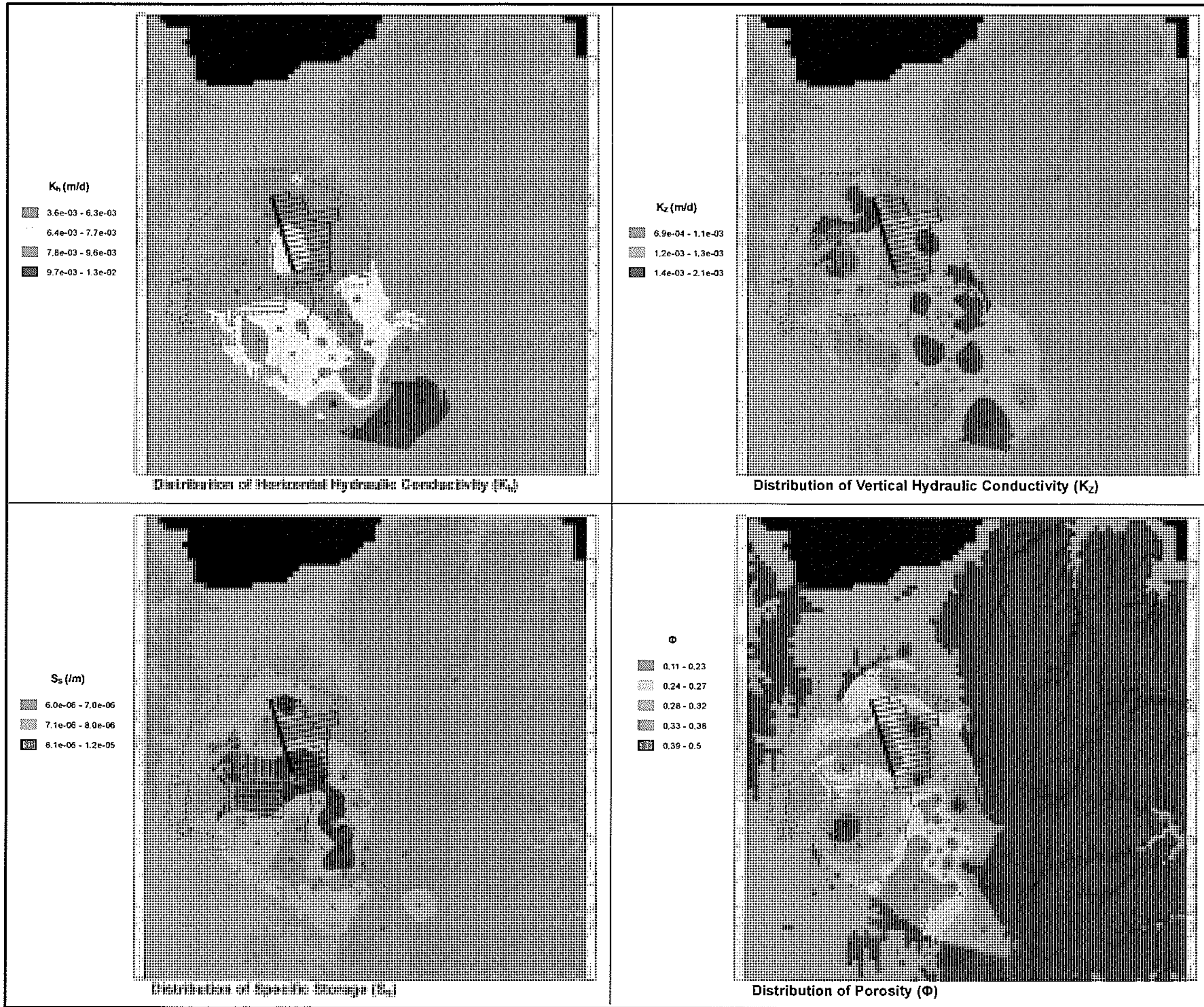
Distribution of Porosity (Φ)

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	
0 1.5 3 km	
Coor. Sys. GDA 1994 MGA Zone 56	

Calibrated Hydraulic Properties (Layer 15) - Angus Place 1000 Panel Area

FIGURE: E.2.15b

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GWR02Rev1_D063a_DistributionOfAquiferProperties_L15_Zoomed.mxd
Reference: © Department of Finance, Services & Innovation 2018



Legend:

- × Pilot Points (Layer 16)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	

0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

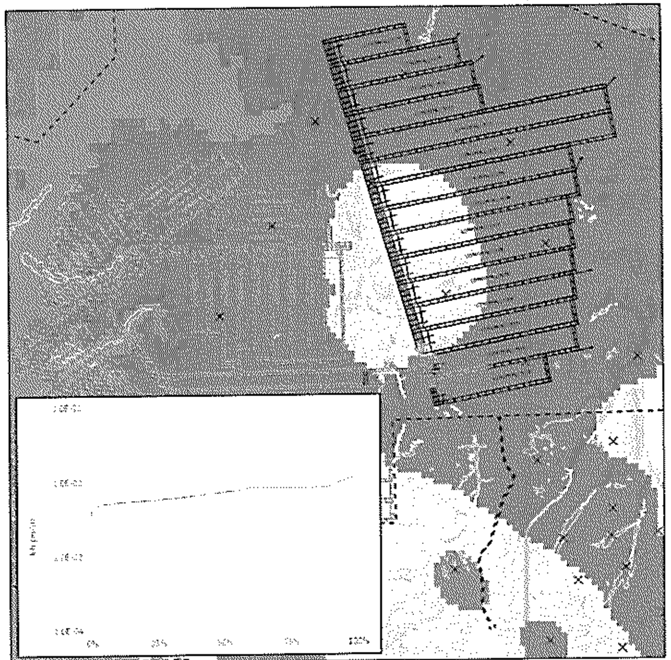
Calibrated Hydraulic Properties (Layer 16)

FIGURE: E.2.16a

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D062_DistributionOfAquiferProperties_L16.mxd
Reference: © Department of Finance, Services & Innovation 2018

K_h (m/d)

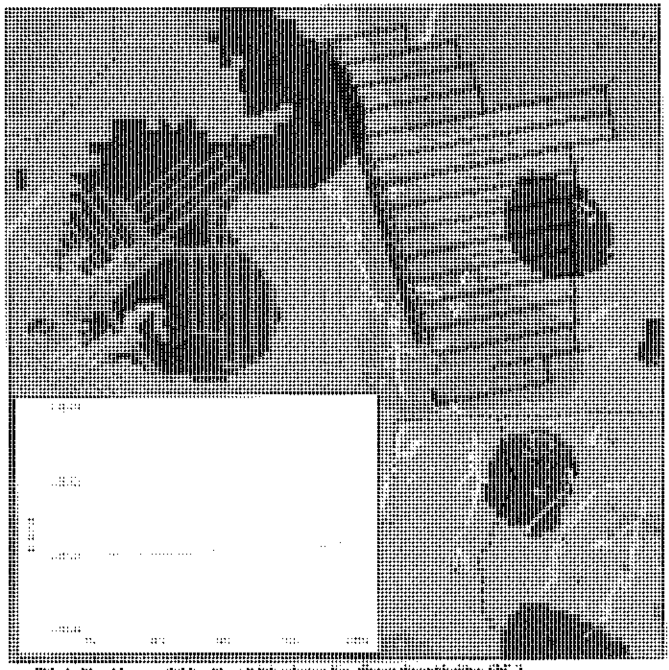
- 3.6e-03 - 6.3e-03
- 6.4e-03 - 7.7e-03
- 7.8e-03 - 9.6e-03
- 9.7e-03 - 1.3e-02



Distribution of Horizontal Hydraulic Conductivity (K_h)

K_z (m/d)

- 6.9e-04 - 1.1e-03
- 1.2e-03 - 1.3e-03
- 1.4e-03 - 2.1e-03



Distribution of Vertical Hydraulic Conductivity (K_z)

Legend:

- × Pilot Points (Layer 16)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

RPS (2019):

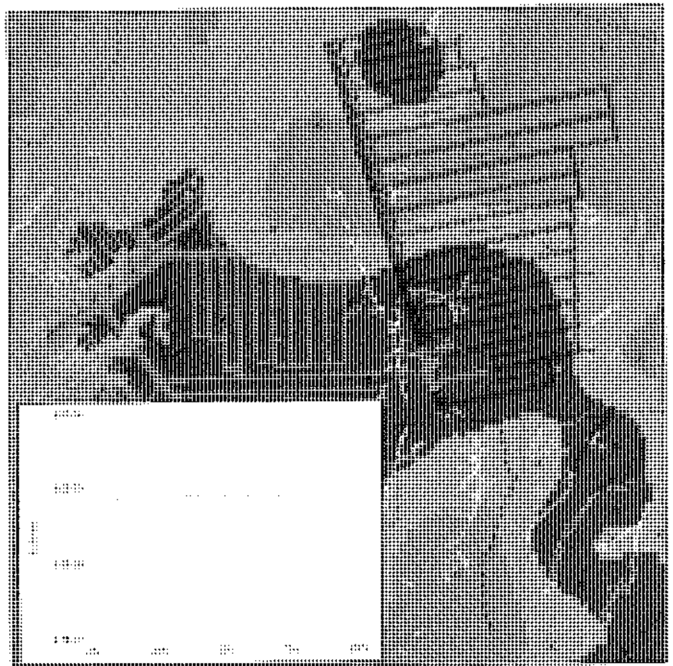
- Shrub Swamps
- Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

S_s (/m)

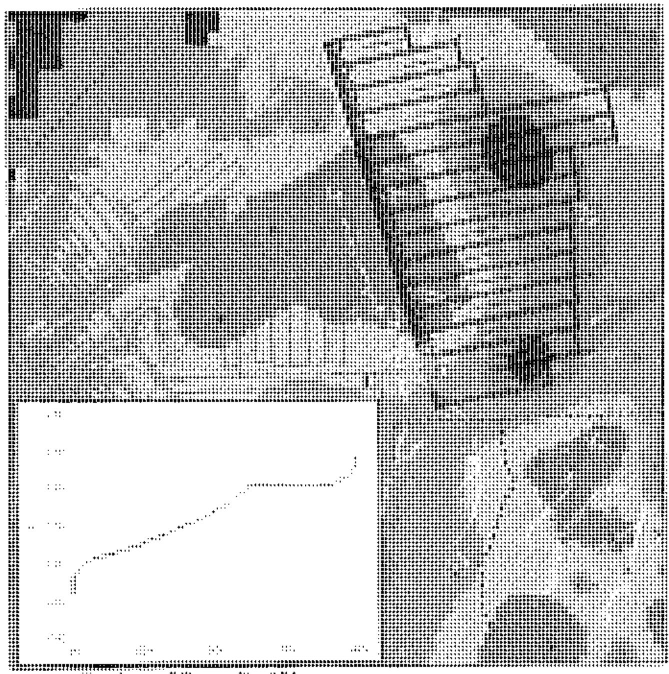
- 6.0e-06 - 7.0e-06
- 7.1e-06 - 8.0e-06
- 8.1e-06 - 1.2e-05



Distribution of Specific Storage (S_s)

Φ

- 0.11 - 0.23
- 0.24 - 0.27
- 0.28 - 0.32
- 0.33 - 0.38
- 0.39 - 0.5



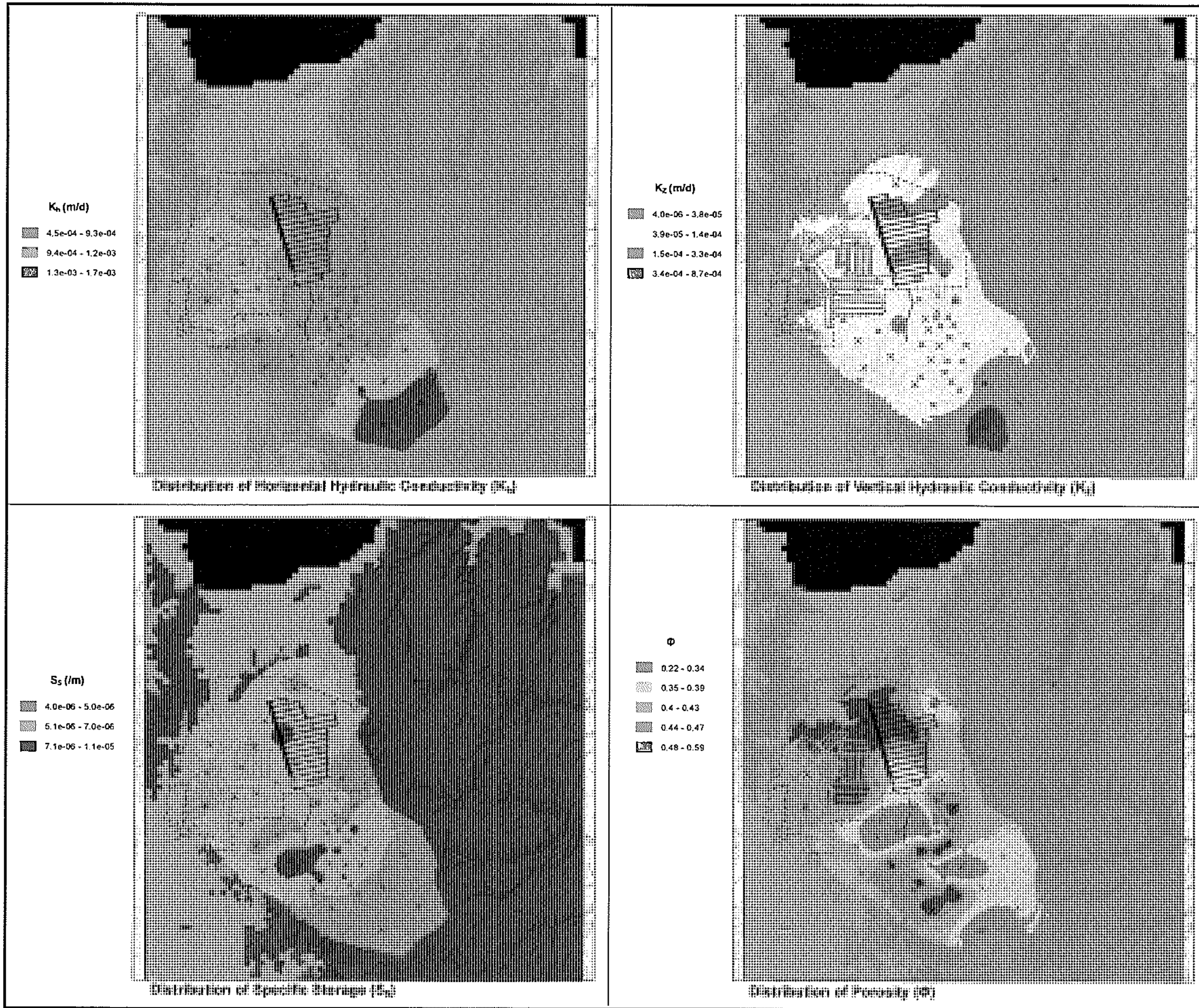
Distribution of Porosity (Φ)

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	
0 1.5 3 km	
Coor. Sys. GDA 1994 MGA Zone 56	

Calibrated Hydraulic Properties (Layer 16) - Angus Place 1000 Panel Area

FIGURE: E.2.16b

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D062a_DistributionOfAquiferProperties_L16_Zoomed.mxd
Reference © Department of Finance Services & Innovation 2018



Distribution of Horizontal Hydraulic Conductivity (K_h)

Distribution of Vertical Hydraulic Conductivity (K_z)

Distribution of Specific Storage (S_s)

Distribution of Porosity (φ)

Legend:

- × Pilot Points (Layer 17)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB

Scale 1:350,000

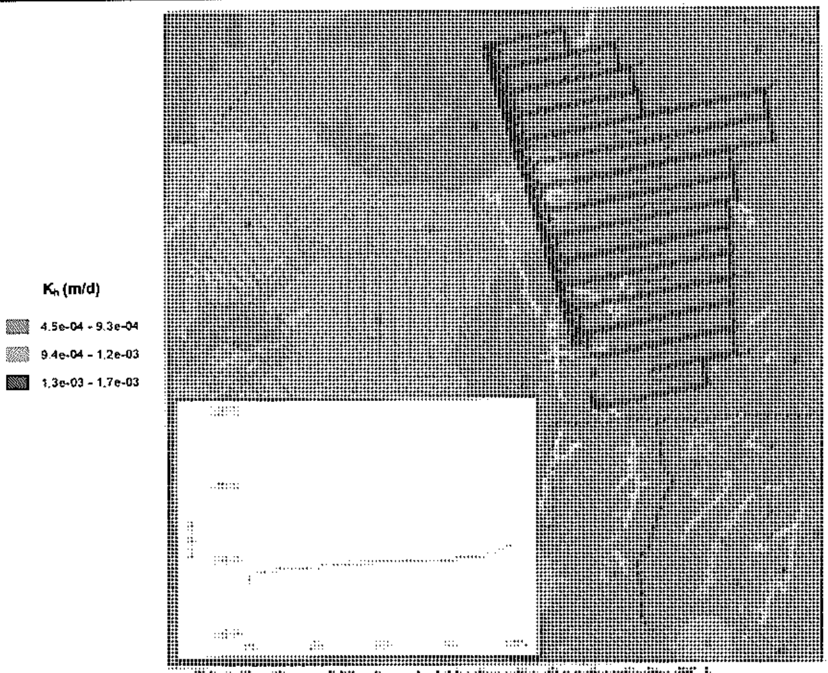
0 5 10 km

Coor. Sys. GDA 1994 MGA Zone 56

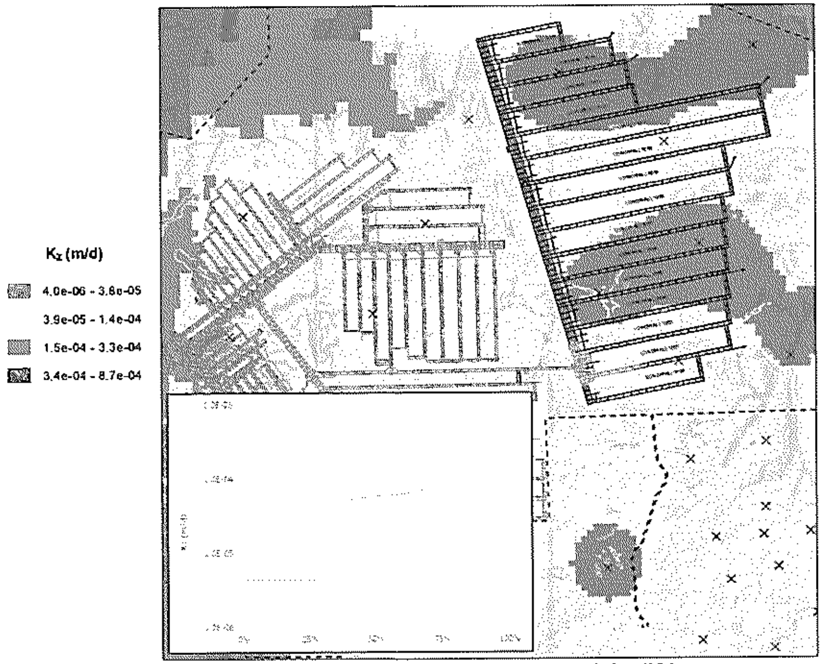
Calibrated Hydraulic Properties (Layer 17)

FIGURE: E.2.17a

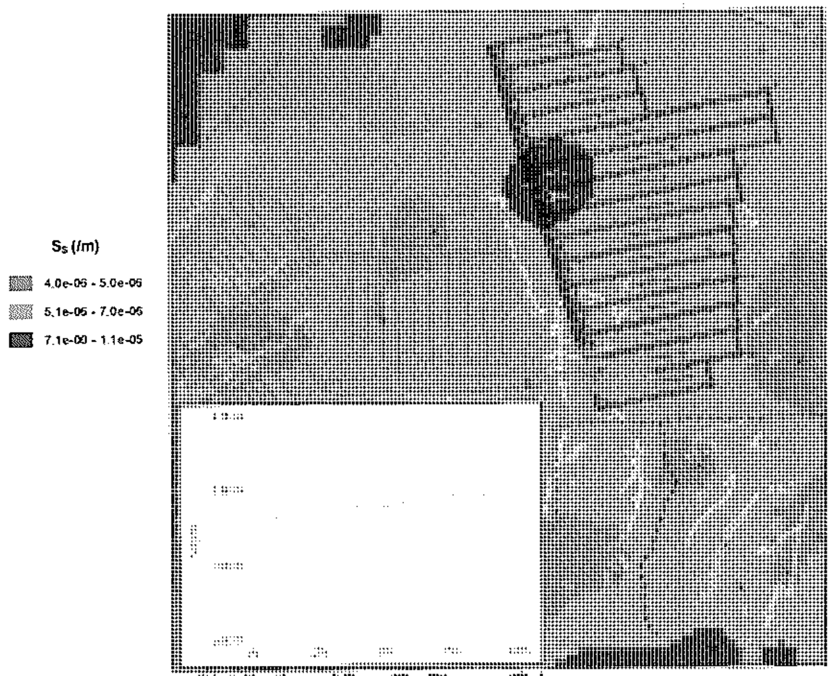
File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D061_DistributionOfAquiferProperties_L17.mxd
Reference: © Department of Finance, Services & Innovation 2018



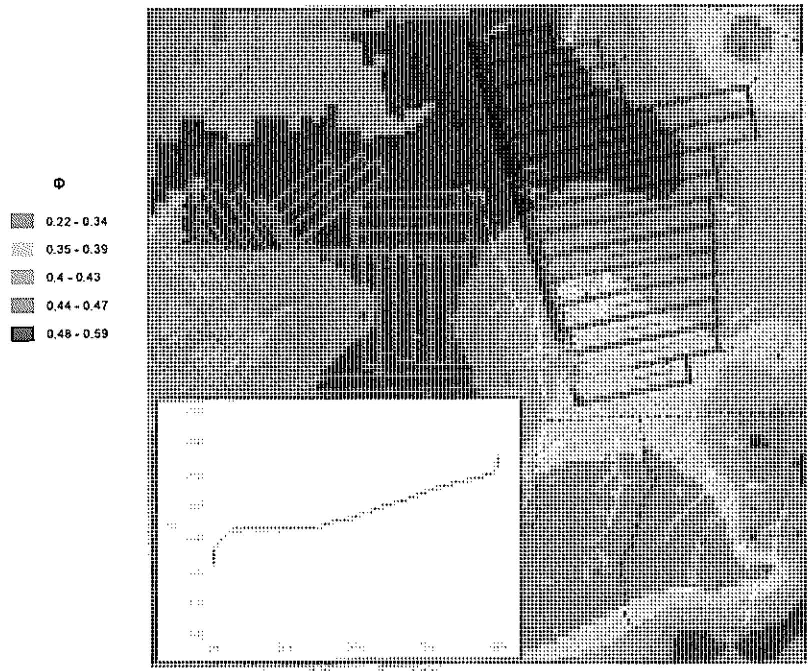
Distribution of Horizontal Hydraulic Conductivity (K_h)



Distribution of Vertical Hydraulic Conductivity (K_z)



Distribution of Specific Storage (S_s)



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 17)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells
- RPS (2019):
  - Shrub Swamps
  - Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	

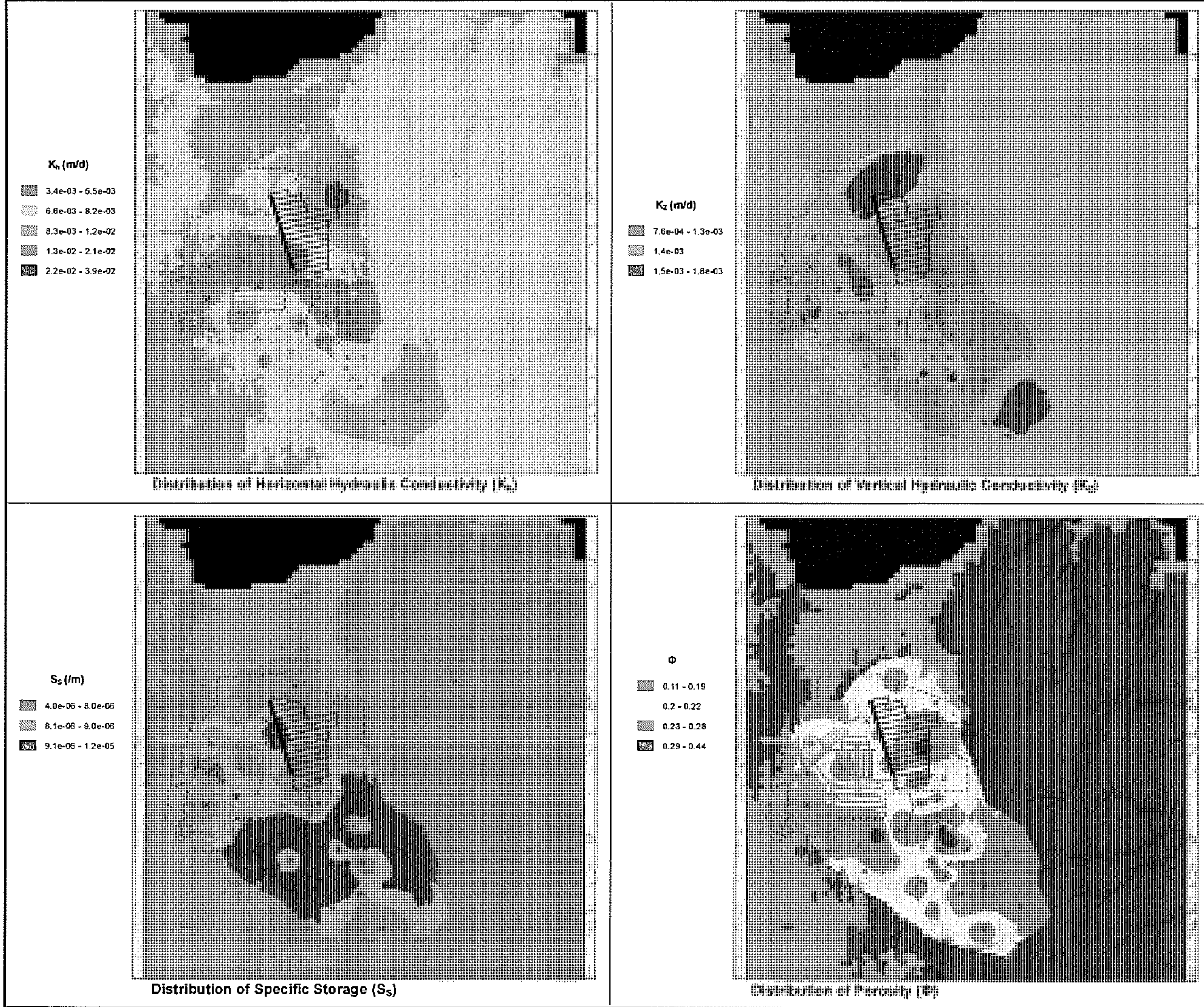
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 17) - Angus Place 1000 Panel Area

FIGURE: E.2.17b

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D051a_DistributionOfAquiferProperties_L17_Zoomed.mxd



Legend:

- × Pilot Points (Layer 18)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB

Scale 1:350,000

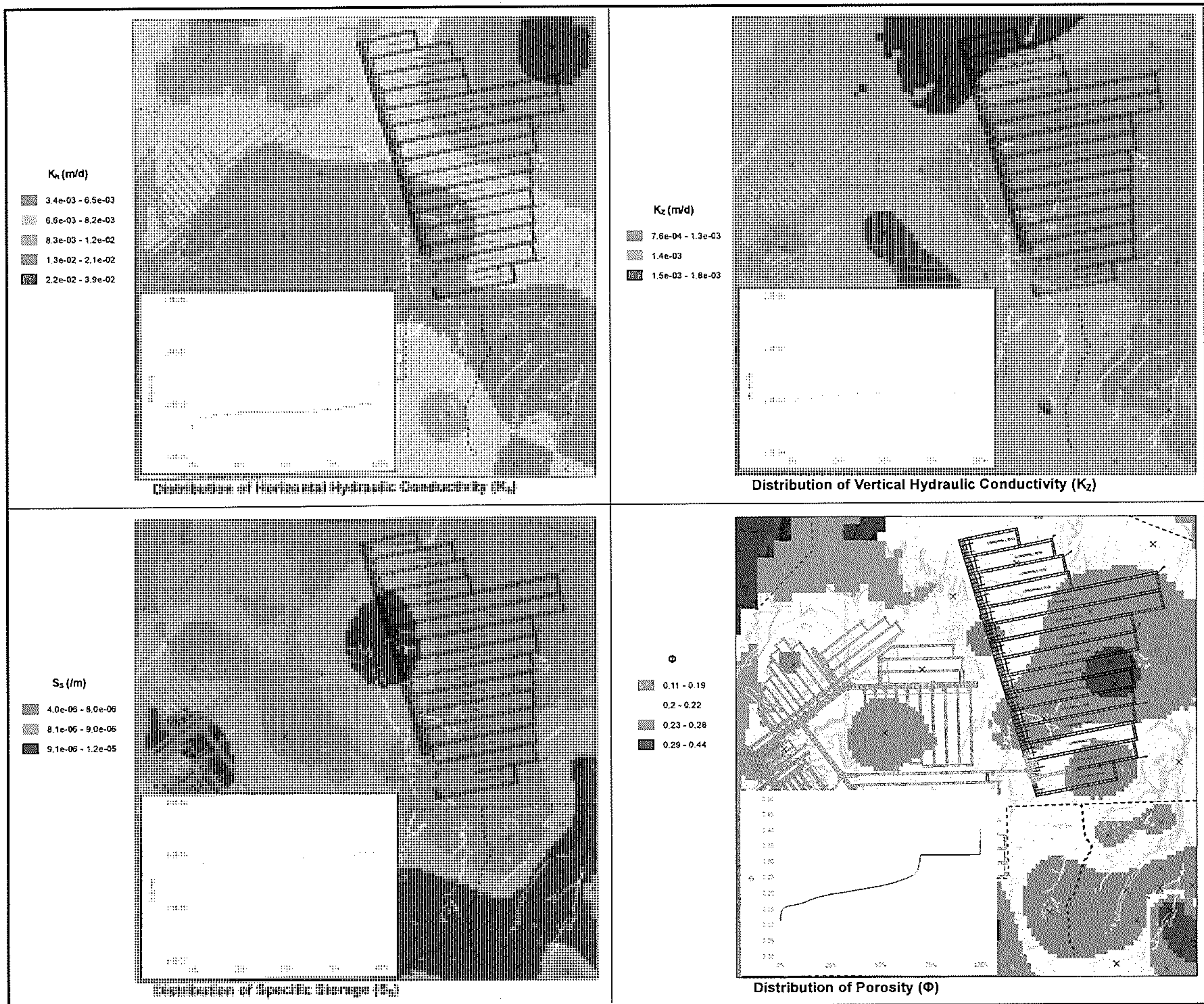
0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 18)

FIGURE: E.2.18a

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D060_DistributionOfAquiferProperties_L18.mxd
Reference © Department of Finance Services & Innovation 2018



Legend:

× Pilot Points (Layer 18)
Angus Place Project Application Area
Groundwater Model Domain
Proposed Extension
Existing Mine
'Pinched-Out' Cells
No Flow Boundary (NFB) Cells
RPS (2019):
Shrub Swamps
Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	

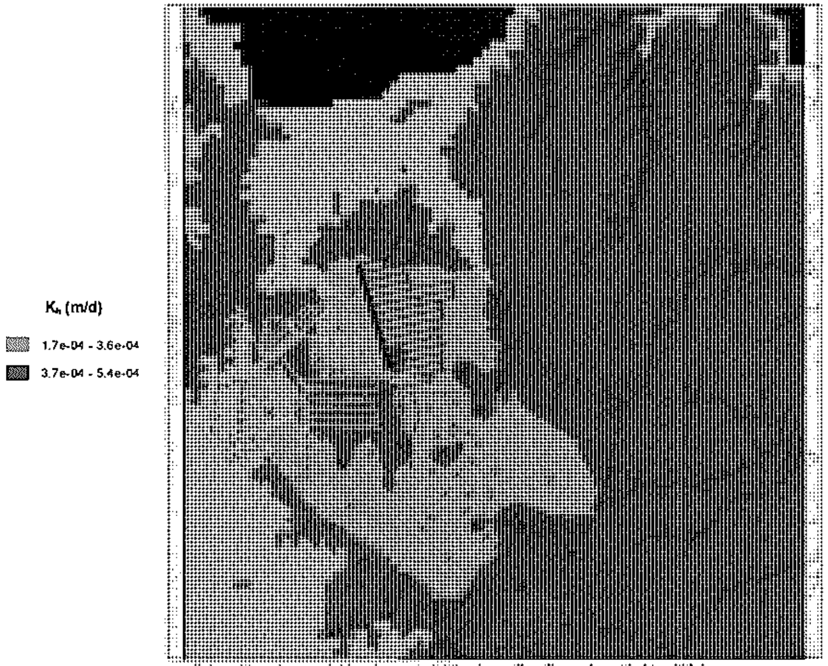
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

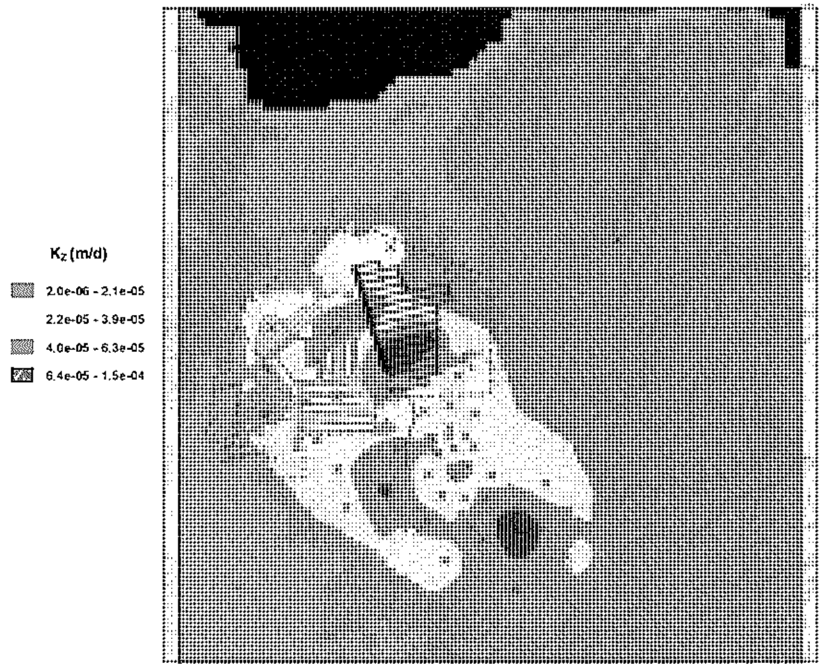
Calibrated Hydraulic Properties (Layer 18) - Angus Place 1000 Panel Area

FIGURE: E.2.18b

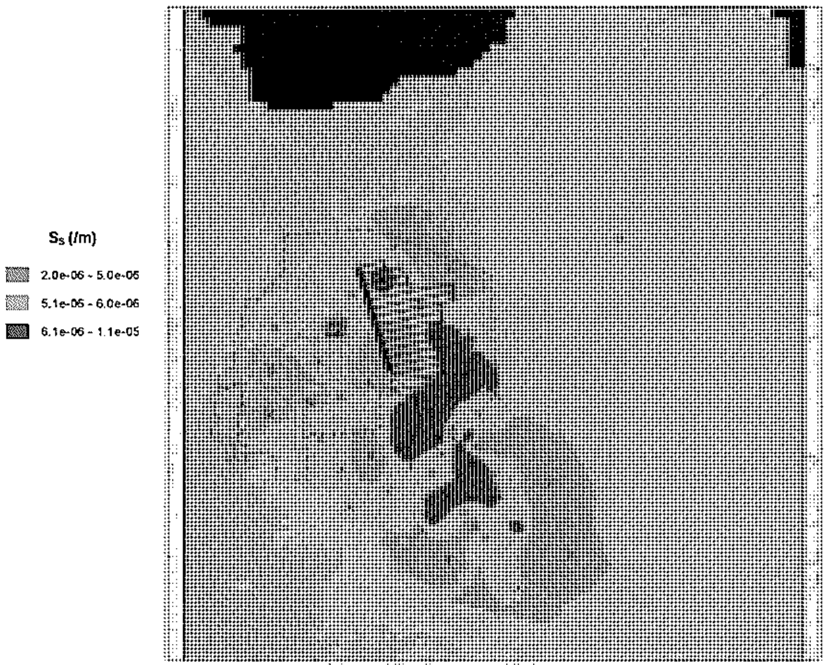
File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D060a_DistributionOfAquiferProperties_L18_Zoomed.mxd
Reference © Department of Finance Services & Innovation 2018



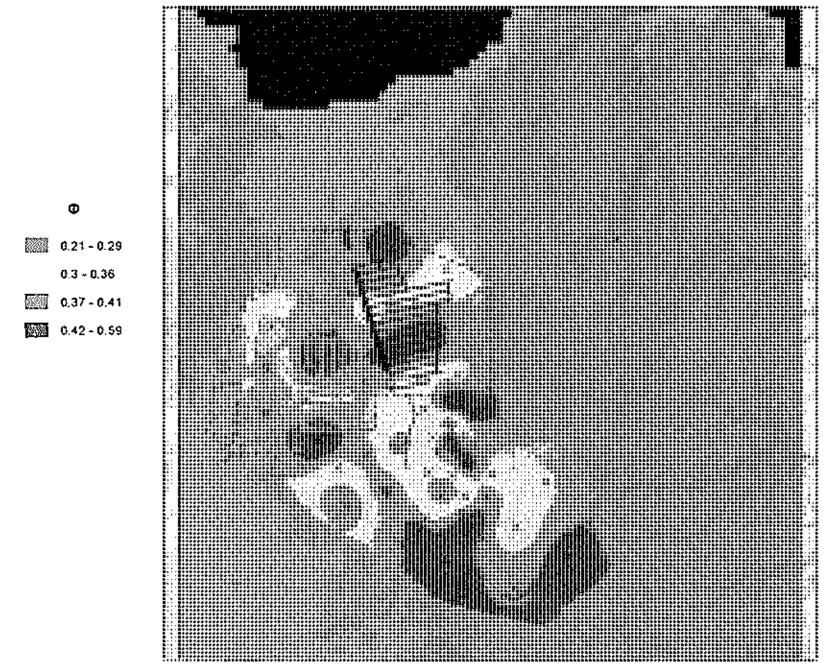
Distribution of Horizontal Hydraulic Conductivity (K_h)



Distribution of Vertical Hydraulic Conductivity (K_Z)



Distribution of Specific Storage (S_s)



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 19)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

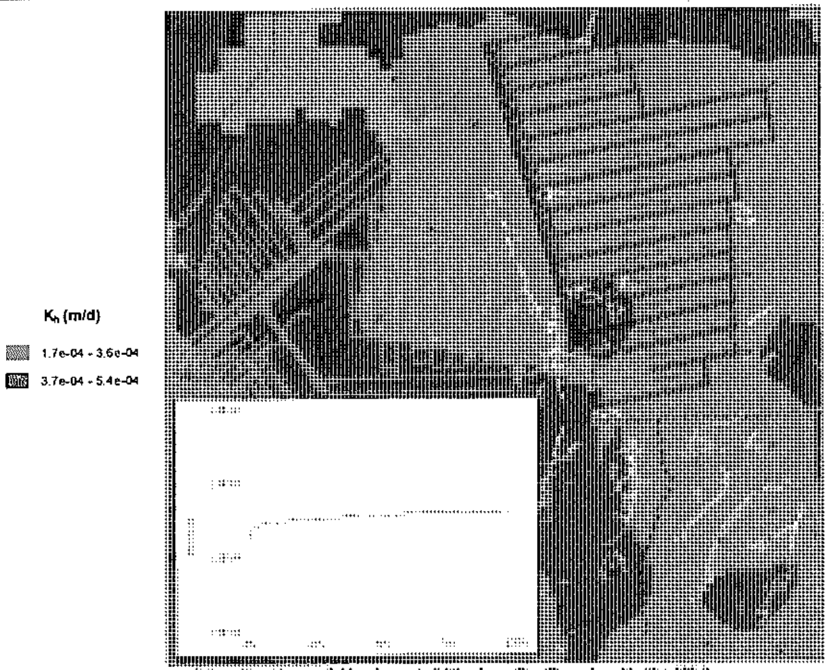
JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	
0 5 10 km	
Coor. Sys. GDA 1994 MGA Zone 56	

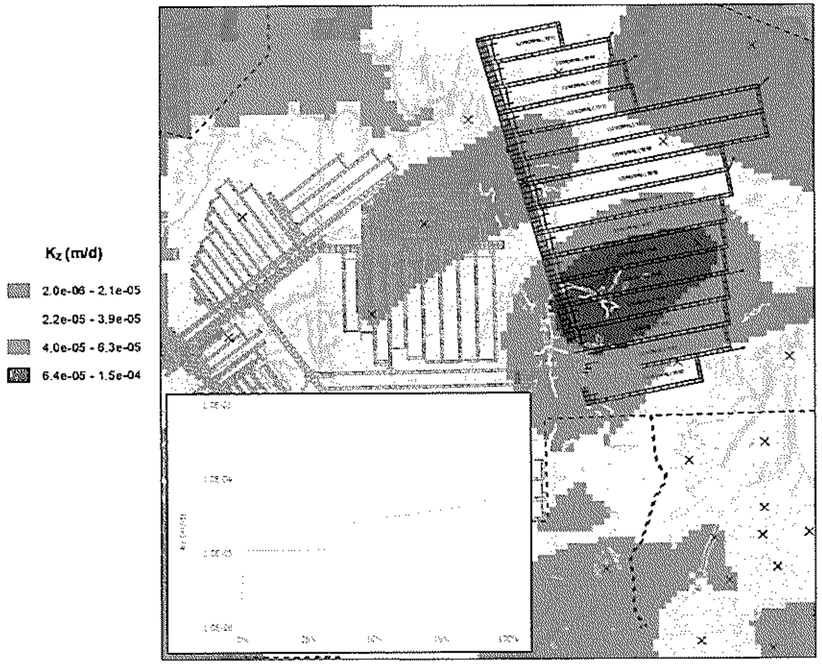
Calibrated Hydraulic Properties (Layer 19)

FIGURE: E.2.19a

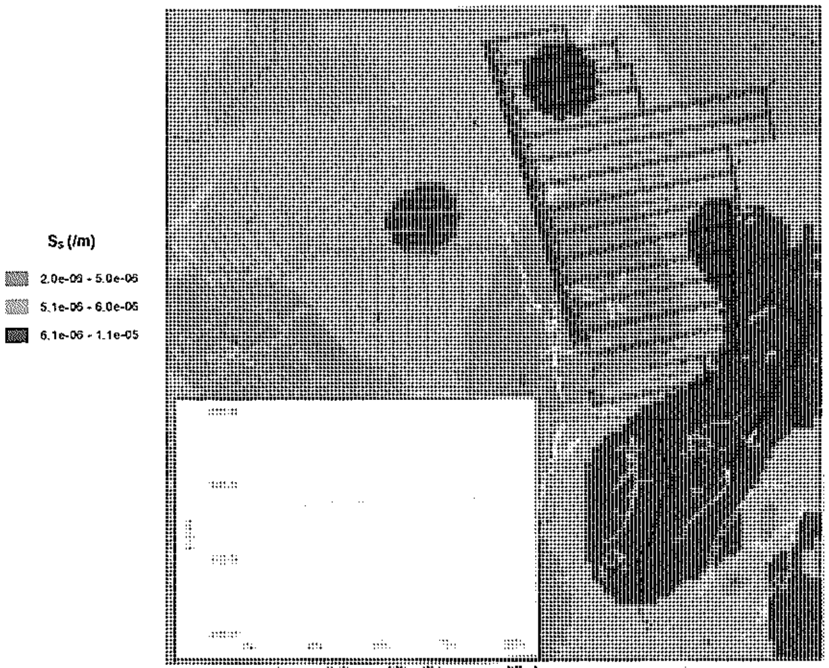
File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D059_DistributionOfAquiferProperties_L19.mxd
Reference © Department of Finance Services & Innovation 2018



Distribution of Horizontal Hydraulic Conductivity (K_h)



Distribution of Vertical Hydraulic Conductivity (K_Z)



Distribution of Specific Storage (S_S)

Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 19)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

RPS (2019):
- Shrub Swamps
- Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	

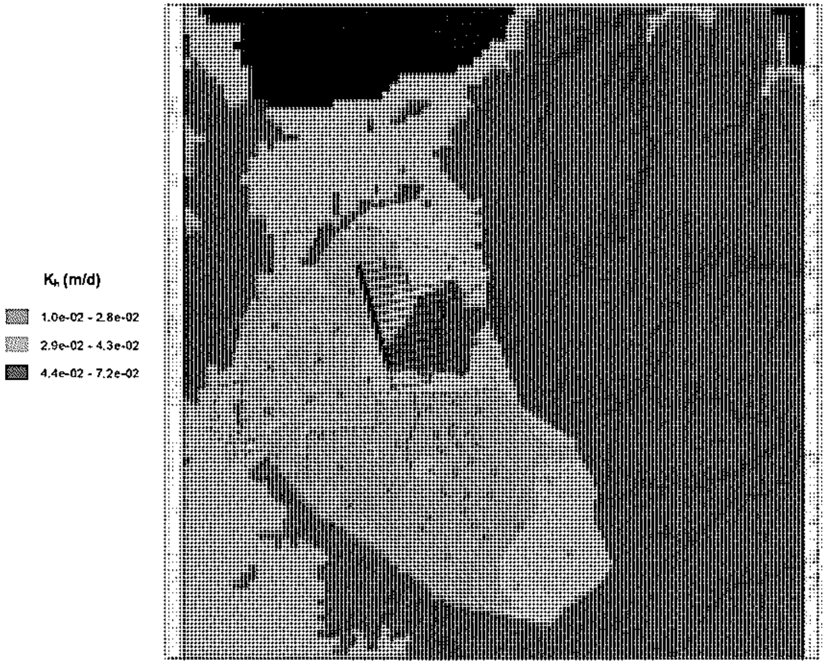
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

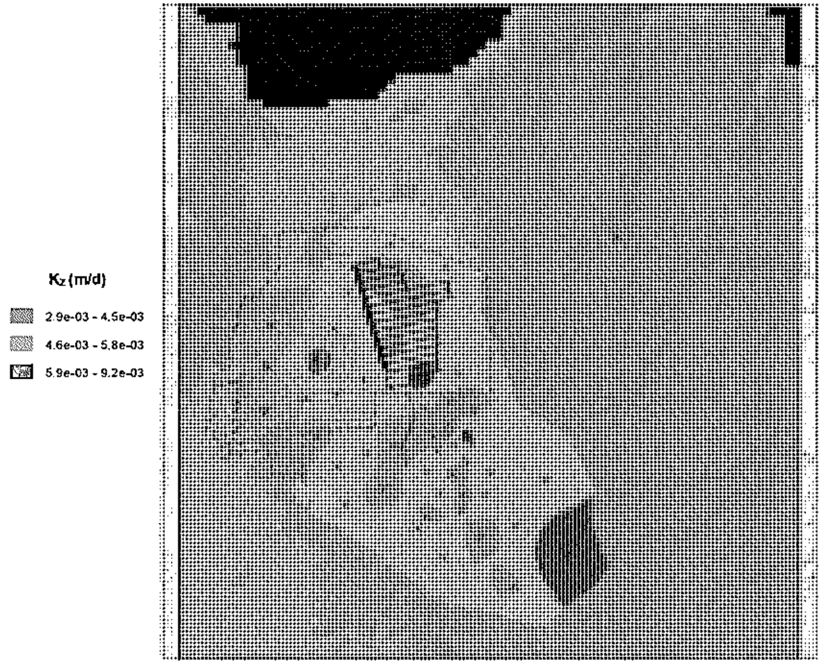
Calibrated Hydraulic Properties (Layer 19) - Angus Place 1000 Panel Area

FIGURE: E.2.19b

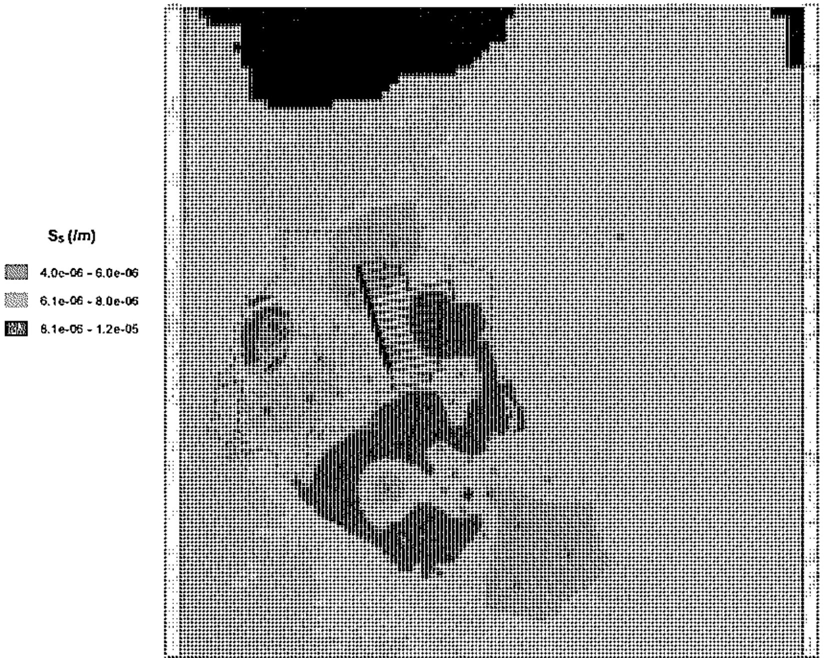
File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D059a_DistributionOfAquiferProperties_L19_Zoomed.mxd



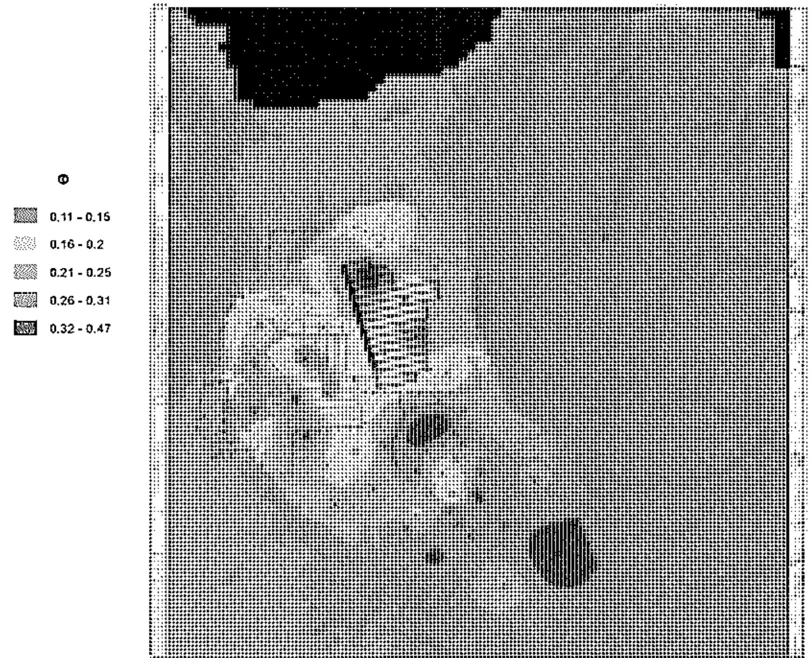
Distribution of Horizontal Hydraulic Conductivity (K_h)



Distribution of Vertical Hydraulic Conductivity (K_Z)



Distribution of Specific Storage (S_s)



Distribution of Porosity (Φ)

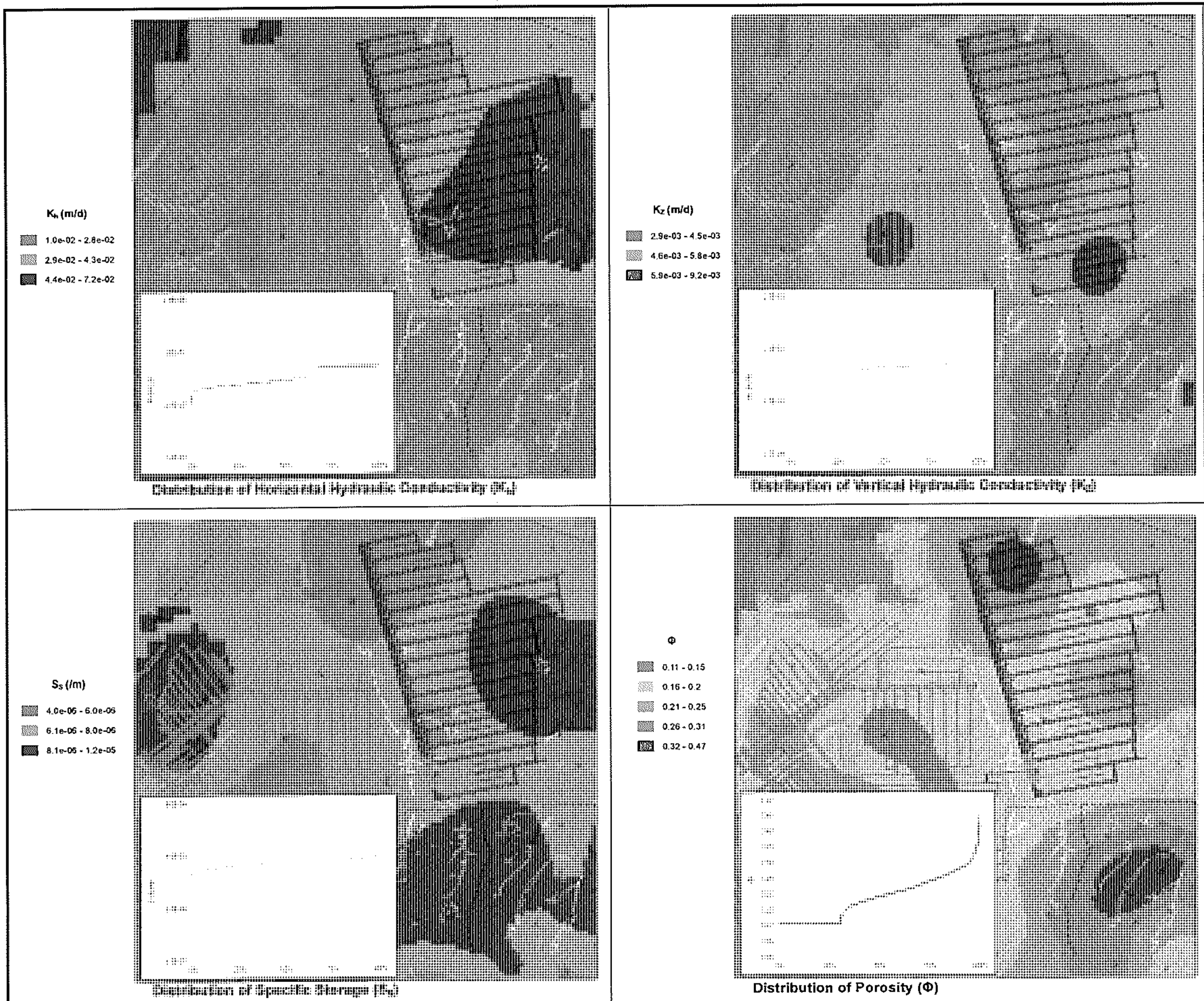
Legend:

- × Pilot Points (Layer 20)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	
0 5 10 km	
Coor. Sys. GDA 1994 MGA Zone 56	
Calibrated Hydraulic Properties (Layer 20)	
FIGURE: E.2.20a	

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D058_DistributionOfAquiferProperties_L20.mxd
Reference © Department of Finance Services & Innovation 2018



Legend:

- × Pilot Points (Layer 20)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells
- RPS (2019):
  - Shrub Swamps
  - Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	

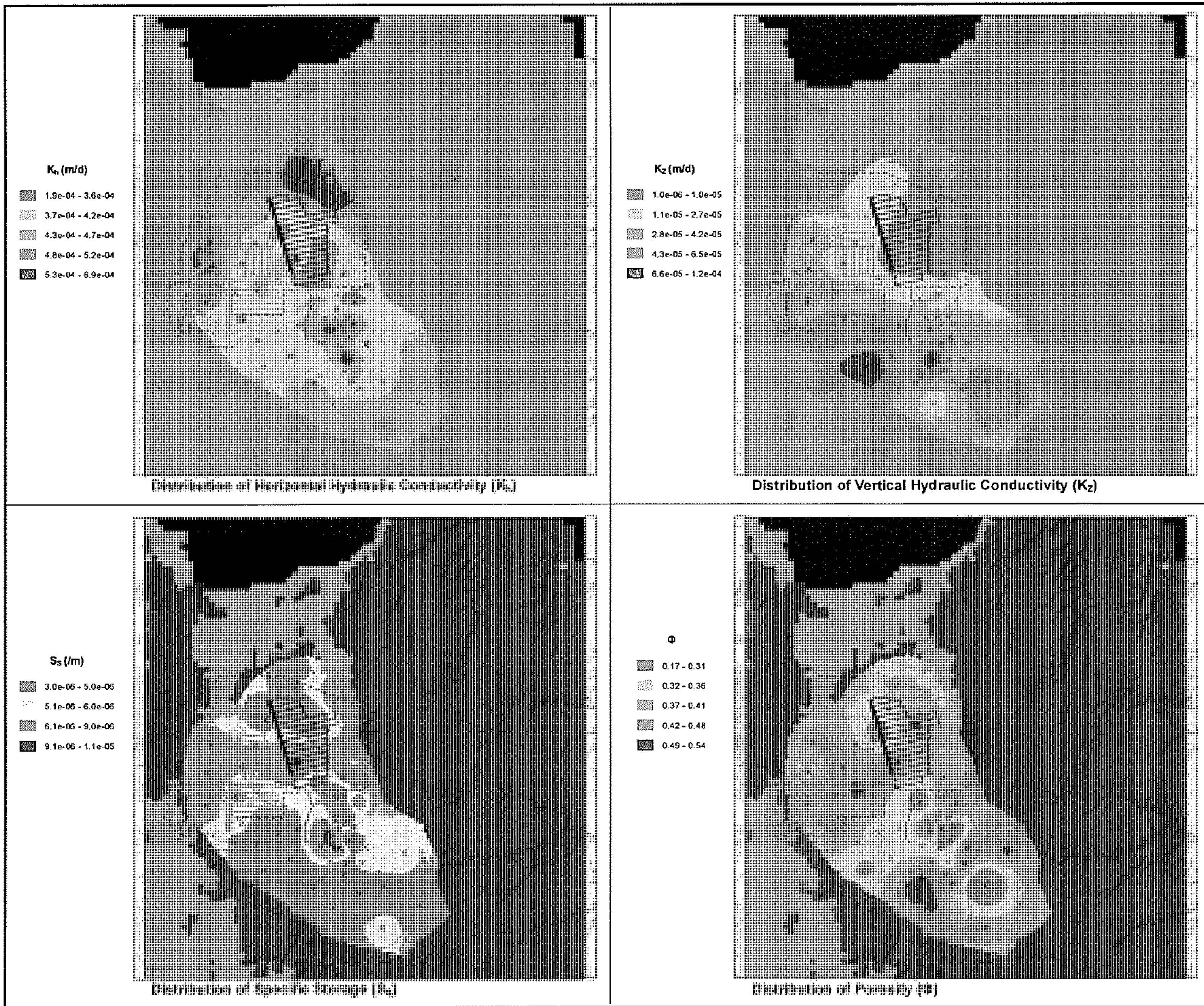
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 20) - Angus Place 1000 Panel Area

FIGURE: E.2.20b

File Name N:\Projects\Centennial\Coal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D058a_DistributionOfAquiferProperties_L20_Zoomed.mxd



Legend:

- × Pilot Points (Layer 21)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	

0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

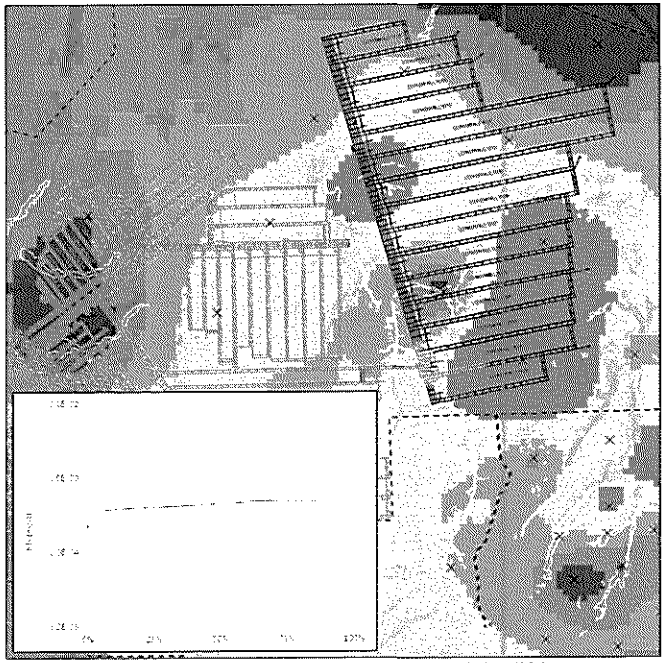
Calibrated Hydraulic Properties (Layer 21)

FIGURE: E.2.21a

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D057_DistributionOfAquiferProperties_L21.mxd
Reference © Department of Finance Services & Innovation 2018

K_h (m/d)

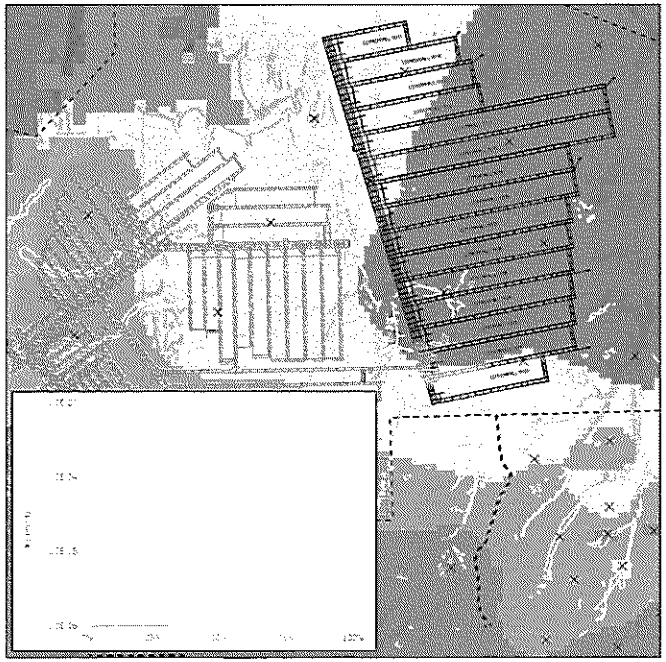
1.9e-04 - 3.6e-04
3.7e-04 - 4.2e-04
4.3e-04 - 4.7e-04
4.8e-04 - 5.2e-04
5.3e-04 - 6.9e-04



Distribution of Horizontal Hydraulic Conductivity (K_h)

K_z (m/d)

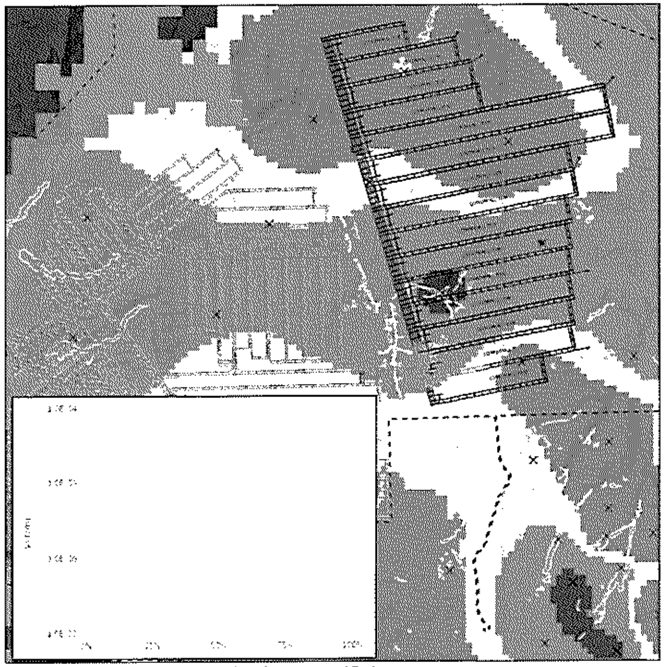
1.0e-06 - 1.0e-05
1.1e-05 - 2.7e-05
2.8e-05 - 4.2e-05
4.3e-05 - 6.5e-05
6.6e-05 - 1.2e-04



Distribution of Vertical Hydraulic Conductivity (K_Z)

S_S (/m)

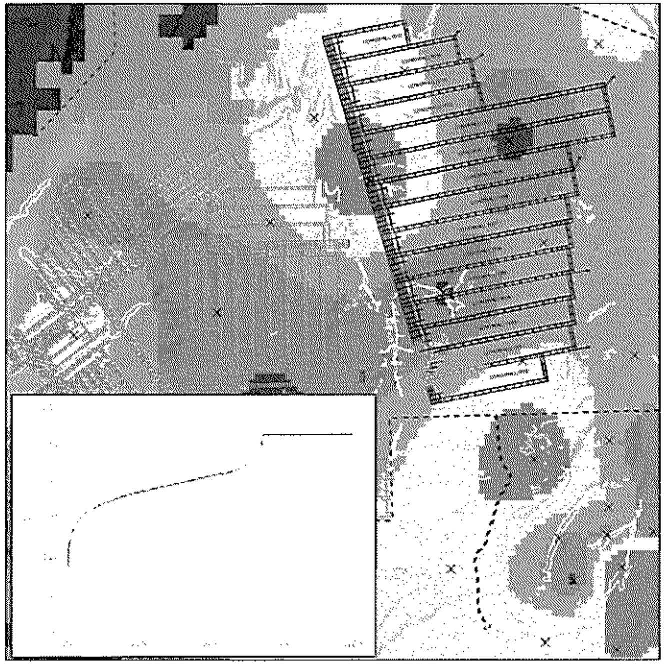
3.0e-06 - 5.0e-06
5.1e-06 - 6.0e-06
6.1e-06 - 9.0e-06
9.1e-06 - 1.1e-05



Distribution of Specific Storage (S_S)

Φ

0.17 - 0.31
0.32 - 0.36
0.37 - 0.41
0.42 - 0.48
0.49 - 0.54



Distribution of Porosity (Φ)

Legend:

× Pilot Points (Layer 21)
Angus Place Project Application Area
Groundwater Model Domain
Proposed Extension
Existing Mine
'Pinched-Out' Cells
No Flow Boundary (NFB) Cells
RPS (2019):
Shrub Swamps
Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	

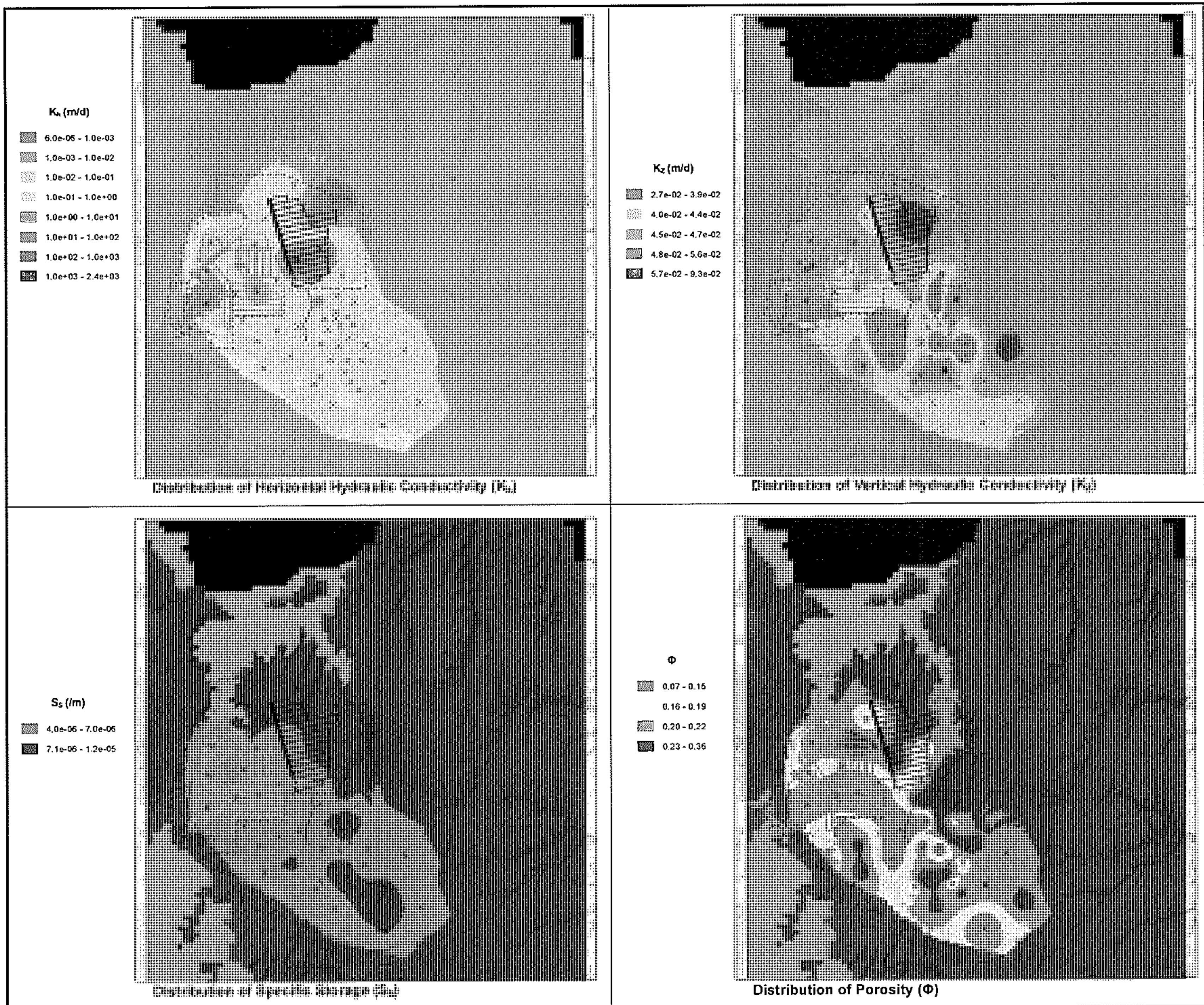
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 21) - Angus Place 1000 Panel Area

FIGURE: E.2.21b

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D057a_DistributionOfAquiferProperties_L21_Zoomed.mxd
Reference: © Department of Finance, Services & Innovation 2018



Legend:

- × Pilot Points (Layer 22)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB

Scale 1:350,000

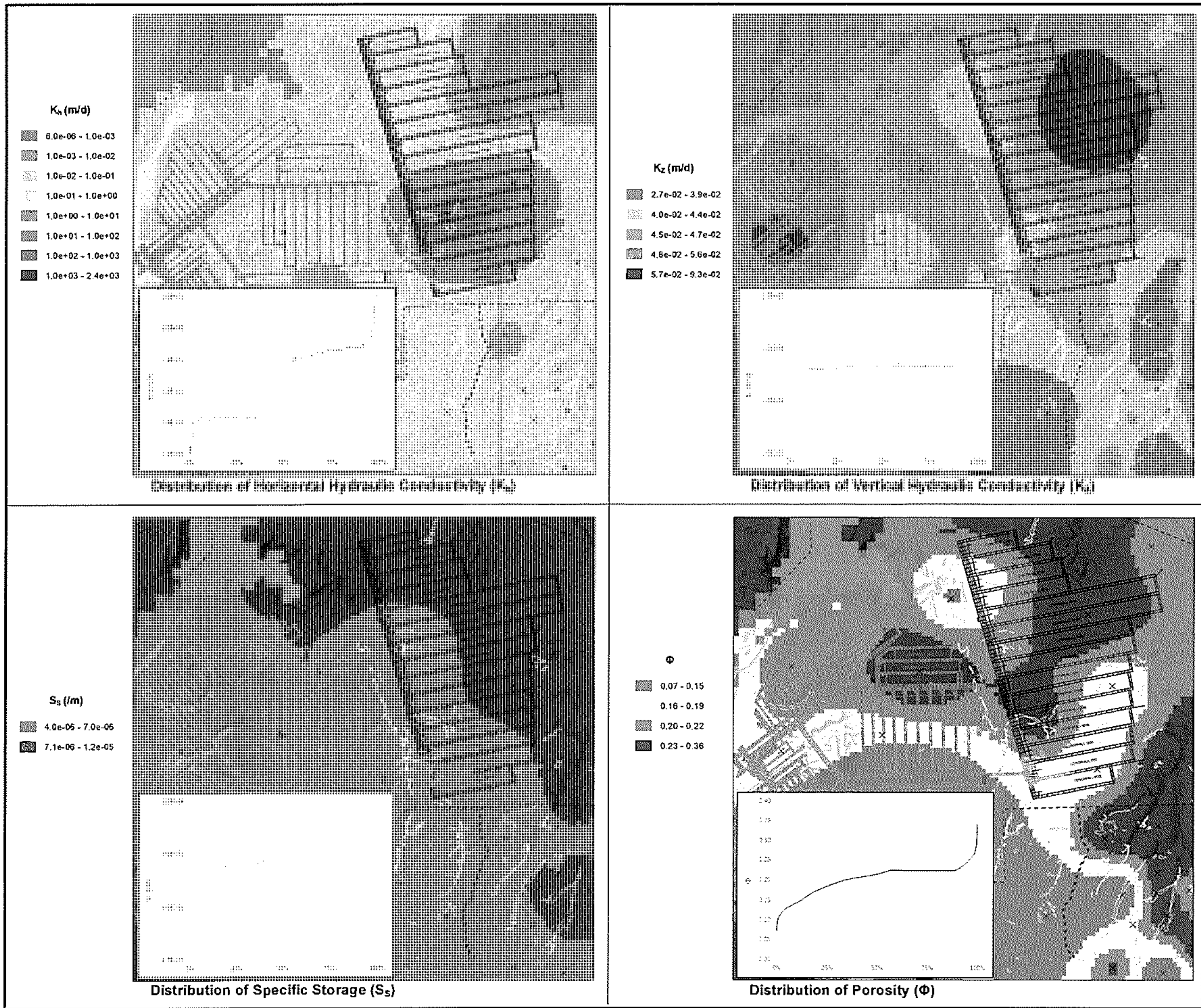
0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 22)

FIGURE: E.2.22a

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D056_DistributionOfAquiferProperties_L22.mxd
Reference: © Department of Finance, Services & Innovation 2018



Legend:

- × Pilot Points (Layer 22)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

RPS (2019):
- Shrub Swamps
- Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	

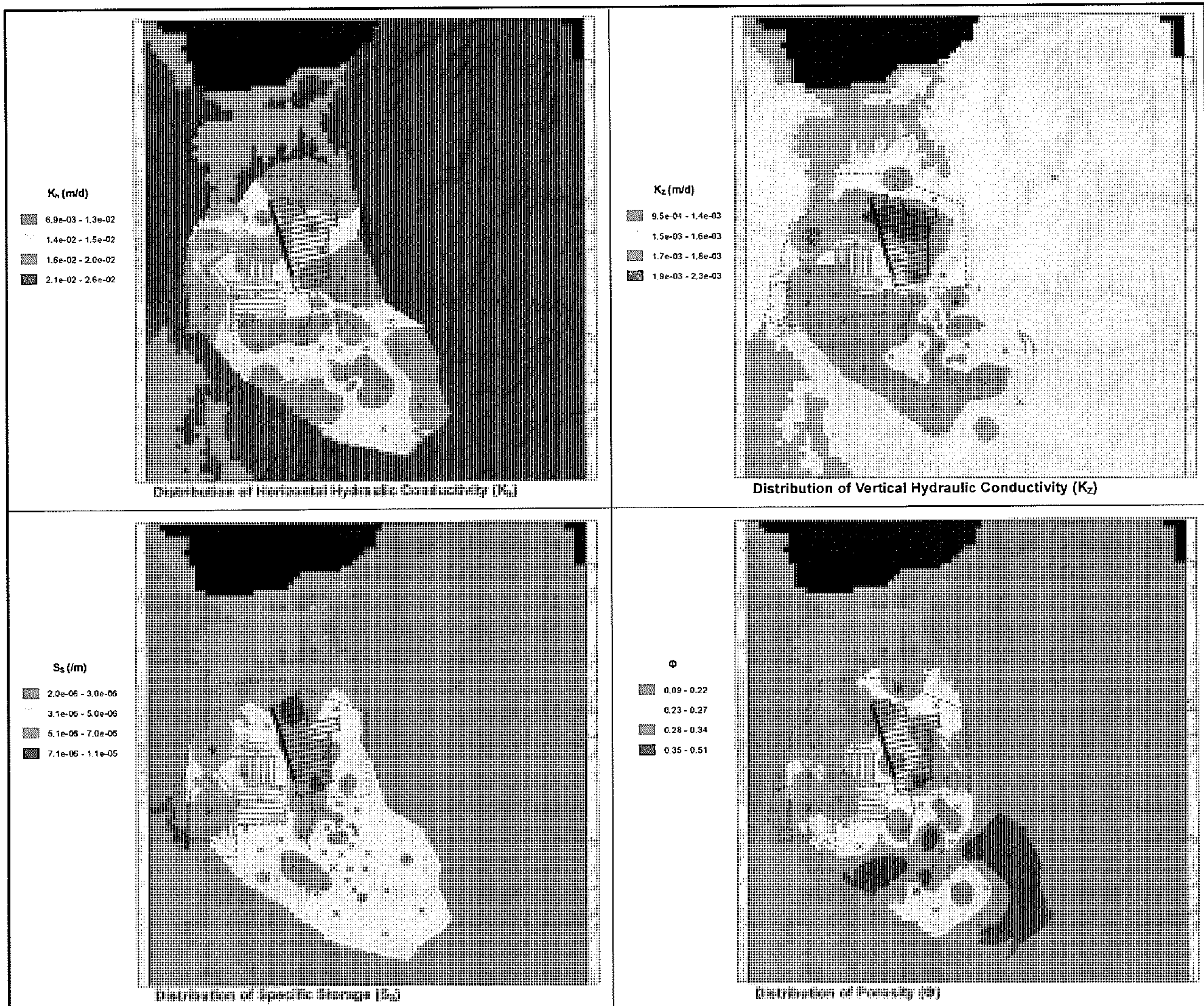
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 22) - Angus Place 1000 Panel Area

FIGURE: E.2.22b

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D056a_DistributionOfAquiferProperties_L22_Zoomed.mxd
Reference © Department of Finance, Services & Innovation 2018



Legend:

- × Pilot Points (Layer 23)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

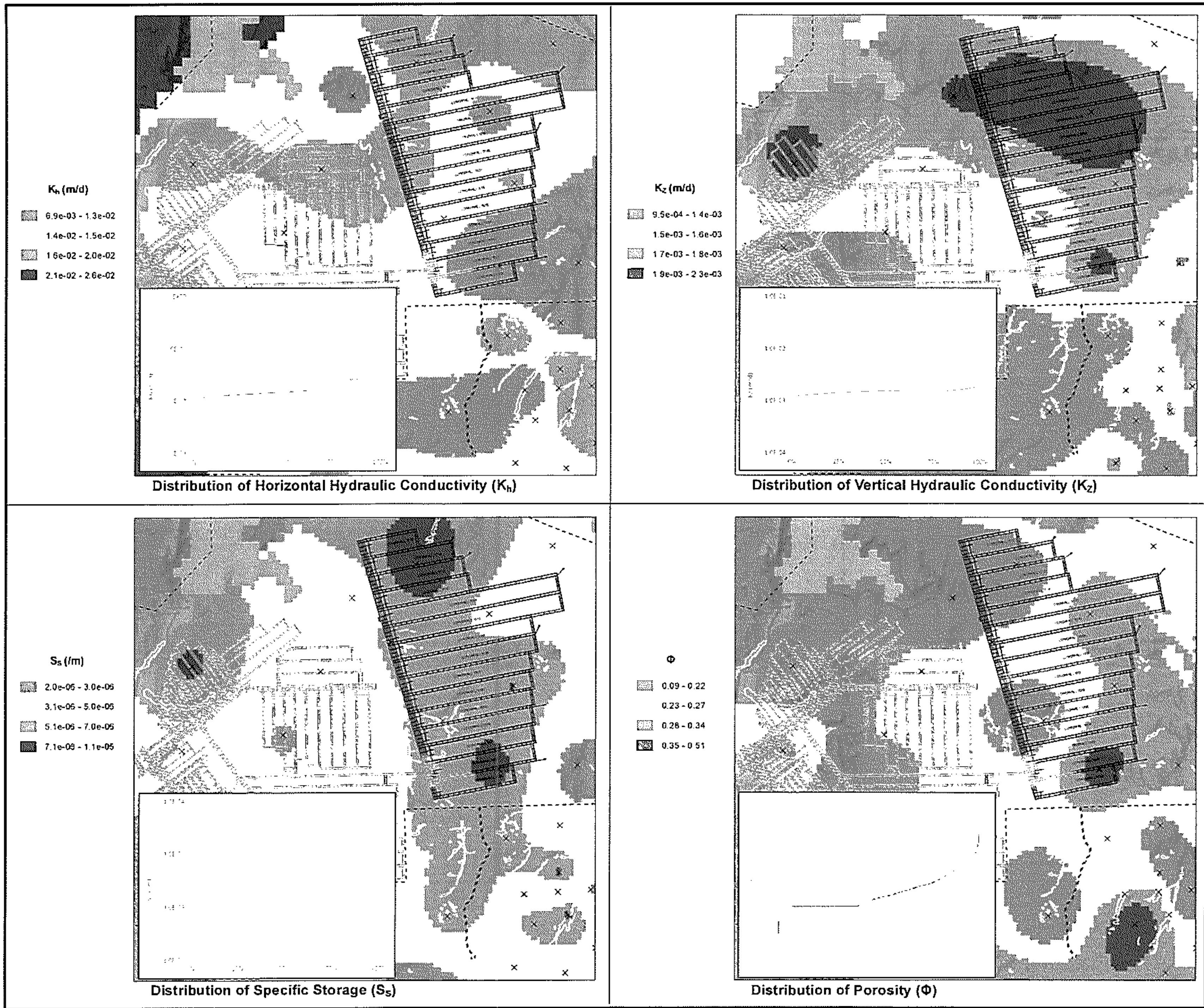
Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	

0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 23)

FIGURE: E.2.23a



Legend:

- × Pilot Points (Layer 23)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

RPS (2019):
- Shrub Swamps
- Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	

0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

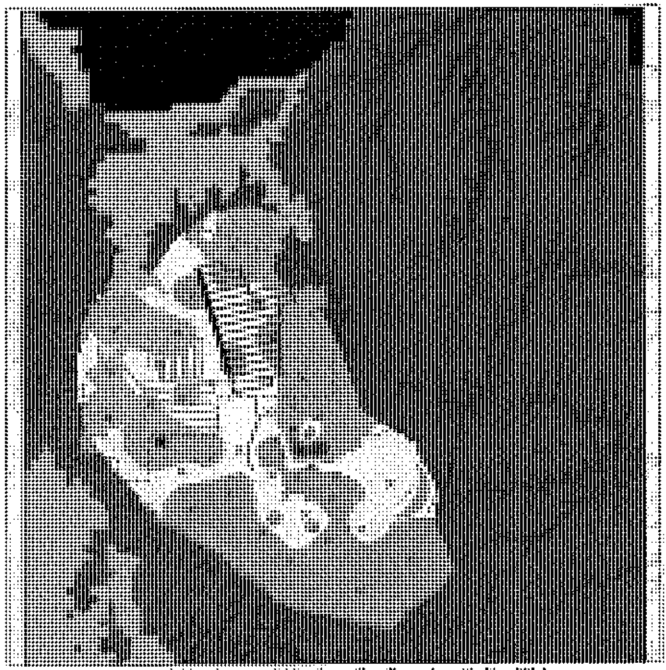
Calibrated Hydraulic Properties (Layer 23) - Angus Place 1000 Panel Area

FIGURE: E.2.23b

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D055a_DistributionOfAquiferProperties_L23_Zoomed.mxd
Reference: © Department of Finance, Services & Innovation 2018

K_h (m/d)

- 1.4e-02 - 1.8e-02
- 1.9e-02 - 2.0e-02
- 2.1e-02 - 2.4e-02
- 2.5e-02 - 3.2e-02



Distribution of Horizontal Hydraulic Conductivity (K_h)

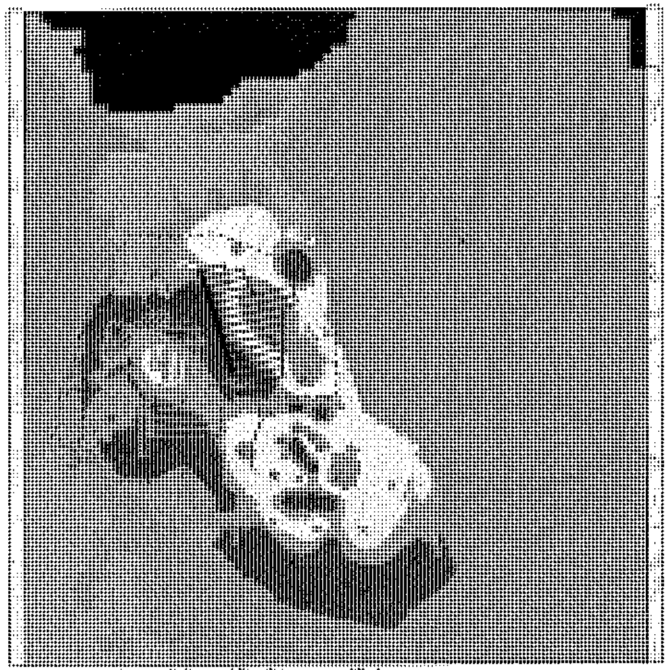
K_z (m/d)

- 2.4e-03 - 4.1e-03
- 4.2e-03 - 7.0e-03
- 7.1e-03 - 1.3e-02
- 1.4e-02 - 2.7e-02

Distribution of Vertical Hydraulic Conductivity (K_z)

S_s (/m)

- 4.0e-06 - 7.0e-06
- 7.1e-06 - 9.0e-06
- 9.1e-06 - 1.0e-05
- 1.1e-05 - 1.3e-05



Distribution of Specific Storage (S_s)

Φ

- 0.10 - 0.18
- 0.19 - 0.21
- 0.22 - 0.26
- 0.27 - 0.32
- 0.33 - 0.48

Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 24)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1 | Date: 18-Oct-2019

Drawn By: JZ | Checked By: JB

Scale 1:350,000

0 5 10 km

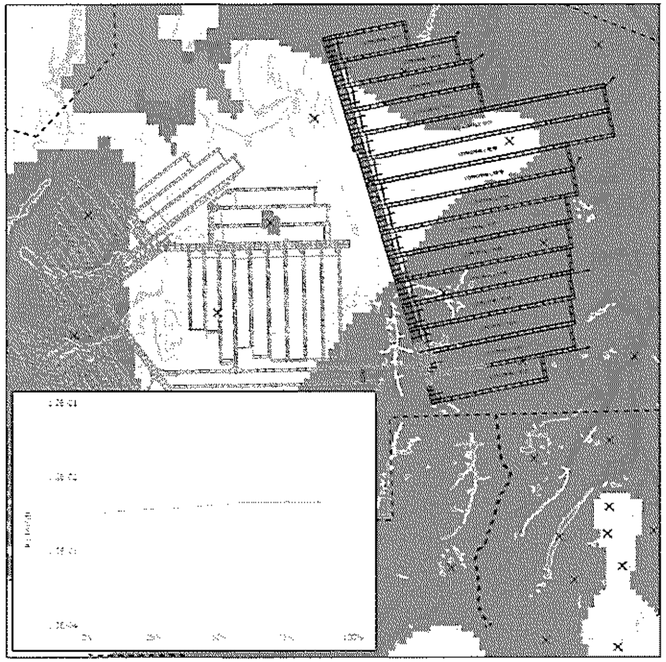
Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 24)

FIGURE: E.2.24a

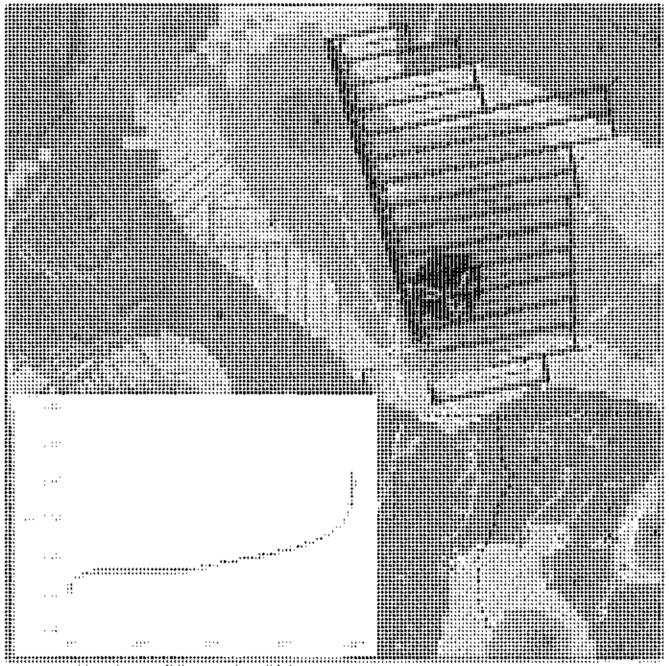
File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D054_DistributionOfAquiferProperties_L24.mxd
Reference © Department of Finance Services & Innovation 2018

Distribution of Horizontal Hydraulic Conductivity (K_h)



Distribution of Vertical Hydraulic Conductivity (K_Z)

Distribution of Specific Storage (S_S)



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 24)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells
- RPS (2019):
  - Shrub Swamps
  - Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	

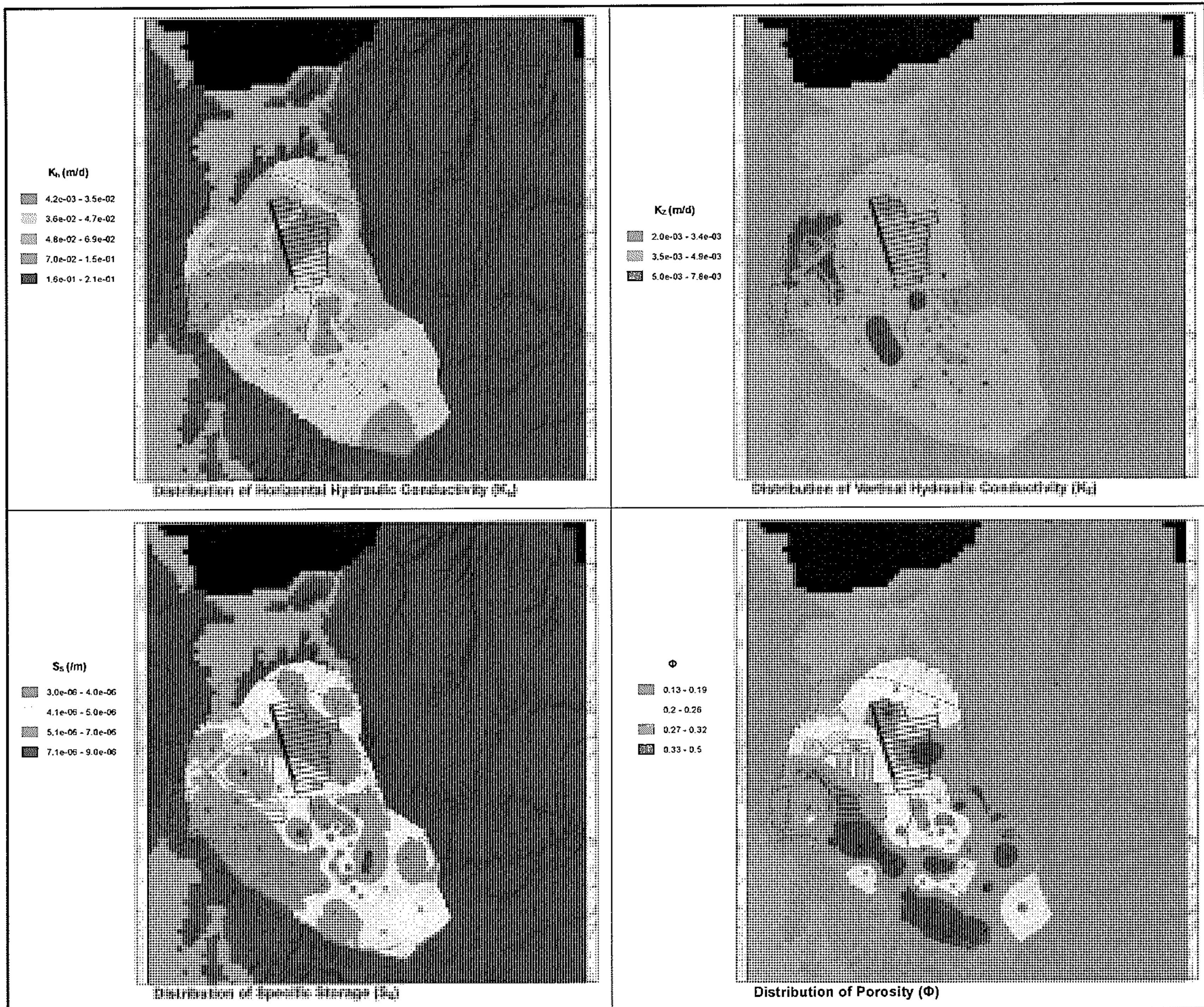
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 24) - Angus Place 1000 Panel Area

FIGURE: E.2.24b

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D054a_DistributionOfAquiferProperties_L24_Zoomed.mxd
Reference © Department of Finance Services & Innovation 2018



Legend:

- × Pilot Points (Layer 25)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

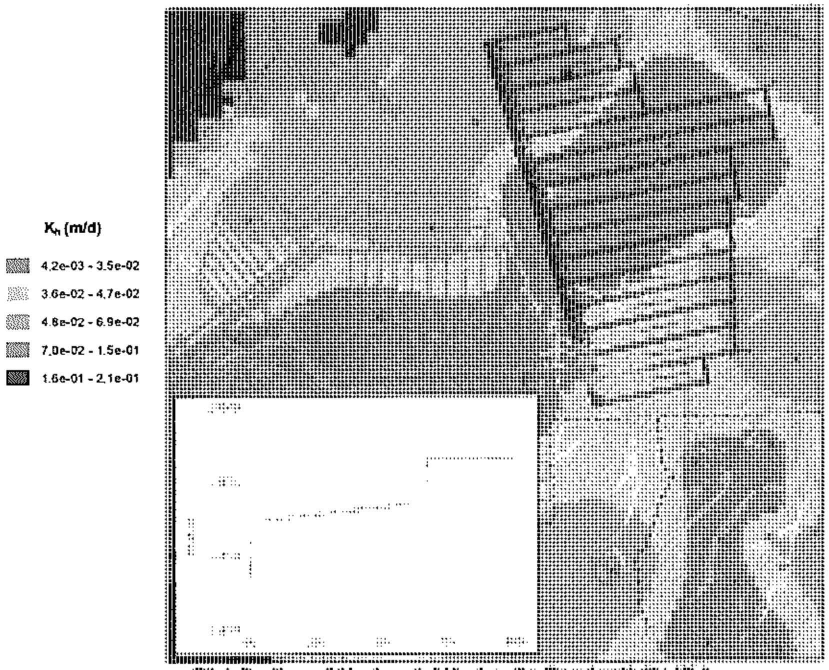
JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	
0 5 10 km	
Coor. Sys. GDA 1994 MGA Zone 56	

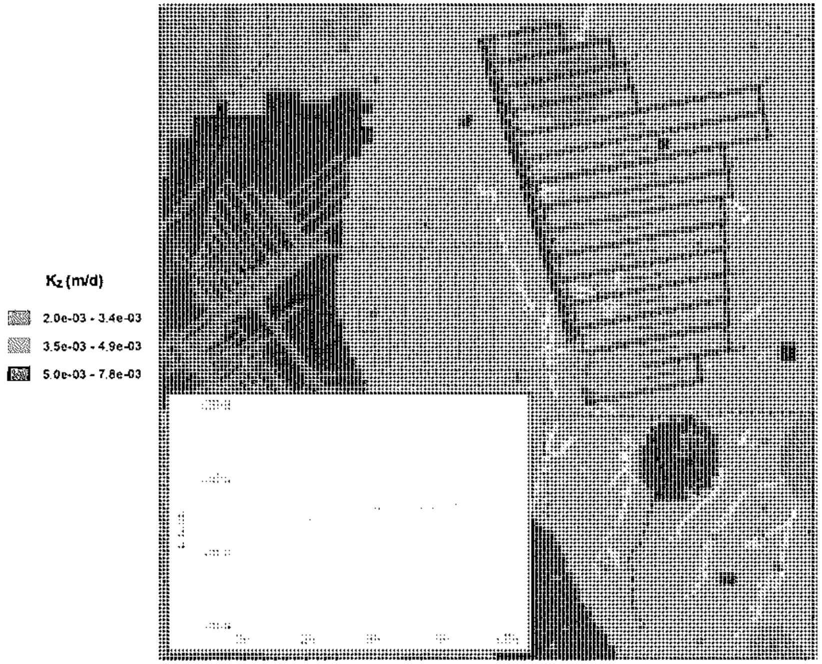
Calibrated Hydraulic Properties (Layer 25)

FIGURE: E.2.25a

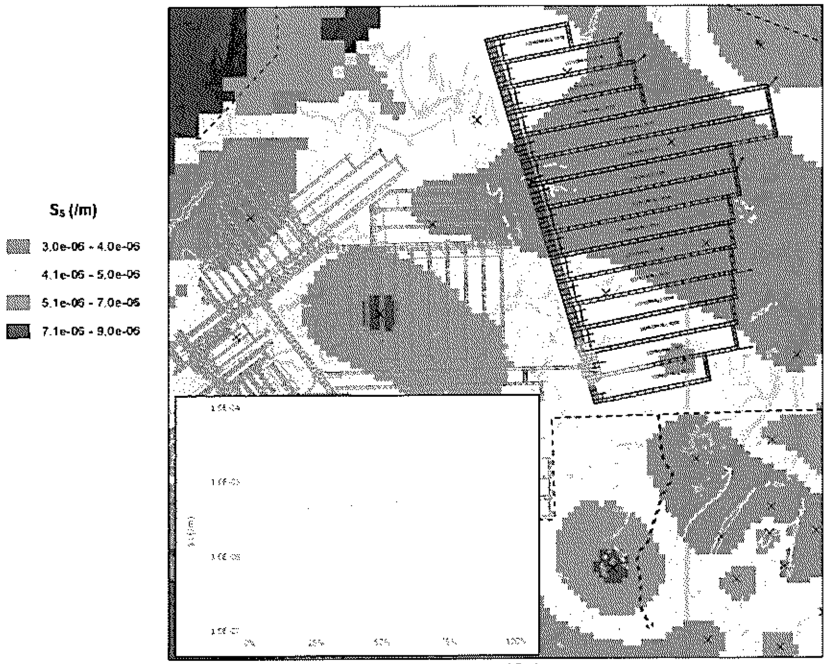
File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D078_DistributionOfAquiferProperties_L25.mxd
Reference © Department of Finance Services & Innovation 2018



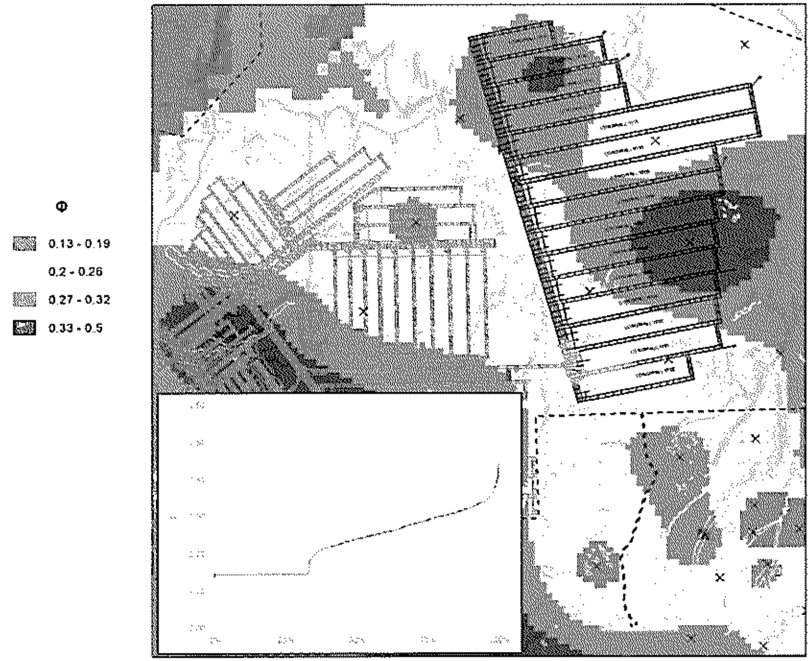
Distribution of Horizontal Hydraulic Conductivity (K_h)



Distribution of Vertical Hydraulic Conductivity (K_Z)



Distribution of Specific Storage (S_S)



Distribution of Porosity (Φ)

Legend:

× Pilot Points (Layer 25)
Angus Place Project Application Area
Groundwater Model Domain
Proposed Extension
Existing Mine
'Pinched-Out' Cells
No Flow Boundary (NFB) Cells
RPS (2019):
Shrub Swamps
Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB

Scale 1:120,000

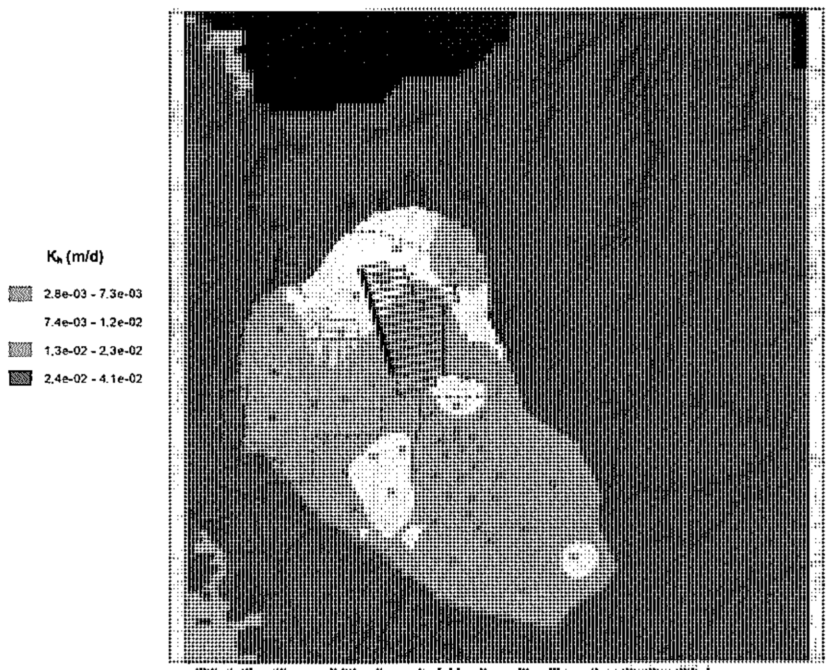
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

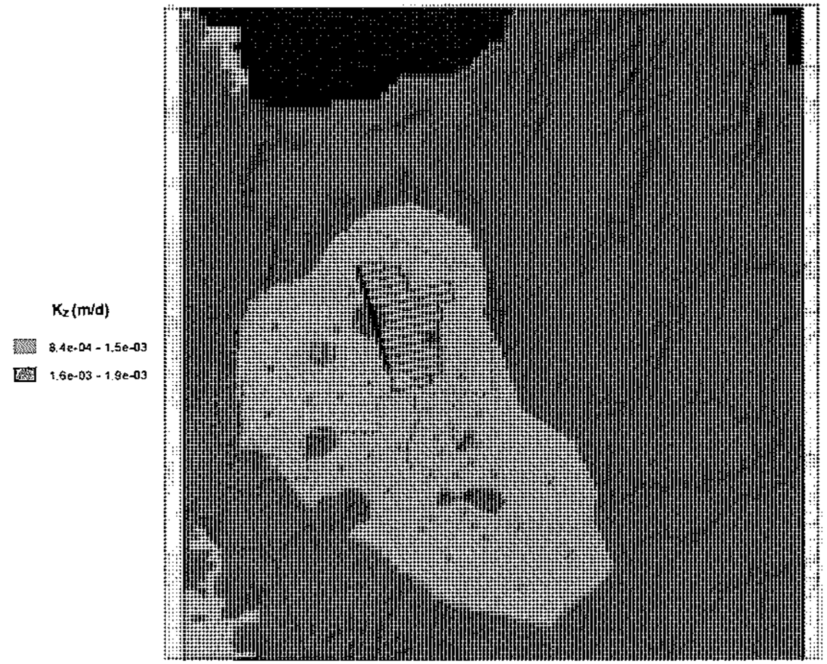
Calibrated Hydraulic Properties (Layer 25) - Angus Place 1000 Panel Area

FIGURE: E.2.25b

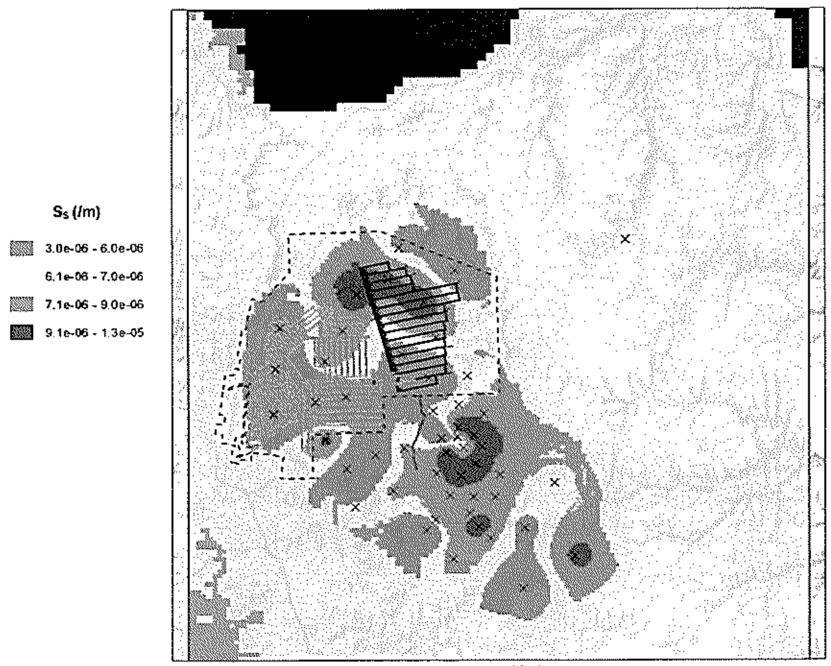
File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D078a_DistributionOfAquiferProperties_L25_Zoomed.mxd



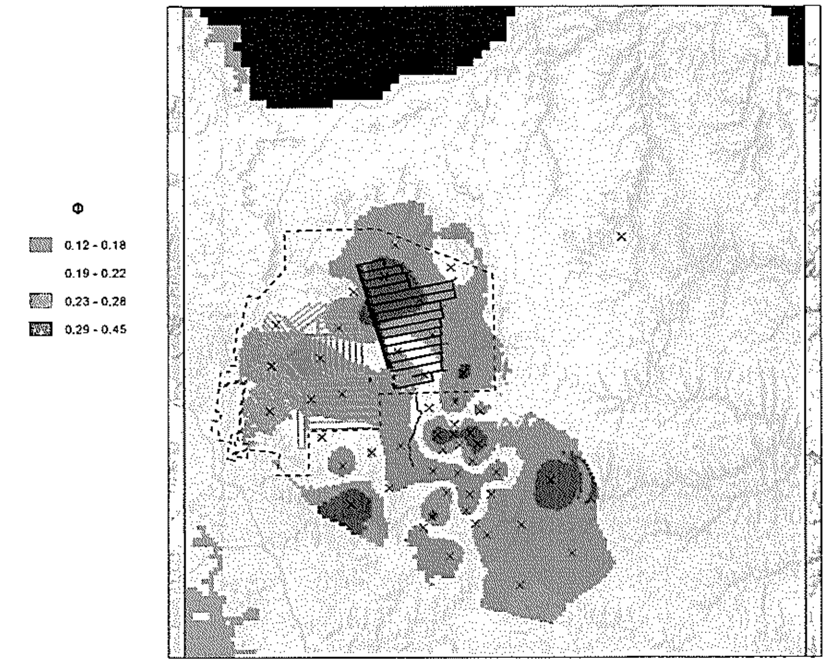
Distribution of Horizontal Hydraulic Conductivity (K_h)



Distribution of Vertical Hydraulic Conductivity (K_Z)



Distribution of Specific Storage (S_S)



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 26)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	
0 5 10 km	
Coor. Sys. GDA 1994 MGA Zone 56	

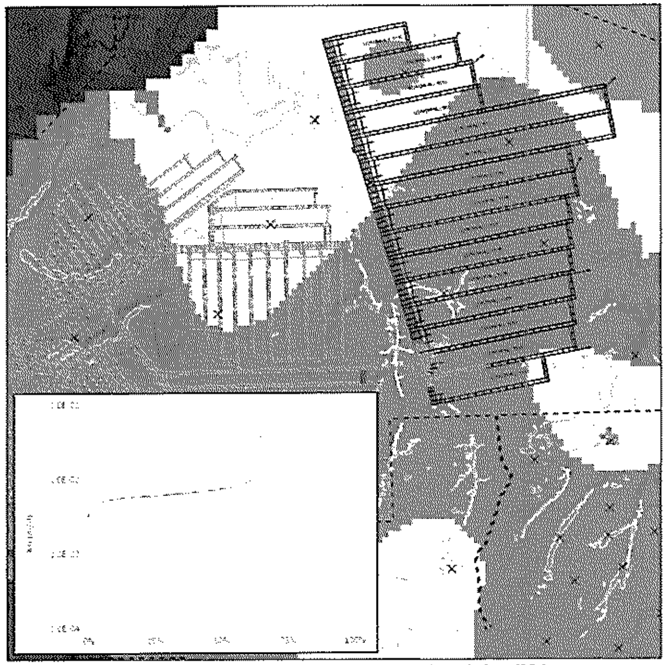
Calibrated Hydraulic Properties (Layer 26)

FIGURE: E.2.26a

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D079_DistributionOfAquiferProperties_L25.mxd
Reference © Department of Finance, Services & Innovation 2018

K_h (m/d)

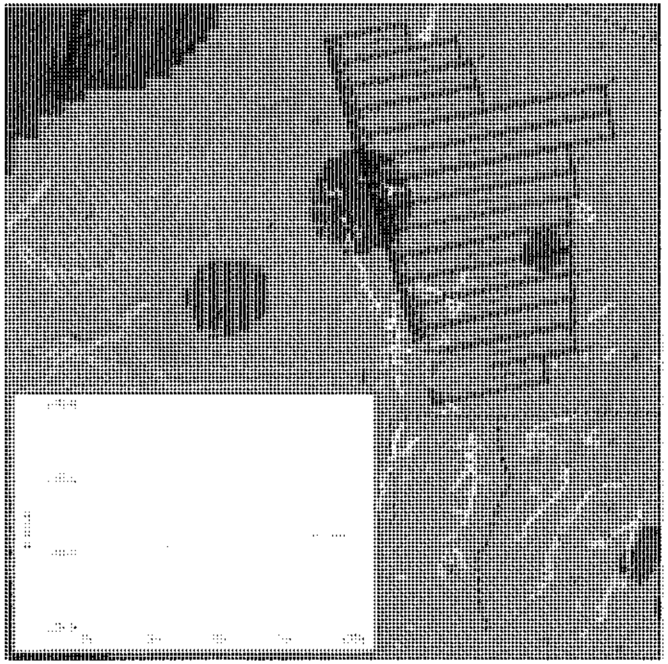
- 2.8e-03 - 7.3e-03
- 7.4e-03 - 1.2e-02
- 1.3e-02 - 2.3e-02
- 2.4e-02 - 4.1e-02



Distribution of Horizontal Hydraulic Conductivity (K_h)

K_z (m/d)

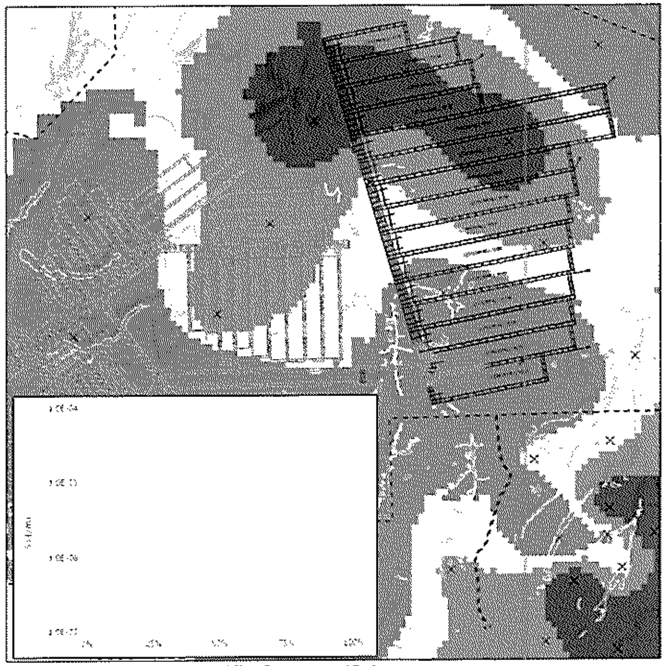
- 8.4e-04 - 1.5e-03
- 1.6e-03 - 1.9e-03



Distribution of Vertical Hydraulic Conductivity (K_Z)

S_S (/m)

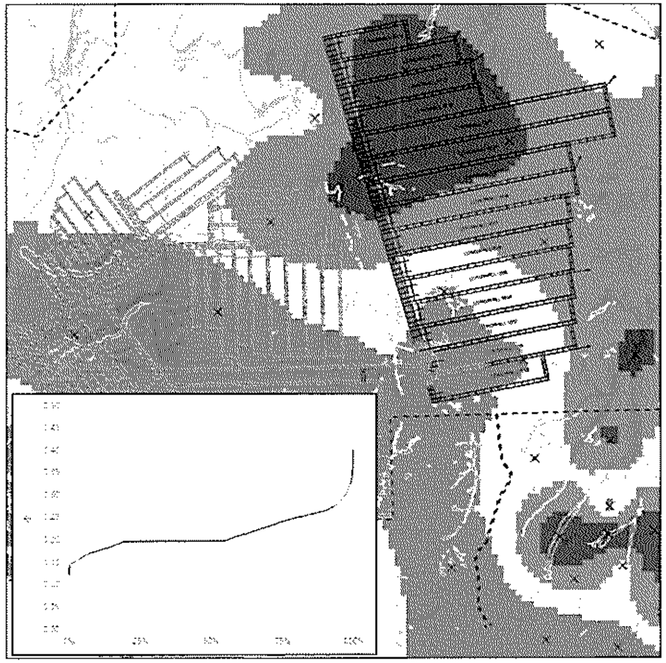
- 3.0e-06 - 6.0e-06
- 6.1e-06 - 7.0e-06
- 7.1e-06 - 9.0e-06
- 9.1e-06 - 1.3e-05



Distribution of Specific Storage (S_S)

Φ

- 0.12 - 0.18
- 0.19 - 0.22
- 0.23 - 0.28
- 0.29 - 0.45



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 26)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

RPS (2019):

- Shrub Swamps
- Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB

Scale 1:120,000

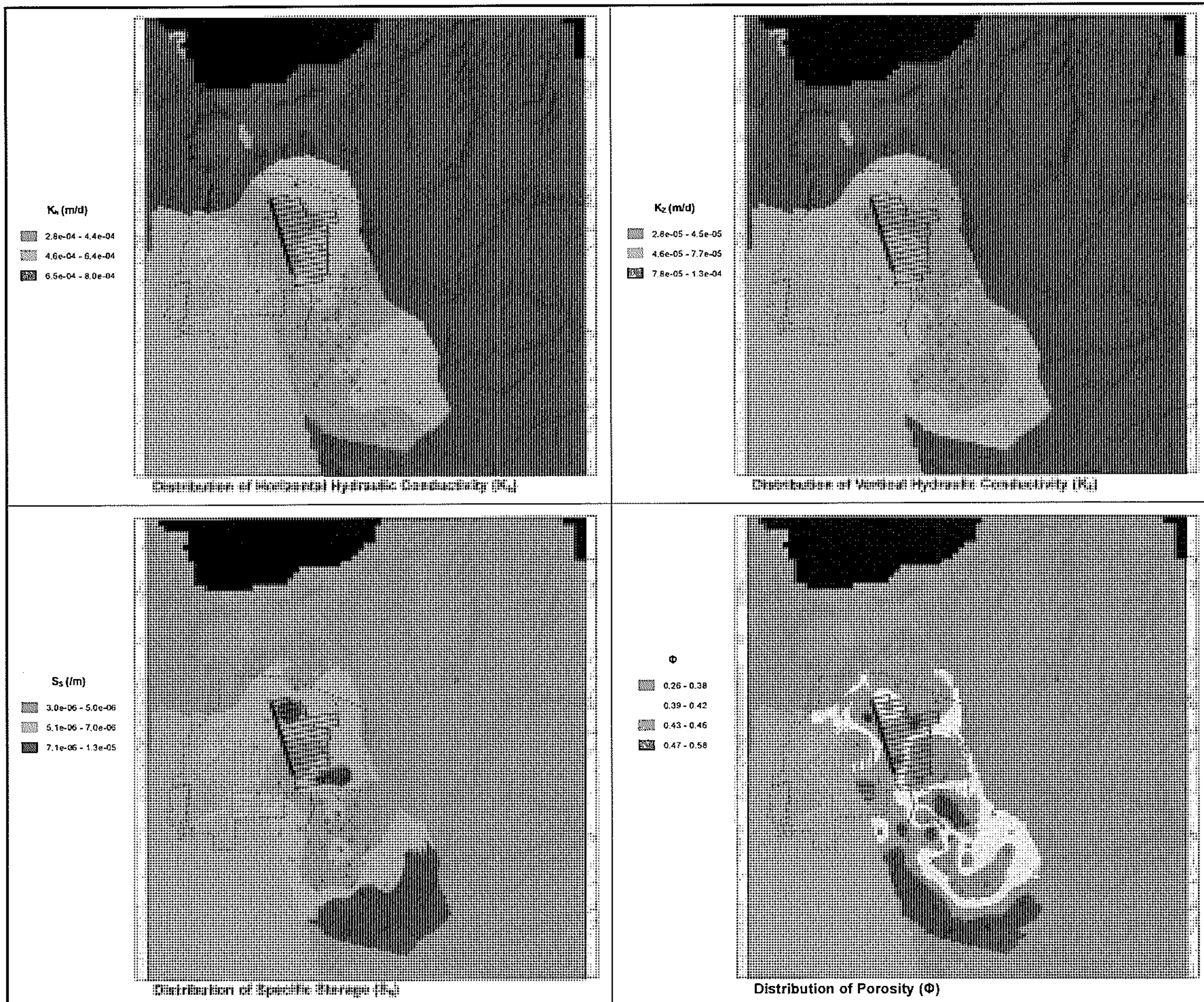
0 1.5 3
km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 26) - Angus Place 1000 Panel Area

FIGURE: E.2.26b

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D079a_DistributionOfAquiferProperties_L26_Zoomed.mxd
Reference: © Department of Finance, Services & Innovation 2018



Legend:

- × Pilot Points (Layer 27)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	

0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

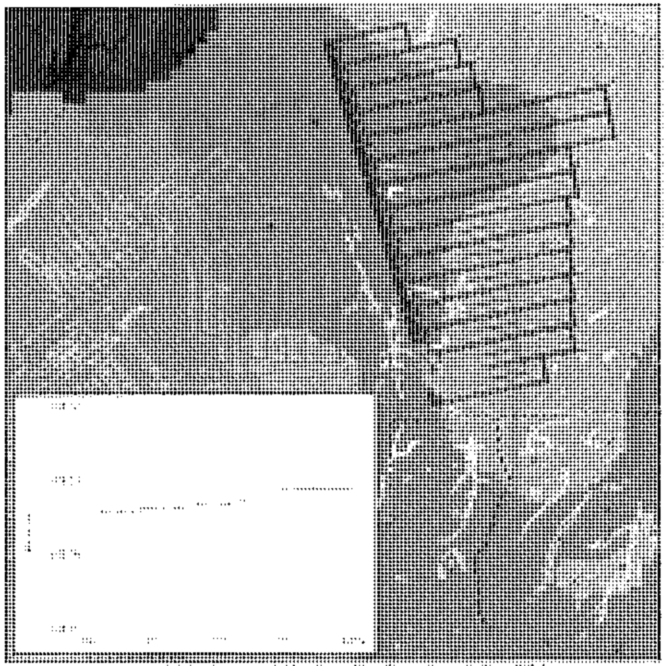
Calibrated Hydraulic Properties (Layer 27)

FIGURE: E.2.27a

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D080_DistributionOfAquiferProperties_L27.mxd
Reference © Department of Finance Services & Innovation 2018

K_h (m/d)

- 2.8e-04 - 4.4e-04
- 4.6e-04 - 6.4e-04
- 6.5e-04 - 8.0e-04



Distribution of Horizontal Hydraulic Conductivity (K_h)

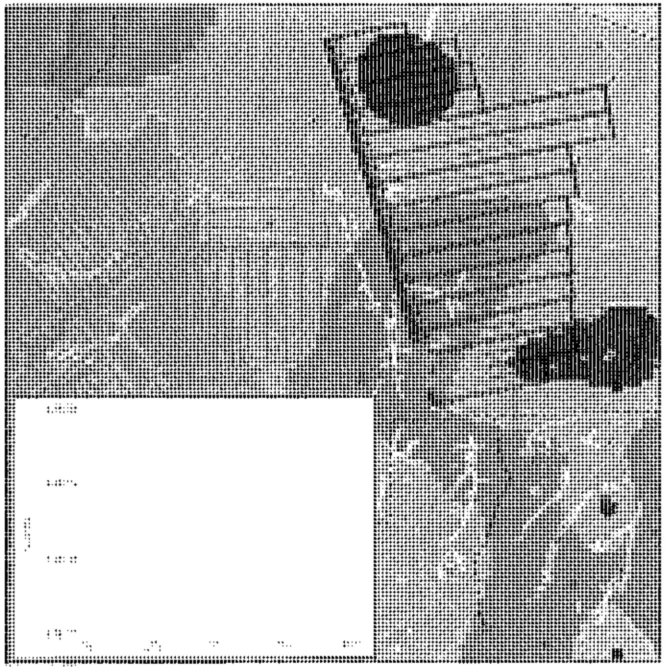
K_z (m/d)

- 2.8e-05 - 4.5e-05
- 4.6e-05 - 7.7e-05
- 7.8e-05 - 1.3e-04

Distribution of Vertical Hydraulic Conductivity (K_z)

S_s (/m)

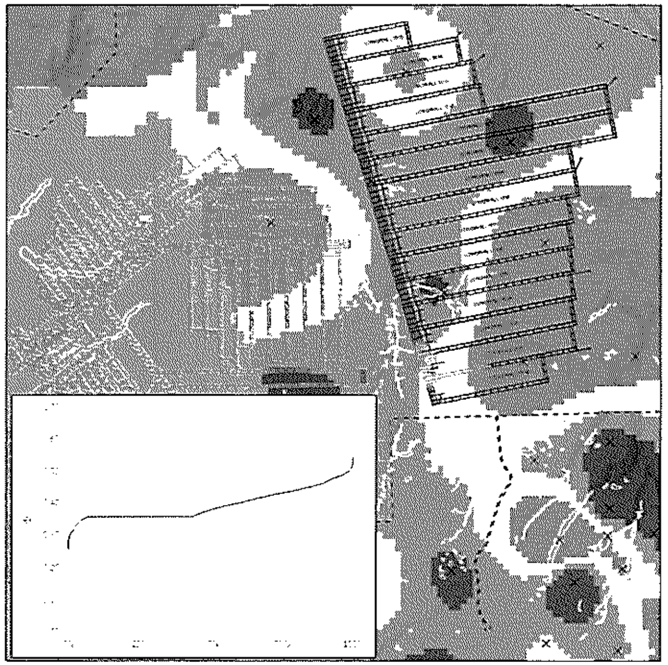
- 3.0e-06 - 5.0e-06
- 5.1e-06 - 7.0e-06
- 7.1e-06 - 1.3e-05



Distribution of Specific Storage (S_s)

Φ

- 0.26 - 0.38
- 0.39 - 0.42
- 0.43 - 0.46
- 0.47 - 0.58



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 27)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

RPS (2019):

- Shrub Swamps
- Hanging Swamps

Note: 1) Charts are cumulative distribution function of all cell values in a layer

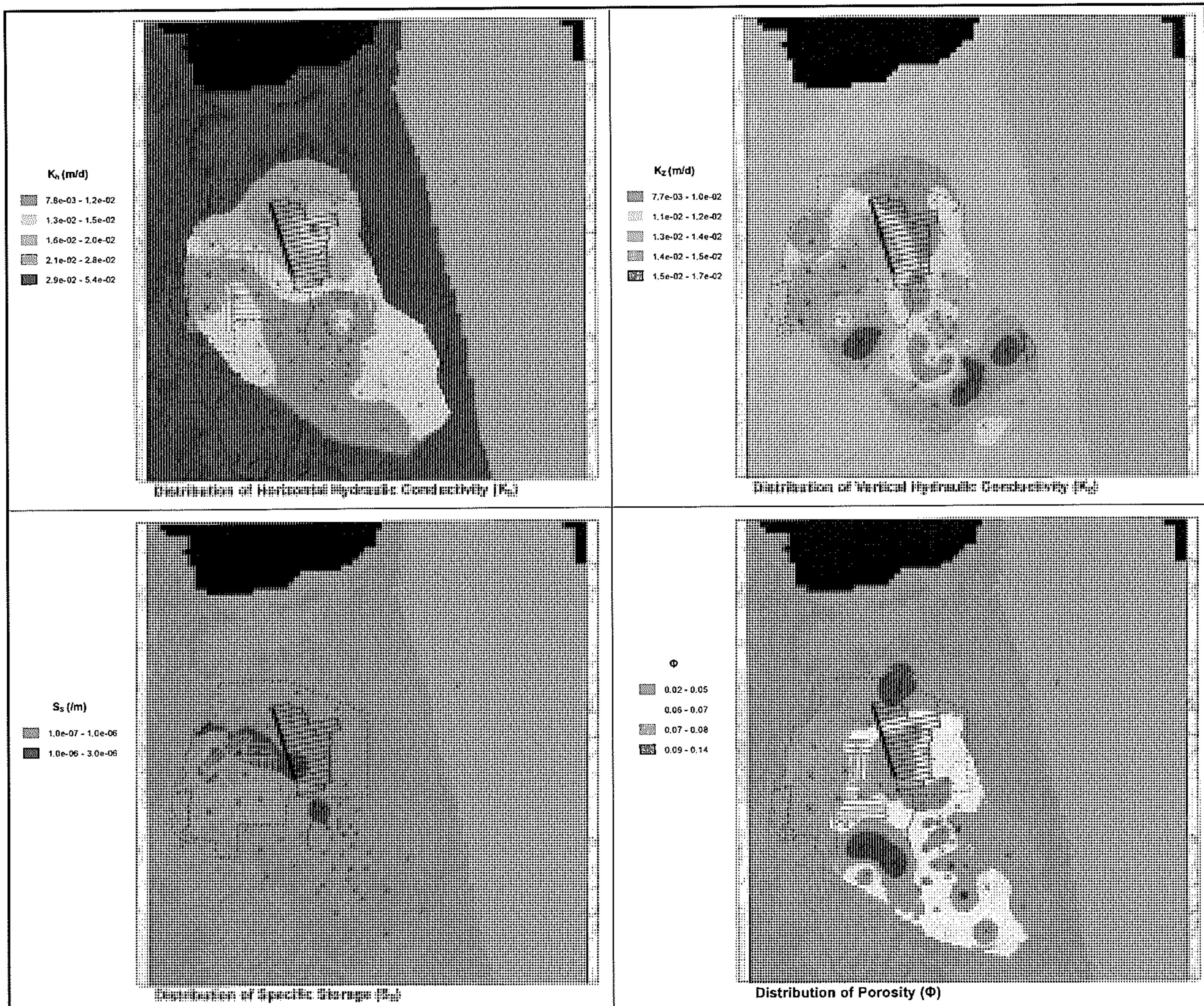
JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:120,000	
0 1.5 3 km	
Coor. Sys. GDA 1994 MGA Zone 56	

Calibrated Hydraulic Properties (Layer 27) - Angus Place 1000 Panel Area

FIGURE: E.2.27b

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D080a_DistributionOfAquiferProperties_L27_Zoomed.mxd
Reference: © Department of Finance, Services & Innovation 2018



Legend:

- × Pilot Points (Layer 28)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells

JBS&G

Job No: 56421	
Client: Centennial Angus Place Pty Ltd	
Version: R02Rev1	Date: 18-Oct-2019
Drawn By: JZ	Checked By: JB
Scale 1:350,000	

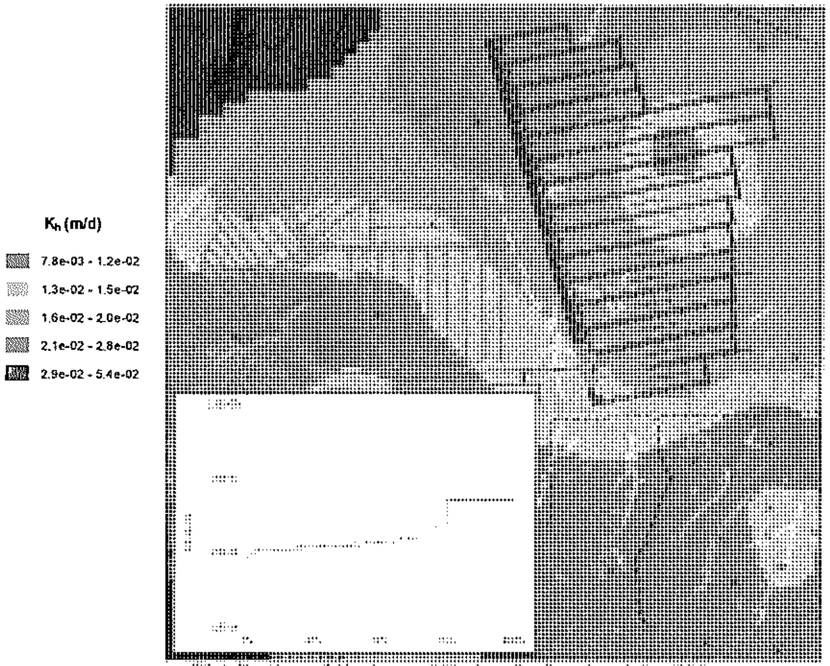
0 5 10
km

Coor. Sys. GDA 1994 MGA Zone 56

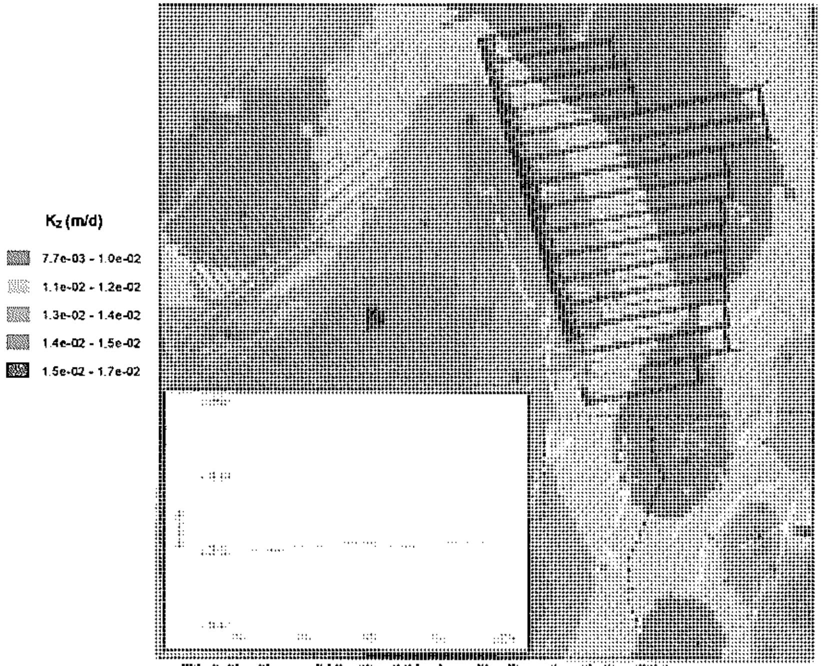
Calibrated Hydraulic Properties (Layer 28)

FIGURE: E.2.28a

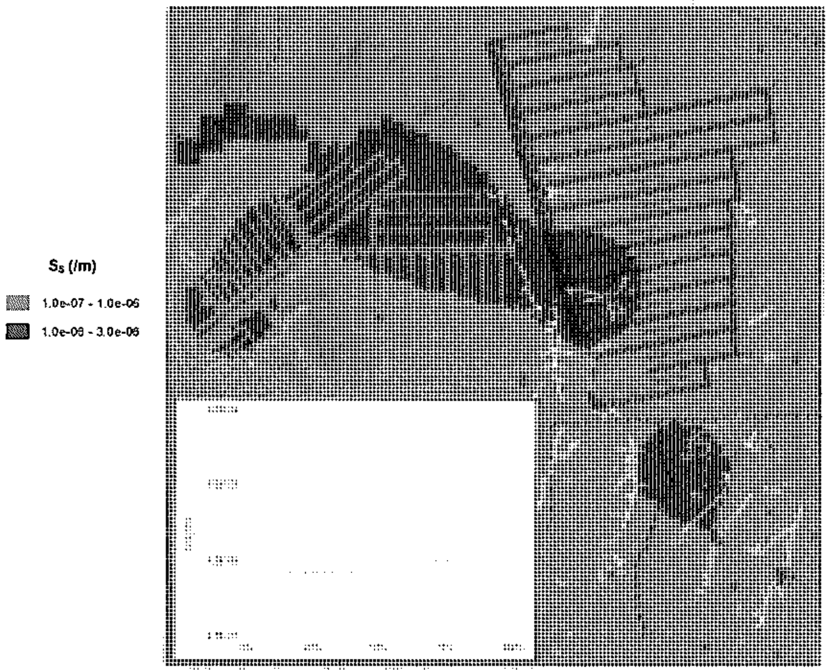
File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D081_DistributionOfAquiferProperties_L28.mxd
Reference © Department of Finance Services & Innovation 2018



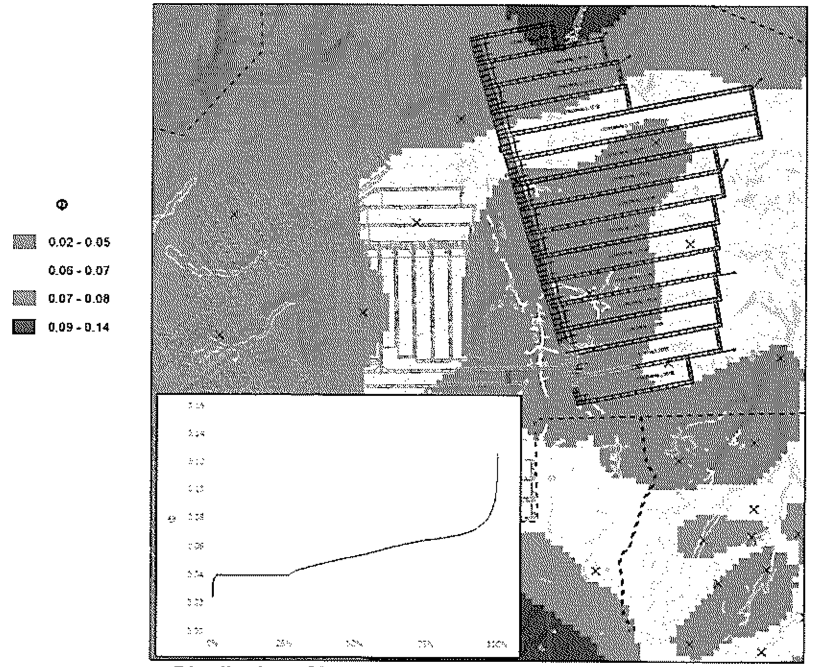
Distribution of Horizontal Hydraulic Conductivity (K_h)



Distribution of Vertical Hydraulic Conductivity (K_z)



Distribution of Specific Storage (S_s)



Distribution of Porosity (Φ)

Legend:

- × Pilot Points (Layer 28)
- Angus Place Project Application Area
- Groundwater Model Domain
- Proposed Extension
- Existing Mine
- 'Pinched-Out' Cells
- No Flow Boundary (NFB) Cells
- RPS (2019):
  - Shrub Swamps
  - Hanging Swamps

Note 1) Charts are cumulative distribution function of all cell values in a layer.

JBS&G

Job No: 56421

Client: Centennial Angus Place Pty Ltd

Version: R02Rev1 | Date: 18-Oct-2019

Drawn By: JZ | Checked By: JB

Scale 1:120,000

0 1.5 3 km

Coor. Sys. GDA 1994 MGA Zone 56

Calibrated Hydraulic Properties (Layer 28) - Angus Place 1000 Panel Area

FIGURE: E.2.28b

File Name N:\Projects\CentennialCoal\AngusPlaceColliery\56421_AngusPlaceMineExtensionProject\Figures\GIS\Delivery\Maps\R02Rev1_GW\R02Rev1_D081a_DistributionOfAquiferProperties_L28_Zoomed.mxd
Reference © Department of Finance, Services & Innovation 2018

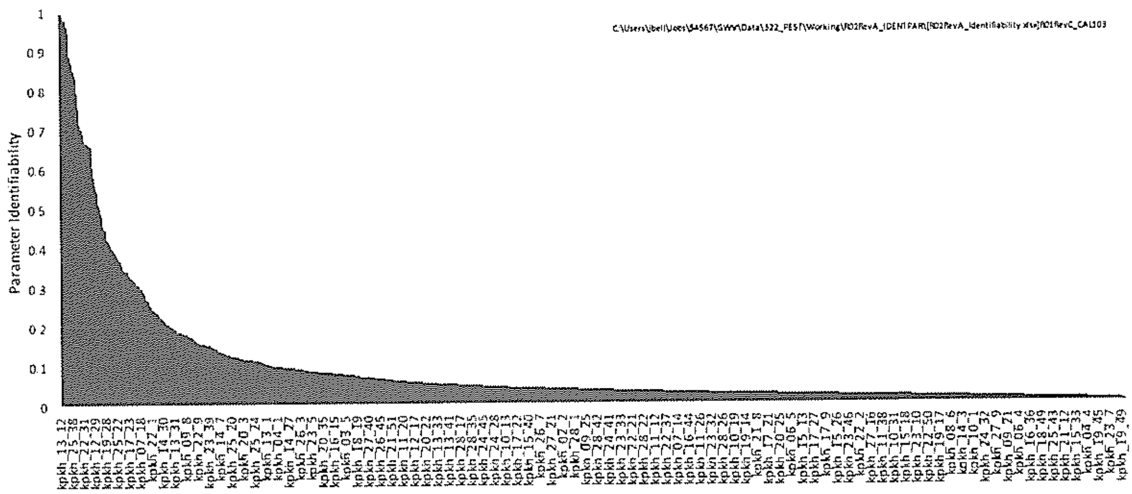
Appendix F Parameter Identifiability Output

This appendix presents further detail to that presented in **Section 4.13,** insofar as analysis of various groups of parameters individually, rather than collectively.

F1. Horizontal Hydraulic Conductivity

Figure F.1 presents the identifiability of horizontal hydraulic conductivity Pilot Points. In **Figure F.1**, the uppermost figure presents all of the available values whereas the lower figure presents the highest values only.

From **Figure F.1**, most of the horizontal hydraulic conductivity Pilot Points are relatively insensitive, namely have an identifiability of less than 0.3. From **Figure F.1**, of the most sensitive parameters most are associated with model layer 11 to 13. This is to be expected given that the THPSS, which are the focus of the monitoring program reside in model layer 13 and above.



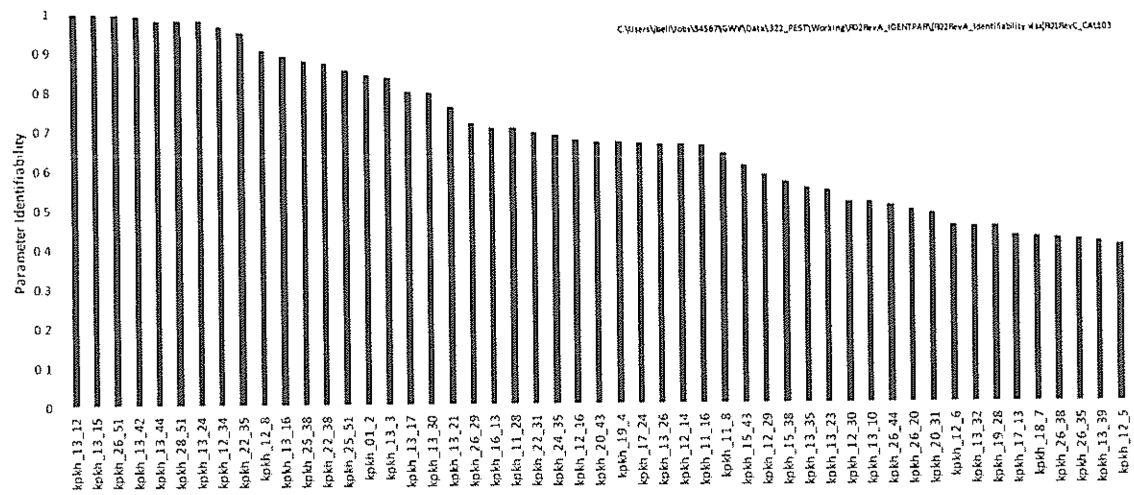
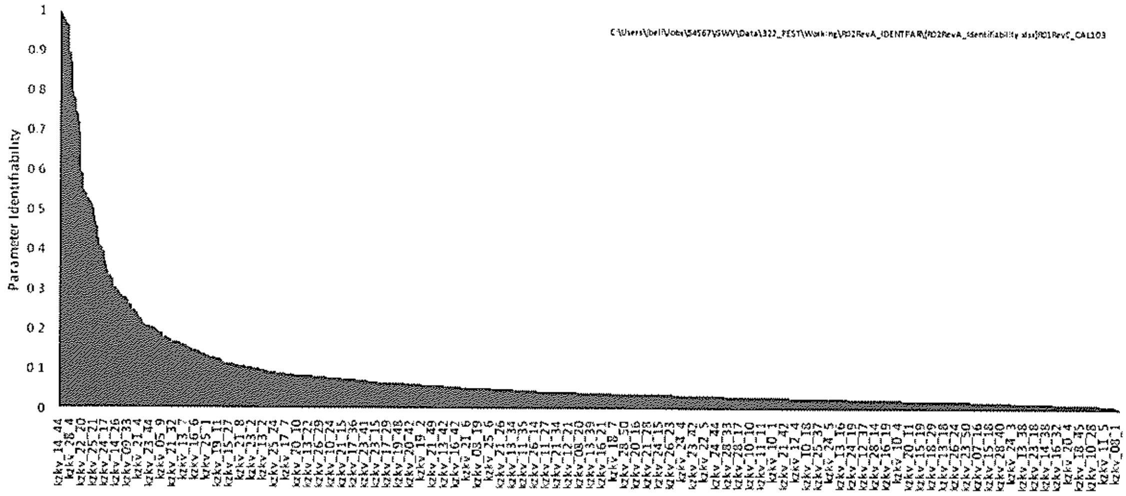


Figure F.1: Parameter Identifiability – Horizontal Hydraulic Conductivity (upper – all values; lower – values greater than 0.4)

F2. Vertical Hydraulic Conductivity

Figure F.2 presents the identifiability of vertical hydraulic conductivity Pilot Points.



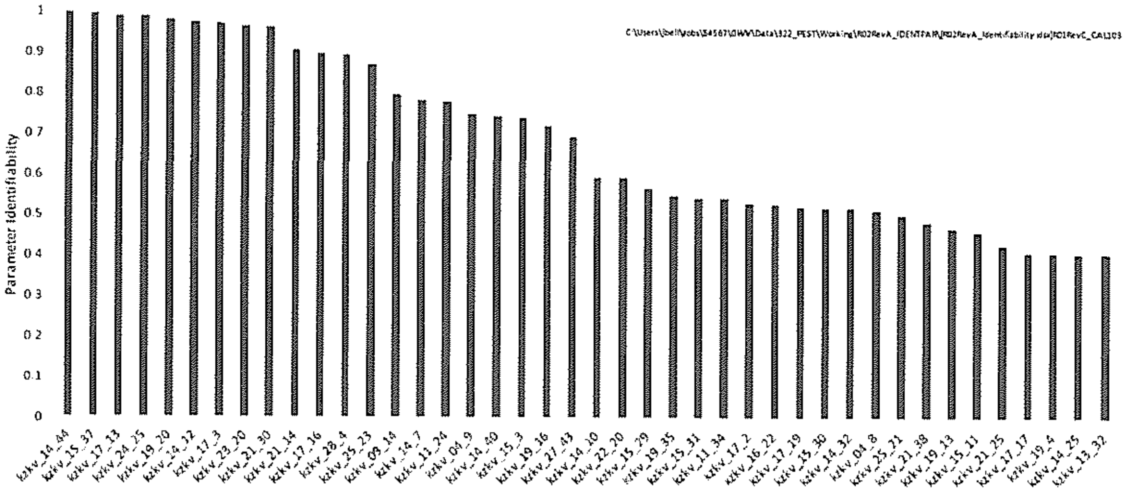


Figure F.2: Parameter Identifiability – Vertical Hydraulic Conductivity (upper – all values; lower – values greater than 0.4)

From **Figure F.2**, the distribution of identifiability for vertical hydraulic conductivity is similar to that of the horizontal hydraulic conductivity Pilot Points, namely that a significant amount of the points are not particularly sensitive.

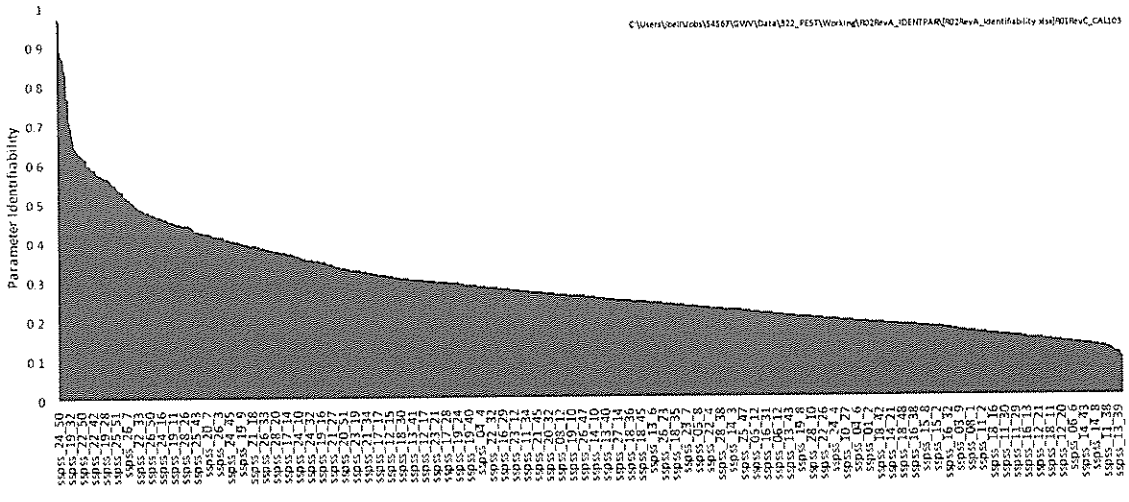
From **Figure F.2**, again there are a quite a number of points that occur in the vicinity of the Mt York Claystone, which is model layer 15, but there are points from most layers in that plot.

F3. Specific Storage

Figure F.3 presents the identifiability of specific storage Pilot Points.

From **Figure F.3**, most of the Pilot Points are quite identifiable, with an identifiability of 0.3 or more. Traditionally, specific storage and specific yield are not normally considered to be the most sensitive parameters, but it is apparent from **Figure F.3** that they are important parameters.

It is interpreted that the increased identifiability is due to this groundwater model having both hydraulic head observations as well as an extensive historical record of mine dewatering rates.



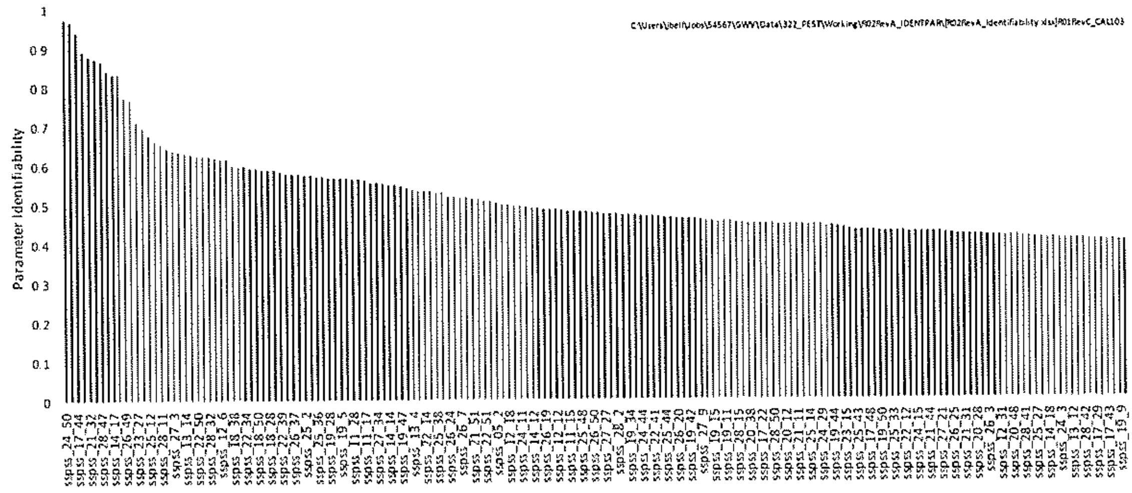
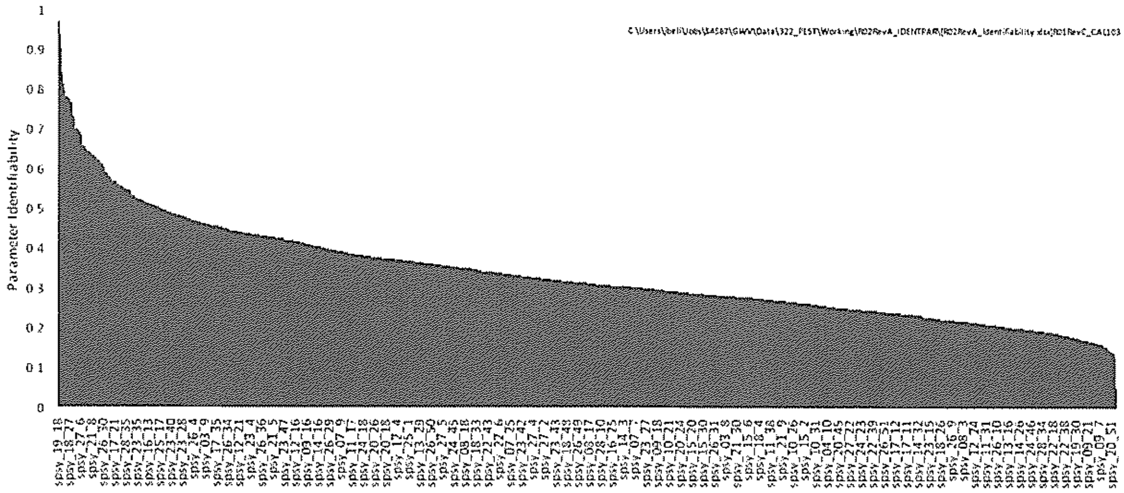


Figure F.3: Parameter Identifiability – Specific Storage (upper – all values; lower – values greater than 0.4)

F4. Specific Yield (Porosity)

Figure F.4 presents the identifiability of specific yield Pilot Points. As noted above, the specific yield parameter in MODFLOW-USG is used as porosity when solving the variably saturated flow equation.

From **Figure F.4**, as per the finding from **Figure F.3**, whilst few parameters are completely identifiable, namely, an identifiability of more than 0.8, there are a lot of Pilot Point values with an identifiability of more than 0.3.



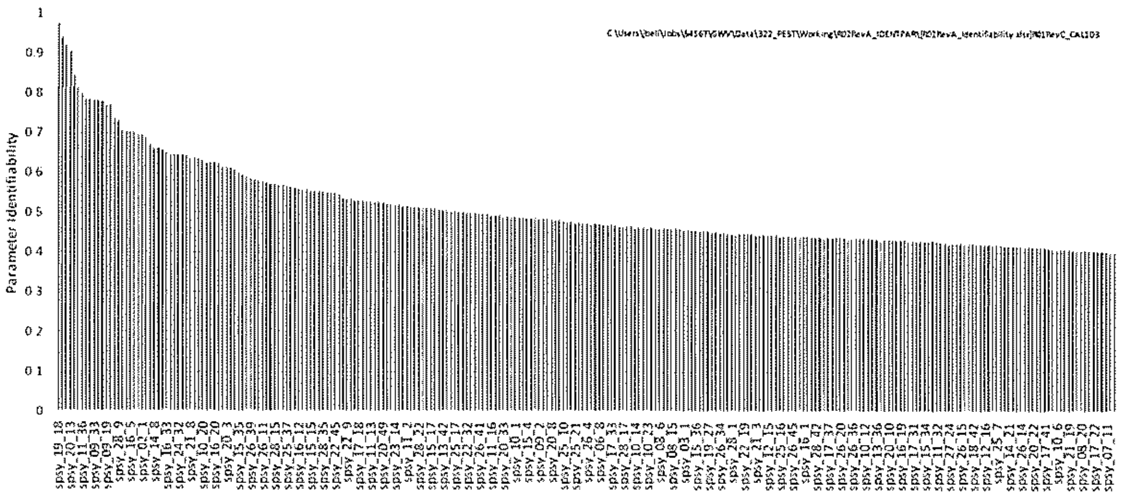


Figure F.4: Parameter Identifiability – Specific Yield (used as Porosity in the model by Richards Equation) (upper – all values; lower – values greater than 0.4)

F5. Drainage K-M Factors

Figure F.5 presents the identifiability of the Drainage K-M factors.

From **Figure F.5**, the K-M factor associated with surface watercourses (DRN001) is highly identifiable and implies, in a future version of the model, subdivision of that parameter into spatially distributed values may lead to further improvement in the model calibration.

From **Figure F.5**, most of the Stacked Drain K-M factors are mostly identifiable, with identifiability of 0.3 and above.

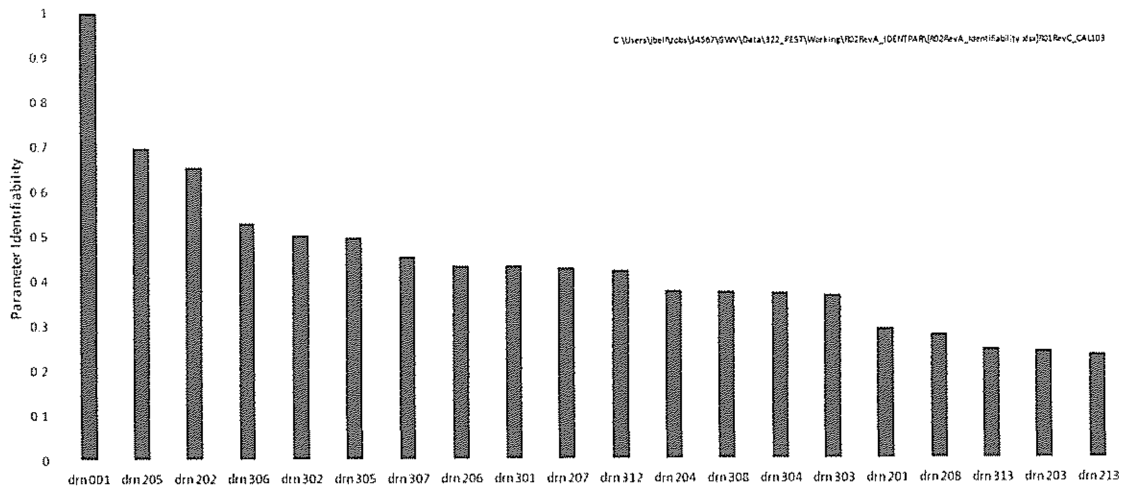


Figure F.5: Parameter Identifiability – Drainage K-M factors (all values)

F6. General Head K-T Factors

Figure F.6 presents the identifiability of the General Head Boundary K-T factors in the model.

From **Figure F.6**, most of the K-T factors are not particularly identifiable. It is worthwhile noting that just because a particular parameter is not identifiable, does not imply that it is not important.

In the case of the K-T factors, because the General Head Boundary is located on the eastern edge of the model domain, in Layer 27, at considerable distance from groundwater level observation, it is unlikely that the calibration dataset will be particularly information of the K-T values.

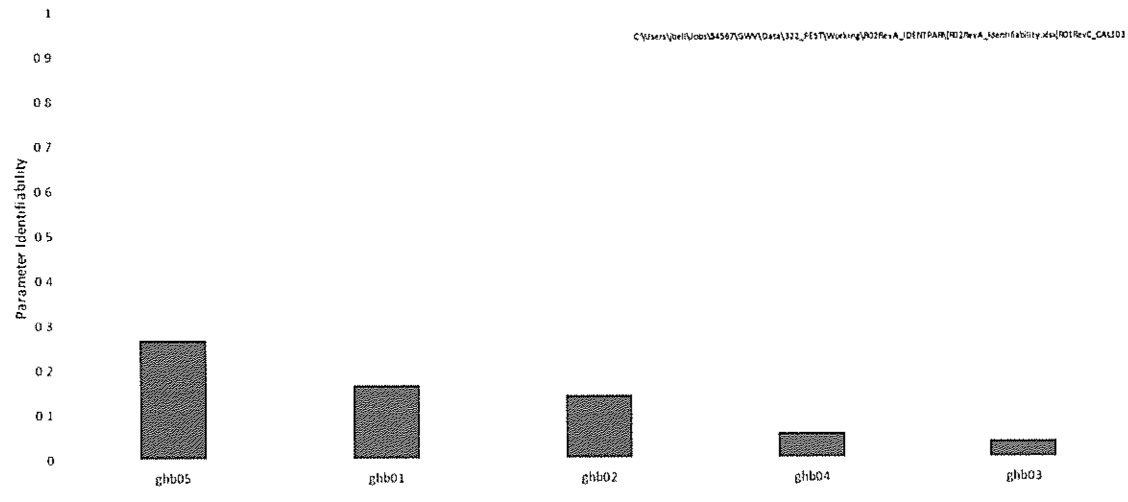


Figure F.6: Parameter Identifiability – General Head Boundary K-T factors (all values)

F7. Recharge Factors

Figure F.7 presents the identifiability of the Recharge factors.

From **Figure F.7**, almost all recharge parameters have an identifiability of 0.3 or more.

From **Figure F.7**, somewhat unsurprisingly, comparing **Table 4.8** with **Figure 3.2**, the highly identifiable recharge factors are clustered around the Angus Place Colliery/Springvale Mine and Clarence Mining area, as that is the location of the observation dataset.

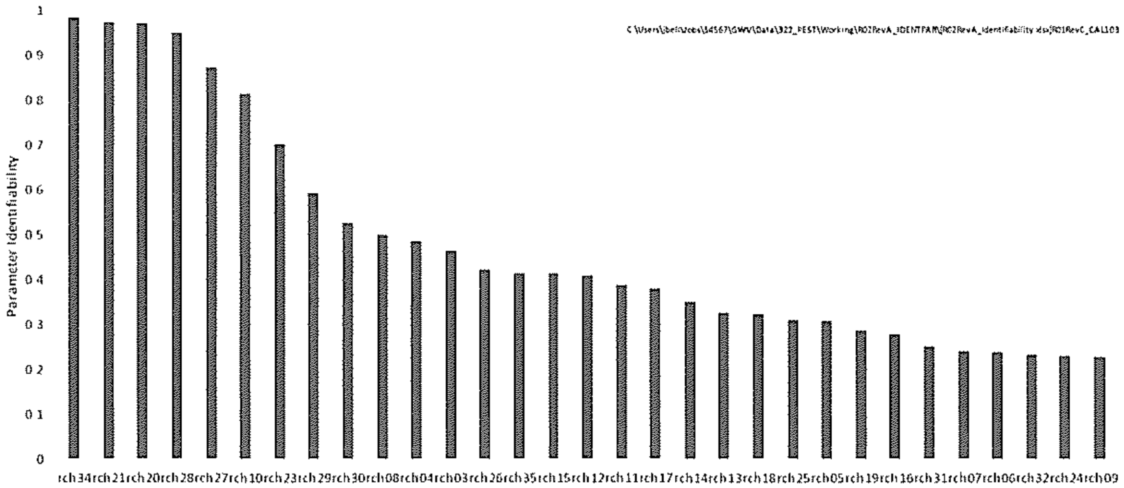


Figure F.7: Parameter Identifiability – Recharge Factor (all values)

F8. Evapotranspiration Factors

Figure F.8 presents the identifiability of the evapotranspiration factors.

From **Figure F.8**, only four of the evapotranspiration factors are particularly identifiable, with the majority of the factors having an identifiability of 0.4 or below.

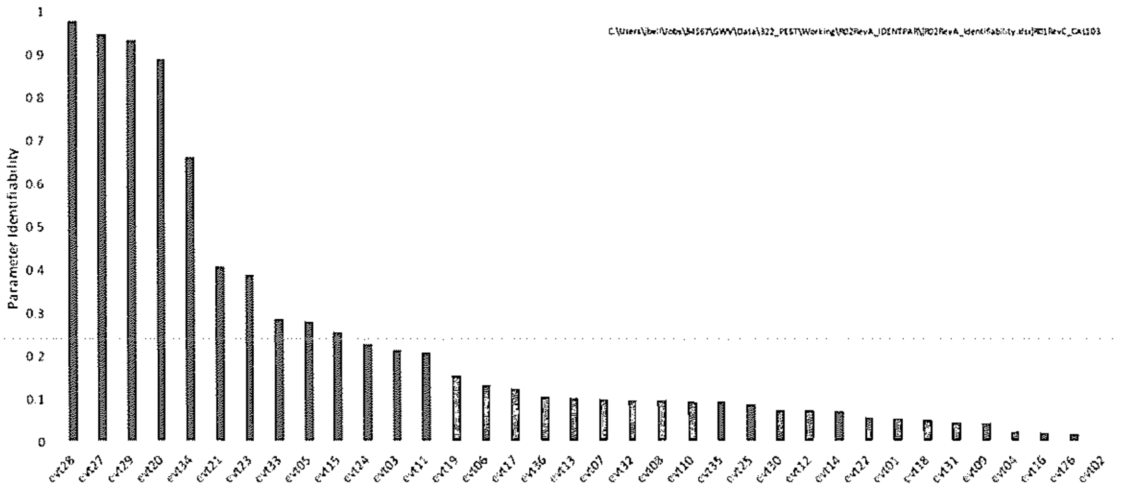


Figure F.8: Parameter Identifiability – Evapotranspiration Factor (all values)

F9. Time-Varying Material Parameters

Figure F.9 presents the identifiability of the TVM parameters. As noted in **Section 4.11**, only a couple of parameters were subject to calibration, due to the adoption of a 'Stacked Drains' approach to the representation of mining instead of a single DRN cell with changes to overlying strata.

From **Figure F.9**, of the TVM included, each was of relatively small identifiability.

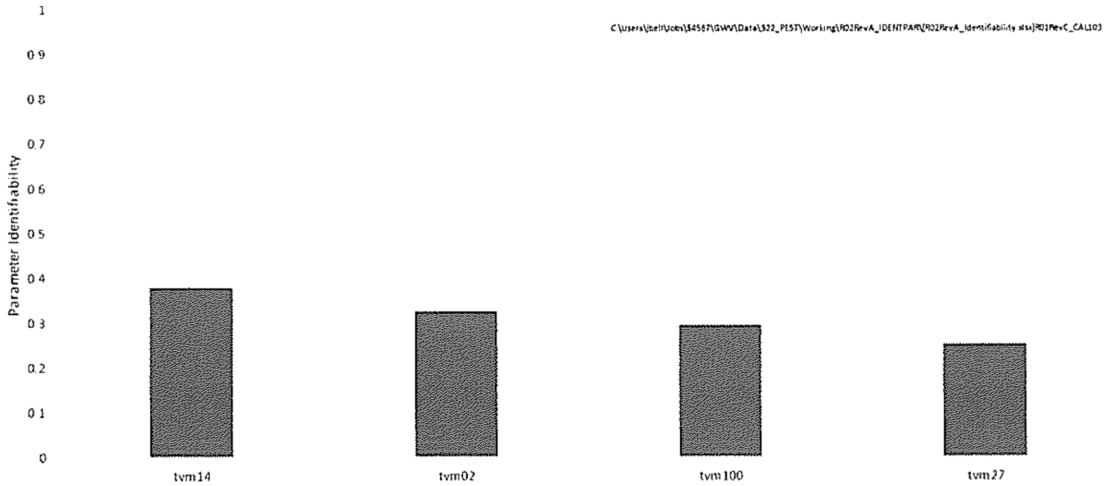


Figure F.9: Parameter Identifiability – TVM (all values)

Appendix G Uncertainty Analysis Convergence

G1. Uncertainty Analysis Convergence

As identified in the Explanatory Note prepared by the IESC (2018b), it is necessary to demonstrate that uncertainty analysis simulations have 'converged'. As discussed in **Section 4.14.3**, this was achieved by considering mine dewatering rates, exported with increasing number of simulations.

Figure G.1 presents the modelled 10th percentile (least) mine dewatering rate for Angus Place Colliery (300, 700, 800, 900 and 1000 Panel Area) for mine drain (DRN) cells located in the Sydney Basin Coxs River Groundwater Source. **Figure G.2** presents the equivalent modelled 10th percentile (least) dewatering rate for the Sydney Basin Richmond Groundwater Source. It is noted that a four-point average was applied to the results presented in **Figure G.1** and **Figure G.2**.

An alternative method to demonstrating 'convergence' is presented **Table G.1**. In **Table G.1**, output in **Figure G.1** was extracted at selected days. An equivalent to **Table G.1** is presented in **Table G.2**, with respect to **Figure G.2**.

Figure G.3 presents the modelled 90th percentile (most) mine dewatering rate for Angus Place Colliery (300, 700, 800, 900 and 1000 Panel Area) for mine drain (DRN) cells located in the Sydney Basin Coxs River Groundwater Source. **Figure G.4** presents the equivalent modelled 90th percentile (most) dewatering rate for the Sydney Basin Richmond Groundwater Source.

Again, an alternative method to demonstrating 'convergence' is presented in **Table G.3**, where results from **Figure G.3** were extracted at selected days. An equivalent table is presented in **Table G.4** with respect to **Figure G.4**.

From the figures and tables presented below, it is demonstrated that 'convergence' is achieved when the number of simulations exceeds about 150 simulations. i.e. the 200 simulation and 300 (299) simulation results are the same. For the assessment, as indicated in **Section 4.14.3**, since 299 simulations were available, the 299 simulation results were utilised.

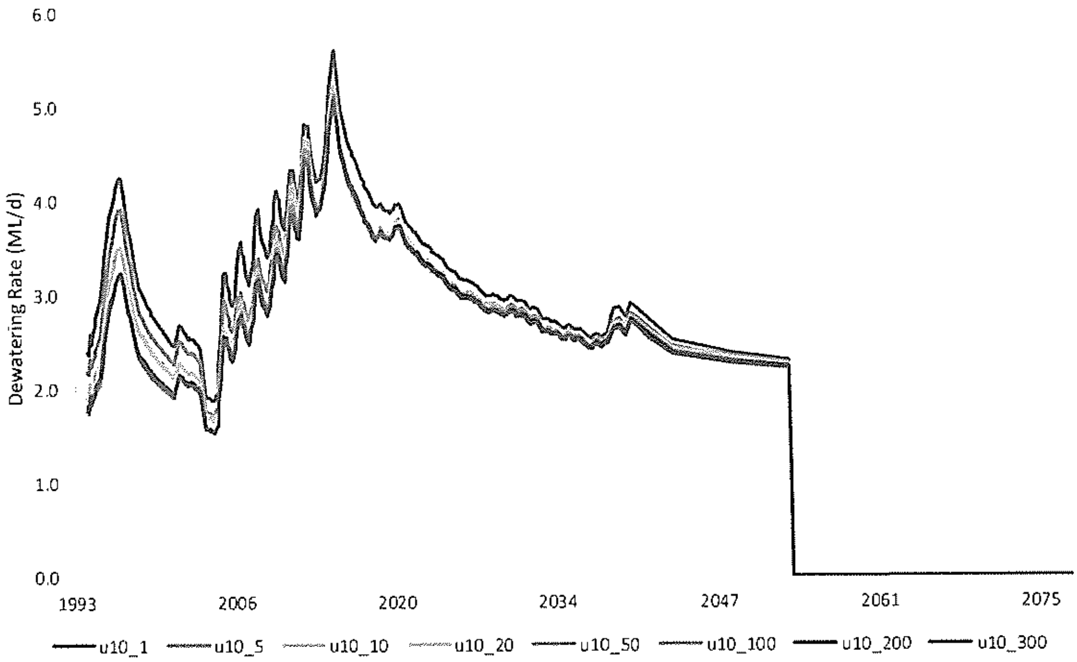


Figure G.1: Angus Place Colliery (300, 700, 800, 900 and 1000 Panel Area) 10th percentile dewatering rate (ML/d) – Sydney Basin Coxs River Groundwater Source

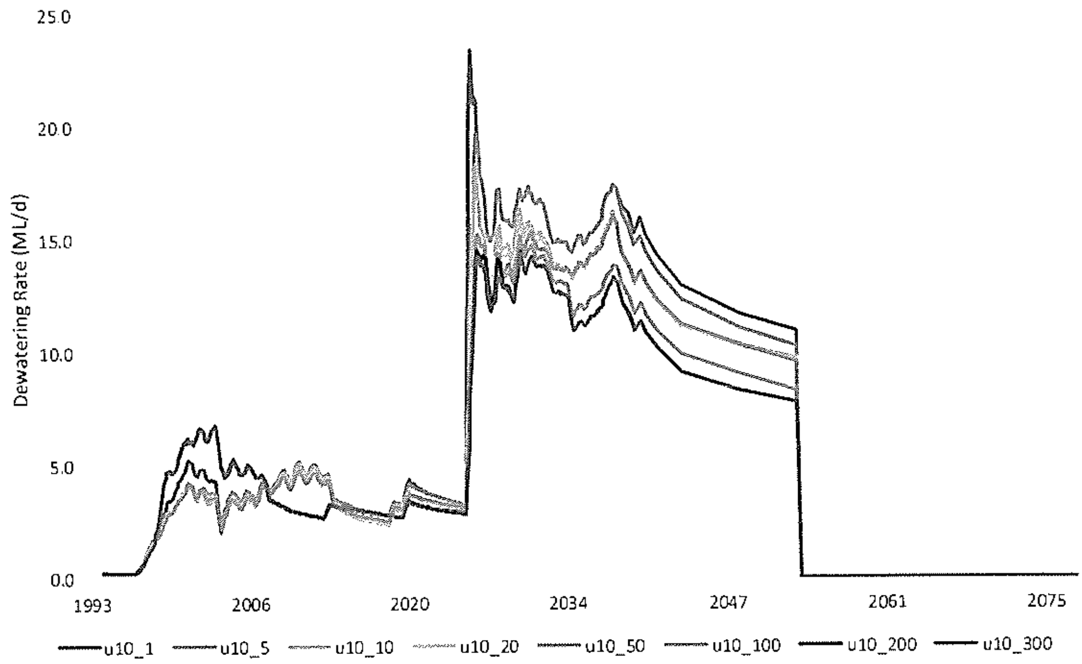


Figure G.2: Angus Place Colliery (300, 700, 800, 900 and 1000 Panel Area) 10th percentile dewatering rate (ML/d) – Sydney Basin Richmond Groundwater Source

Table G.1: Angus Place Colliery (300, 700, 800, 900 and 1000 Panel Area) 10th percentile dewatering rate (ML/d) – Sydney Basin Coxs River Groundwater Source at Selected Dates

Number of Samples	5-Aug-96	5-Nov-14	31-Dec-40
1	4.15	5.17	2.85
5	3.80	4.87	2.75
10	3.42	4.87	2.71
20	3.42	4.81	2.72
50	3.14	4.77	2.70
100	3.14	4.73	2.68
200	3.14	4.73	2.67
300	3.14	4.74	2.66

Table G.2: Angus Place Colliery (300, 700, 800, 900 and 1000 Panel Area) 10th percentile dewatering rate (ML/d) – Sydney Basin Richmond Groundwater Source at Selected Dates

Number of Samples	5-Aug-96	5-Nov-14	31-Dec-40
1	0.23	3.33	15.26
5	0.23	3.33	14.51
10	0.23	3.06	13.09
20	0.24	2.94	12.99
50	0.23	3.03	13.09
100	0.22	3.14	11.65
200	0.21	3.13	10.87
300	0.21	3.13	10.87

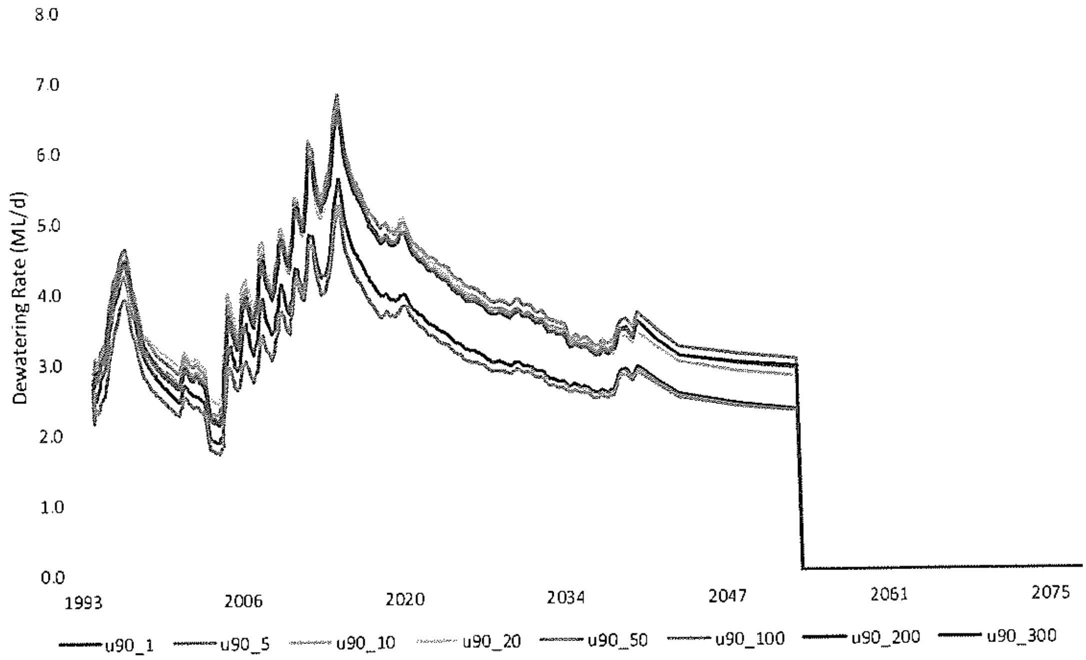


Figure G.3: Angus Place Colliery (300, 700, 800, 900 and 1000 Panel Area) 90th percentile dewatering rate (ML/d) – Sydney Basin Coxs River Groundwater Source

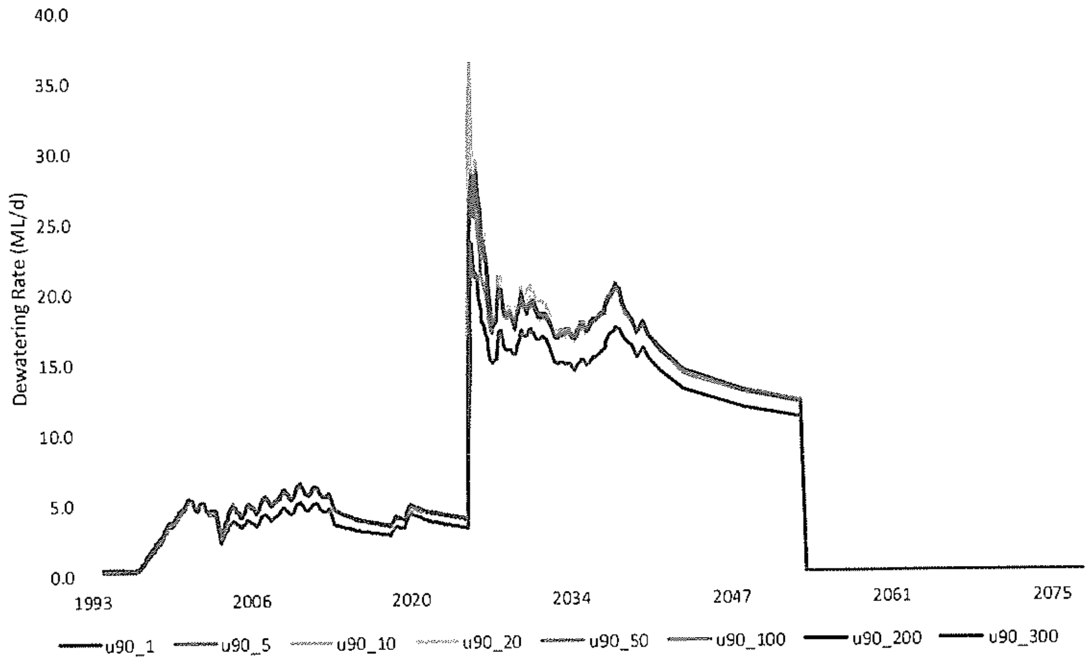


Figure G.4: Angus Place Colliery (300, 700, 800, 900 and 1000 Panel Area) 90th percentile dewatering rate (ML/d) – Sydney Basin Richmond Groundwater Source

Table G.3: Angus Place Colliery (300, 700, 800, 900 and 1000 Panel Area) 90th percentile dewatering rate (ML/d) – Sydney Basin Coxs River Groundwater Source at Selected Dates

Number of Samples	5-Aug-96	5-Nov-14	31-Dec-40
1	4.15	5.17	2.85
5	3.80	4.87	2.79
10	4.24	6.39	3.34
20	4.46	6.43	3.62
50	4.51	6.37	3.59
100	4.37	6.23	3.46
200	4.34	6.17	3.46
300	4.31	6.18	3.46

Table G.4: Angus Place Colliery (300, 700, 800, 900 and 1000 Panel Area) 90th percentile dewatering rate (ML/d) – Sydney Basin Richmond Groundwater Source at Selected Dates

Number of Samples	5-Aug-96	5-Nov-14	31-Dec-40
1	0.23	3.33	15.26
5	0.33	4.21	17.05
10	0.38	4.27	17.05
20	0.38	4.21	16.98
50	0.39	4.25	16.82
100	0.38	4.22	16.80
200	0.38	4.22	16.92
300	0.37	4.22	16.91

Appendix H Letter of 3rd Party Review of Groundwater Model

It is noted that the request for Global Water Balance identified in the 3rd party review was addressed in Revision 1 of this report.

HydroAlgorithmics Pty Ltd ● ABN 25 163 284 991
PO Box 241, Gerringong NSW 2534. Phone: (+61 2) 4234 3802

noel.merrick@hydroalgorithmics.com

DATE: 14 October 2019

TO: Nagindar Singh
Approvals Coordinator
Centennial Angus Place Pty Ltd
1384 Castlereagh Highway
Lidsdale NSW 2790
Tel: (02) 6355 9814

FROM: Dr Noel Merrick

RE: Angus Place Mine Extension Project – Peer Review of Hydrogeological Model

YOUR REF: SP307116

OUR REF: HA2019/15

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1. Introduction

This report provides a peer review of the hydrogeological modelling that underpins the groundwater impact assessment for the Angus Place Mine Extension Project (the Project), as amended from that submitted in 2014, which attracted a number of comments from the Independent Expert Scientific Committee (IESC) on Coal Seam Gas and Large Coal Mining Development. The Angus Place Colliery adjoins the Springvale Colliery, both located about 15 km north-west of Lithgow NSW.

The Angus Place Colliery is currently under care and maintenance. The intention of the Project is to extend underground mining of the Lithgow Seam into the 1000 Panel Area to the east and north-east of historical mining at Angus Place, and to the north of historical mining at the Springvale Colliery.

The Project consists of 15 longwall panels (LW1001 to LW1015) with void widths of 360 m and pillar widths of 55 m, with maximum target coal production of 4.5 Mtpa.

An earlier interim review dated 22 August 2019 by HydroAlgorithmics provided comments and notes to allow the Hydrogeological Model Report (HMR) to be modified to be more complete and more informative. The previous review comments have been addressed satisfactorily and responded to in detail.

2. Documentation

The peer review is based on the following report:

✓ JBS&G, 2019, Angus Place Mine Extension Project (SSD 06_0021): Amended Project – Hydrogeological Model Report. Report JBS&G56421-123003_R02Rev0, for Centennial Angus Place Pty Ltd, 27 August 2019. 145p plus 7 Appendices.

The HMR has the following major sections:

1. Introduction
2. Limitations
3. Hydrogeological Setting
4. Conceptual Model and Numerical Analysis
    - 4.1 Risk Assessment Framework
    - 4.2 Model Objectives and Model Class
    - 4.3 Conceptual Model
    - 4.4 Model Approach and Code .
    - 4.5 Model Grid and Domain
    - 4.6 Model Layering
    - 4.7 Model Geometry and Initial Values of Hydraulic Parameters .
    - 4.8 Model Temporal Discretisation
    - 4.9 Model Boundary Conditions
    - 4.10 Subsidence-Induced Changes to Hydraulic Properties
    - 4.11 Model Calibration
    - 4.12 Sensitivity Analysis / Parameter Identifiability
    - 4.13 Model Results incorporating Predictive Uncertainty .
    - 4.14 Climate Change Scenarios
    - 4.15Summary of Model Results including Uncertainty Analysis
5. Licensing
6. Conclusions
7. References.

The Appendices are:

A. Risk Assessment
B. Approach to Variably Saturated Flow
C. Mine Schedule
D. Subsidence Induced Change to Hydraulic Properties
E. Pilot Point Distribution
F. Parameter Identifiability Output
G. Uncertainty Analysis Convergence

Apart from the HMR, there is a separate Groundwater Impact Assessment (GIA) report (in press) and a separate 68-page Swamp Water Balance (SAPSWBM) report that assesses potential changes to Temperate Highland Peat Swamps on Sandstone (THPSS) and surface water flow due to mining-induced changes to groundwater contributions. Neither report is reviewed here.

3. Review Methodology

There are two accepted guides to the review of groundwater models: (A) the Murray-Darling Basin Commission (**MDBC**) Groundwater Flow Modelling Guideline1, issued in 2001, and (B) guidelines issued by the National Water Commission (**NWC**) in June 2012 (Barnett *et al.*, 2012[2]). The NWC national guidelines were built upon the original MDBC guide, with substantial consistency in the model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details.

The NWC guide promotes the concept of "model confidence level", which is defined using a number of criteria that relate to data availability, calibration, and prediction scenarios. The NWC guide is almost silent on coal mine modelling and offers no direction on best practice

[1] MDBC (2001). Groundwater flow modelling guideline. Murray-Darling Basin Commission. URL: www.mdbc.gov.au/nrm/water_management/groundwater/groundwater_guides

[2] Barnett, B, Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A. (2012). *Australian Groundwater Modelling Guidelines.* Waterlines report 82, National Water Commission, Canberra.

methodology for such applications. There is, however, an expectation of more effort in uncertainty analysis, although the guide is not prescriptive as to which methodology should be adopted.

Guidelines on uncertainty analysis for groundwater models were issued by the **IESC** in February 2018 in draft form and finalised in December 2018[3].

The groundwater guides include useful checklists for peer review. The HMR assessment has been reviewed according to the 2-page Model Appraisal checklist[4] in MDBC (2001). This checklist has questions on (1) The Report; (2) Data Analysis; (3) Conceptualisation; (4) Model Design; (5) Calibration; (6) Verification; (7) Prediction; (8) Sensitivity Analysis; and (9) Uncertainty Analysis. Non-modelling components of a groundwater assessment are addressed by the first three sections of the checklist.

It should be recognised that the effort put into the modelling component of a groundwater assessment is very dependent on possible timing and budgetary constraints that are generally not known to a reviewer. However, this is less of an issue with a progressive review.

This review by Dr Noel Merrick has been conducted progressively since November 2017, with involvement of the peer reviewer through four meetings[5] and email exchanges, including commentary on the risk assessment.

Earlier modelling of Angus Place and Springvale Colliery Operations by CSIRO using COSFLOW software was reviewed by HydroSimulations in May 2014 (by Dr Noel Merrick). Report HS2014/11 finalised a long process that dated back to April 2012.

The detailed assessment of the groundwater modelling is recorded in the peer review checklist in **Table 1**. Supplementary comment is offered in the following sections of this review.

4. Report Matters

The HMR is a detailed modelling report of about 250 pages in total, providing an adequate record of the numerical modelling undertaken in support of the Amended Project. It is not fully "standalone", as it relies on the companion SAPSWBM report to convey the expected effects on THPSS, and on the GIA for documentation on datasets and fuller exploration of potential environmental impacts. The groundwater model and the swamp model are coupled loosely.

The objectives of the study are stated in Section 1.5 as being "to support the Groundwater Impact Assessment being prepared for the Angus Place Mine Extension Project: Amended Project", and in Section 4.2 as to "quantify the spatially and temporally varying change to the groundwater system due to the Angus Place Mine Extension Project: Amended Project".

The report contains a plethora of detail, some of which could have been relegated to Appendices – e.g. the uncertainty analysis reporting for the climate change scenarios. On the other hand, the Executive Summary (a half page) is rather brief. The figures are all of high quality.

There are some items missing from the report that could have been included:

- Best-estimate groundwater elevation contour maps (for key horizons) based on field measurements.
- Global water balance tables for inputs and outputs averaged over the calibration period, and over the prediction period.

[3] Middlemis H and Peeters LJM (2018) *Uncertainty analysis—Guidance for groundwater modelling within a risk management framework*. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia 2018.

[4] The newer guidelines include a more detailed checklist with yes/no answers but without the graded assessments of the 2001 checklist, which this reviewer regards as more informative for readers.

[5] November 10, 2017; September 7, 2018; May 8, 2019; July 4, 2019

- Local water balance tables for each key swamp for inputs and outputs averaged over the calibration period, and over the prediction period.
- Pressure-head sections (at end of mining) for the geological sections in Figures 4.6 (south-north) and 4.7 (west-east).
- Colour-flood maps of the hydraulic conductivities (for key layers) resulting from PEST calibration; alternatively cumulative distribution functions for each layer. It is noted that the final geomean hydraulic conductivities in Table 4.10 are quite different from the initial values in Table 4.3.

It would be interesting to compare the pressure-head sections with diagrams provided by the previous CSIRO modelling by Adhikary and Wilkins (2013[6]), in which unsaturated zones are shown developing beneath aquitards as mining progresses. Two of the diagrams are shown here at **Figure 1**.

There is no literature review on physical properties measured or inferred from related prior studies. However, this could be in the GIA under preparation. The initial values for hydraulic conductivities and porosities in Table 4.3 do not agree well with previous studies. Fortunately, the values are modified substantially to lower values during the calibration process.

5. Modelling

The documented model is a complete re-build of the CSIRO model developed for the Angus Place and Springvale Colliery Operations Groundwater Assessment in 2013-2014. The previous model was a coupled geotechnical-groundwater model using proprietary COSFLOW software. The new model uses more familiar MODFLOW-USG software for groundwater flow only, using a structured (rectangular) grid. Finer spatial resolution has been achieved where required through quad-tree refinement, a feature of MODFLOW-USG.

The model covers a substantial area of 32 km (north-south) by 30 km (east-west). Its western boundary passes through the township of Wallerawang, and its southern boundary passes near the city of Lithgow. The western boundary has been assumed as "no-flow", although some flow is likely to cross the boundary from west to east. However, it would be captured by Coxs River or diverted southwards.

The stratigraphy is subdivided into 28 layers, which decrease in areal extent with altitude (due to erosion). Where layers are pinched out, seepage faces are applied.

There is a substantial dataset for model calibration, consisting of 18,624 target observations. Targets are specified for groundwater levels, changes in groundwater levels (relative to initial readings), mine inflow rate and cumulative mine inflow. PEST software with spatially distributed pilot points has been used to achieve optimal model parameterisation. There is no cause-and-effect analysis of groundwater hydrographs to deduce what stresses are affecting observations, but this could be in the GIA under preparation.

One instance of an observation that deserves scrutiny is the set of VWP hydrographs in Figure 4.21 with observed rises not matched by the model, presumably instances of compression responses for which there is no modelled mechanism. Examples are shown here in **Figure 2**. There is a case for excluding these rising values from statistics and scattergrams, as MODFLOW has no in-built process for simulating compression effects.

Calibration statistics for matching groundwater levels are quite good (6.6 %RMS, 30 mRMS), and most temporal matches are reasonably good. The weakest agreement is at Trail Six swamp.

The replication of historical mine inflows is excellent. Given very high inflows compared to most other NSW coal mines, the model has inferred magnitudes of some properties that the reviewer

[6] Adhikary, D. P. and Wilkins, A., 2013, Angus Place and Springvale Colliery Operations Groundwater Assessment. CSIRO Report No EP132799 for Angus Place Colliery and Springvale Colliery. May 2013.

considers to be unexpectedly high, namely:

- some horizontal and vertical hydraulic conductivities;
- porosity values for claystones and some sandstones;
- stacked drain conductances; and
- fracture zone heights where the coal seam thickness to be mined exceeds about 3 m.

The adopted hydraulic conductivities are not fully disclosed, as only the geomean is provided for each layer for horizontal and vertical directions. An indication of the typical values is provided by the medians of the geomeans:

- Sandstone: Kx ~ 0.026 m/day; Kz ~ 0.0033 m/day; porosity ~ 21%
- Shale: Kx ~ 0.037 m/day; Kz ~ 0.0026 m/day; porosity ~ 34%
- Claystone: Kx ~ 4.3E-4 m/day; Kz ~ 3.3E-5 m/day; porosity ~ 41%
- Conglomerate: Kx ~ 0.028 m/day; Kz ~ 0.0028 m/day; porosity ~ 26%
- Coal: Kx ~ 0.013 m/day; Kz ~ 0.0026 m/day; porosity ~ 21%

The CSIRO model adopted similar values for sandstone and coal, but much lower values for aquitards (by several orders of magnitude), and good matches to vertical head profiles were achieved with that model.

The stacked drain conductances are 1,800-2,900 m^2/day for the upper half and 1,700-7,400 m^2/day for the lower half of the stack. These values are very high compared with experience in other coalfields, but they appear to be necessary to account for the large volumes of water entering the mine voids.

The fracture heights are determined using the Tammetta algorithm. This reviewer is of the view that the Tammetta algorithm is not reliable for mined seam thicknesses greater than about 3.4 m, as that is the highest value in the Tammetta database, and the dependence on seam thickness follows a power law (exponent >1) which causes large increases in fracture height for small increases in seam thickness. This occurs in the south-western portion of the 1000 Panel Area, near the Tri Star Swamp, and this is where the Tammetta algorithm predicts fracturing to land surface – see **Figure 3**. For the example in Appendix D that has panel width 350.38 m, seam thickness 3.4 m, and depth of cover (to Lithgow Seam) 322.79 m, the Tammetta formula gives a fracture height of 345 m. This contrasts with a height of 185 m using the Ditton geology algorithm (using t'=20 m), or a range of 141-245 m (for t' from 10 to 40 m). It remains uncertain whether the Tri Star Swamp would be fractured from below due to planned mining.

Is there independent evidence (e.g. from extensometers) that favours the Tammetta formula over the Ditton formula?

For assessment of fracturing to land surface, it is assumed that surface cracks would occur down to 10 m. Is there evidence for this, as cracks could extend to 20 m or perhaps 30 m at most? How does the cracking depth relate to the thicknesses of the top two layers in the model, where horizontal hydraulic conductivity is increased by a factor of 10.

A thorough IESC-compliant uncertainty analysis has been undertaken that accords with the most computationally demanding advocated approach using stochastic model variants with outputs of percentile probabilities for metrics of interest. A complete uncertainty analysis has been run for two climate change extremes, resulting in a finding of limited influence compared to other stresses.

The new model has achieved similar model calibration performance to that of the previous CSIRO model. As CSIRO model predictions to 2018 proved to be too low (by 25-30%), the new model has been able to calibrate very well to the full period of record. As a result, the new model predicts future inflows (to combined Angus Place and Springvale Mines; Figure 4.50) that are considerably higher than predicted by the CSIRO model (~50%).

More detailed comments on the modelling are to be found in **Table 1**.

6. Conclusion

It is recognised that the Hydrogeological Model Report documents a monumental effort for a very complex groundwater system subject to extensive historical and current mining stresses, with important groundwater dependent ecosystems at risk of impact.

As with all groundwater models, there is no unique solution. The HMR includes a thorough uncertainty analysis that indicates the probable bounds of simulated effects for the adopted geological structure and conceptualisation. Other conceptualisations could give different probability ranges. As the adopted conceptualisation has been demonstrated to be consistent with observations and measurement data, the numerical model should be regarded as the best tool currently available for ongoing predictions.

The reviewer has some reservations about the elevated magnitudes of some of the parameters that were required to achieve calibration, namely:

- some horizontal and vertical hydraulic conductivities;
- porosity values for claystones and some sandstones;
- stacked drain conductances; and
- fracture zone heights where the coal seam thickness to be mined exceeds about 3 m.

Each elevated value serves to provide more available water for discharging into underground mine voids. On the other hand, development headings and mains roadways have been excluded from simulation as voids, in the expectation of minimal inflows (contrary to observations ion other coalfields).

It cannot be denied that the current model replicates historical mine inflow exceptionally well. For that reason, the model should be regarded as *fit-for-purpose* as a predictor of future mine inflow, and a good predictor of environmental effects (at least in the interim).

Yours sincerely

N P Merrick

Dr Noel Merrick

Table 1. MODEL APPRAISAL: Angus Place Groundwater Model

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max Score (0, 3, 5)	COMMENT
1.0	THE REPORT								
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	Very Good			S1.5: support GIA. S4.2: quantify spatial & temporal changes to the groundwater system.
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	Yes				Reference to NWC national guidelines. Table 4.2 substantiated as Class 2 confidence classification. Appropriate.
1.3	Is a water or mass balance reported?		Missing	Deficient	Adequate	Very Good			No global model balances for calibration or prediction periods. Only components of interest – mine inflow, surface water take. (NOTE - companion swamp water balance model report)
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	Very Good			Meets objectives
1.5	Are the model results of any practical use?			No	Maybe	Yes			Demonstrates risk and quantifies uncertainty in potential impacts.
2.0	DATA ANALYSIS								**SEPARATE GIA REPORT**
2.1	Has hydrogeology data been collected and analysed?	Deferred	Missing	Deficient	Adequate	Very Good			S3.4: geology
2.2	Are groundwater contours or flow directions presented?	Deferred	Missing	Deficient	Adequate	Very Good			
2.3	Have all potential recharge data been collected and analysed? (rainfall, streamflow, irrigation, floods, etc.)	Deferred	Missing	Deficient	Adequate	Very Good			S3.2: rainfall & ET (SILO)
2.4	Have all potential discharge data been collected and analysed? (abstraction, evapotranspiration, drainage, springflow, etc.)	Deferred	Missing	Deficient	Adequate	Very Good			S3.5: GDEs
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?	Deferred	Missing	Deficient	Adequate	Very Good			
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	Yes			

2.7	Have consistent data units and standard geometrical datums been used?			No	**Yes**				
3.0	CONCEPTUALISATION								
3.1	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	**Yes**			
3.2	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	**Very Good**			S4.3
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	**Very Good**			Figures 4.2a,b
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	**No**				Fracture zone height by Tammetta algorithm – exaggerated height for coal seams thicker than 3m. Surface cracking to 10m depth (could be more).
4.0	MODEL DESIGN								
4.1	Is the spatial extent of the model appropriate?			No	Maybe	**Yes**			32km N-S x 30km E-W. 28 layers, 80 major rows, 75 major columns. Quad-tree refinement: cell sizes 100-400m (structured grid).
4.2	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	**Adequate**	Very Good			Outcrop pinchouts = seepage faces. No-flow on N, S and W faces – western face should be justified. GHBs for open flow on arbitrary eastern boundary. Some RIV but mostly DRNs for watercourses (implying baseflow; preventing rain recharge).
4.3	Is the software appropriate for the objectives of the study?			No	Maybe	**Yes**			MODFLOW-USG with QuadTree. GV v7. Richards Equation. PEST + FORTRAN bespoke code.
5.0	CALIBRATION								1979-2018 [40 yrs]. Interval 3 months.

5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	Very Good			Transient calibration with groundwater level and head change targets at 346 of max.371 sites (swamps, standpipes, VWPs); also mine inflow rate and cumulative inflow targets. Total 18,624 target observations. RMS and %RMS performance statistics and scattergrams (Figs.4.18, 4.19). Hydrograph matches (Figs.4.21, 4.23, 4.25, 4.26). Use of PEST + pilot points; 4,334 parameters.
5.2	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	Adequate	Very Good			No field h(x,y) contours for comparison. Scattergrams suggest no spatial bias over 400m groundwater elevation range. No display of VWP vertical gradient matches (scattergram suggests OK).
5.3	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate	Very Good			Very good match to mine inflow. Hydrographs: Figs.4.21, 4.23, 4.25, 4.26 – quite good; weakest at Trail Six. Some observed rising heads due to compaction – cannot be simulated with MODFLOW.
5.4	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	Yes			Initial hydraulic conductivities very high, especially vertical; is there a literature review in the GIA report? Final K(x,y,z) geomeans in Table 4.10 – more reasonable for coal and claystone. Sandstone porosities are near upper limit (16-27%), and claystone porosities are very high (37-41%) if used as Sy – suggest lab core measurements. Unsaturated properties not well resolved, hence uncertain. Rain recharge rates OK (8-18%).

5.5	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	Very Good			Transient model: 6.6 %RMS, 30 mRMS
5.6	Are there good reasons for not meeting agreed performance criteria?		Missing	Deficient	Adequate	Very Good			
6.0	VERIFICATION								OPTIONAL
6.1	Is there sufficient evidence provided for model verification?	N/A	Missing	Deficient	Adequate	Very Good			
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?	N/A	Unknown	No	Maybe	Yes			
6.3	Are there good reasons for an unsatisfactory verification?	N/A	Missing	Deficient	Adequate	Very Good			
7.0	PREDICTION								**2018-2053 [36 yrs] Intervals 3, 6, 12, 24, 60 months. 2054-2128 [75 years].**
7.1	Have multiple scenarios been run for climate variability?		Missing	Deficient	Adequate	Very Good			Long-term average climate base run. Two extreme NARCliM models with max/min cumulative rain – relative % to base? Full uncertainty analysis for extremes. *(Result: limited influence)*
7.2	Have multiple scenarios been run for operational /management alternatives?		Missing	Deficient	Adequate	Very Good			One mine plan. Many neighbouring mines included for cumulative impact assessment. Null & Proposed runs. The Null run has quite a few differences, not simply with/without 1000 panel area.
7.3	Is the time horizon for prediction comparable with the length of the calibration / verification period?		Missing	No	Maybe	Yes			Calibration period 40 years (1979-2018). Prediction period 36 years (2018-2053).

7.4	Are the model predictions plausible?			No	Maybe	Yes			Drawdown maps are presented at 2053 & 2091; most drawdown occurs where fractured to surface. Focus is on uncertainty bands (except mine inflow). Surface water impacts similar to CSIRO trends & magnitudes. Higher predicted mine inflow than CSIRO (~50% higher) – combined Centennial mines. Some shift in swamp water take in transitioning from stacked DRNs to porous medium ramp.
8.0	SENSITIVITY ANALYSIS								
8.1	Is the sensitivity analysis sufficiently intensive for key parameters?		Missing	Deficient	Adequate	Very Good			Investigated by identifiability analysis – better than perturbation method.
8.2	Are sensitivity results used to qualify the reliability of model calibration?	N/A	Missing	Deficient	Adequate	Very Good			
8.3	Are sensitivity results used to qualify the accuracy of model prediction?	N/A	Missing	Deficient	Adequate	Very Good			
9.0	UNCERTAINTY ANALYSIS								
9.1	If required by the project brief, is uncertainty quantified in any way?		Missing	No	Maybe	Yes			Investigation for 300 model variants by null-space monte carlo [IESC method 3 for high-risk projects]. Appropriate approach. Convergence after 150-200 runs – evidence in Tables G.1, G.2. Side-by-side drawdown maps per layer at P10 and P90 at 2053; down to 0.5m
	TOTAL SCORE								PERFORMANCE: %

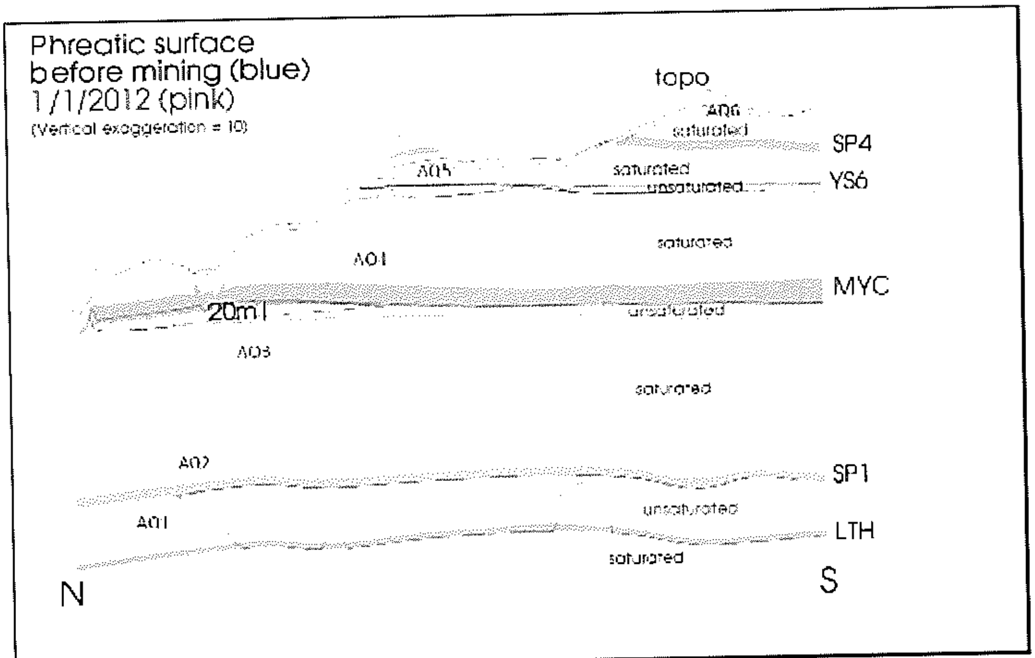


Figure 63 Phreatic surface before mining (blue lines) and after validation (pink lines) along N-S section

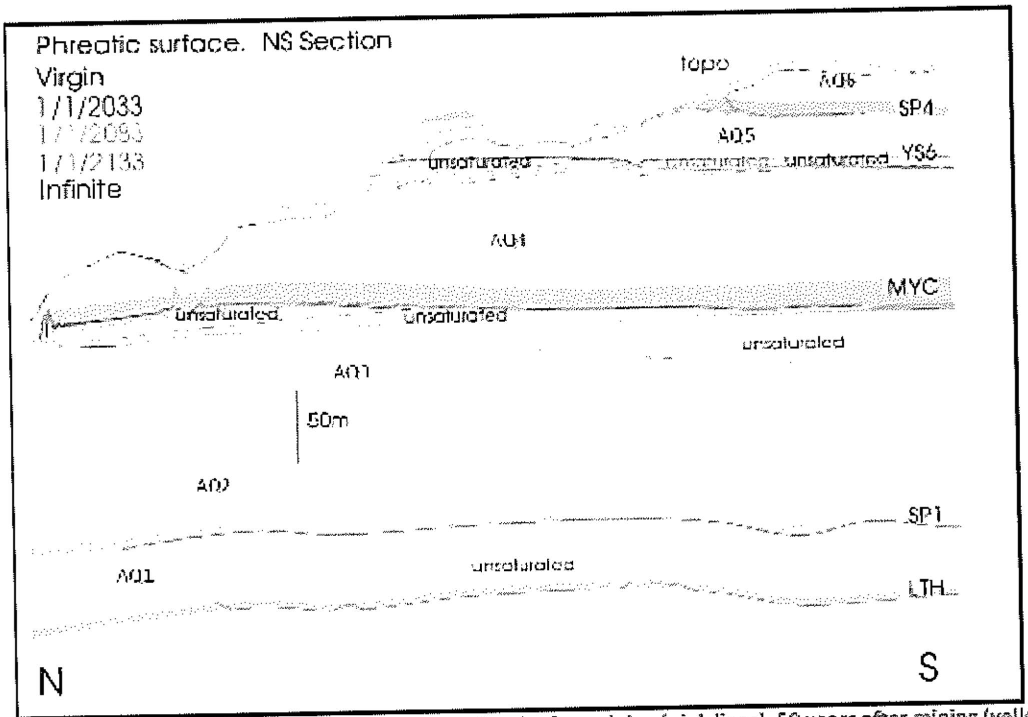


Figure 77 Phreatic surface before mining (blue lines), after mining (pink lines), 50 years after mining (yellow lines), 100 years after mining (green lines) and steady-state after mining (black lines) along N-S section

Figure 1. Indications of alternating saturated and unsaturated zones

[Source: Adhikary, D. P. and Wilkins, A., 2013, Angus Place and Springvale Colliery Operations Groundwater Assessment. CSIRO Report No EP132799 for Angus Place Colliery and Springvale Colliery. May 2013.]

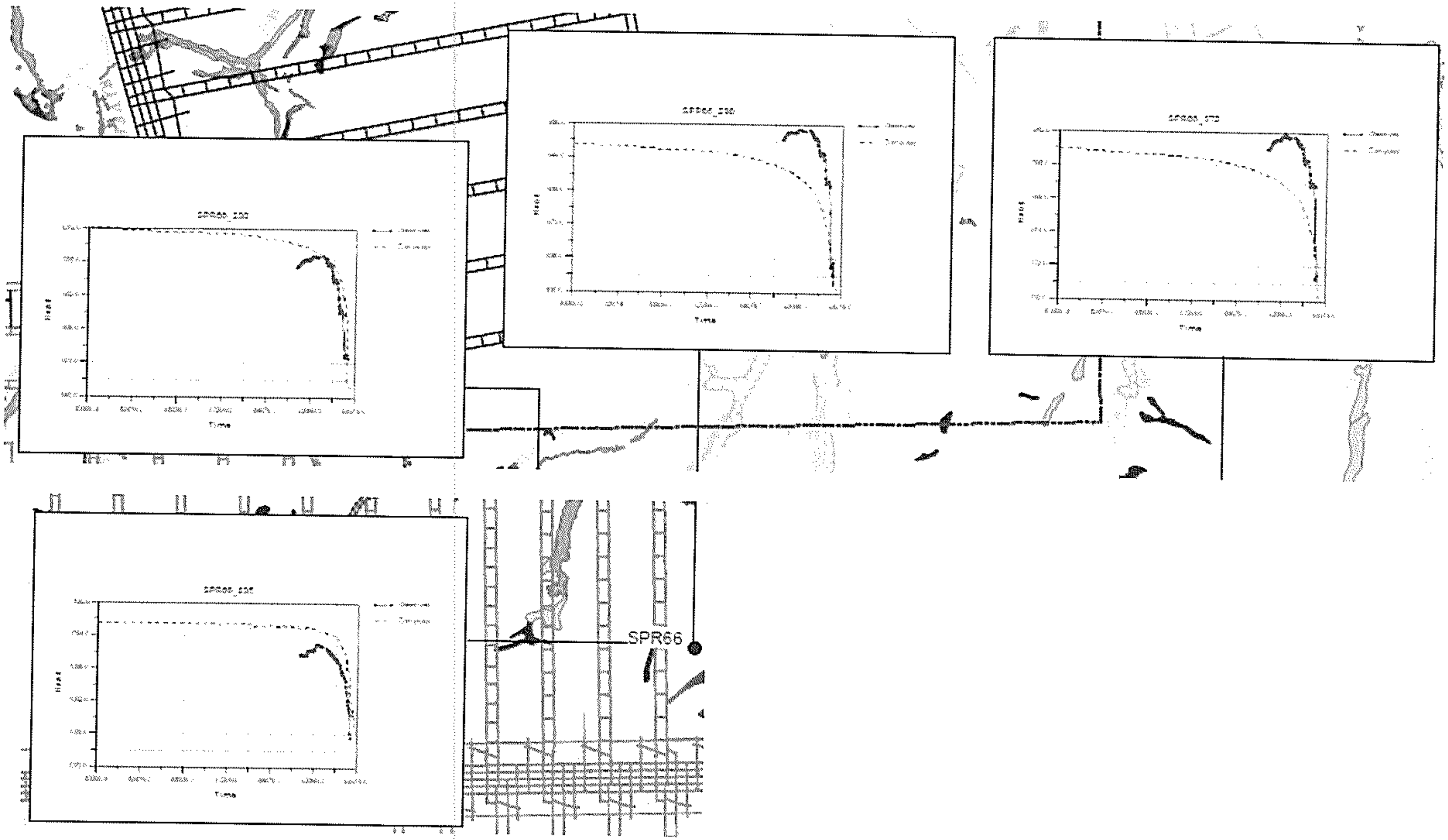
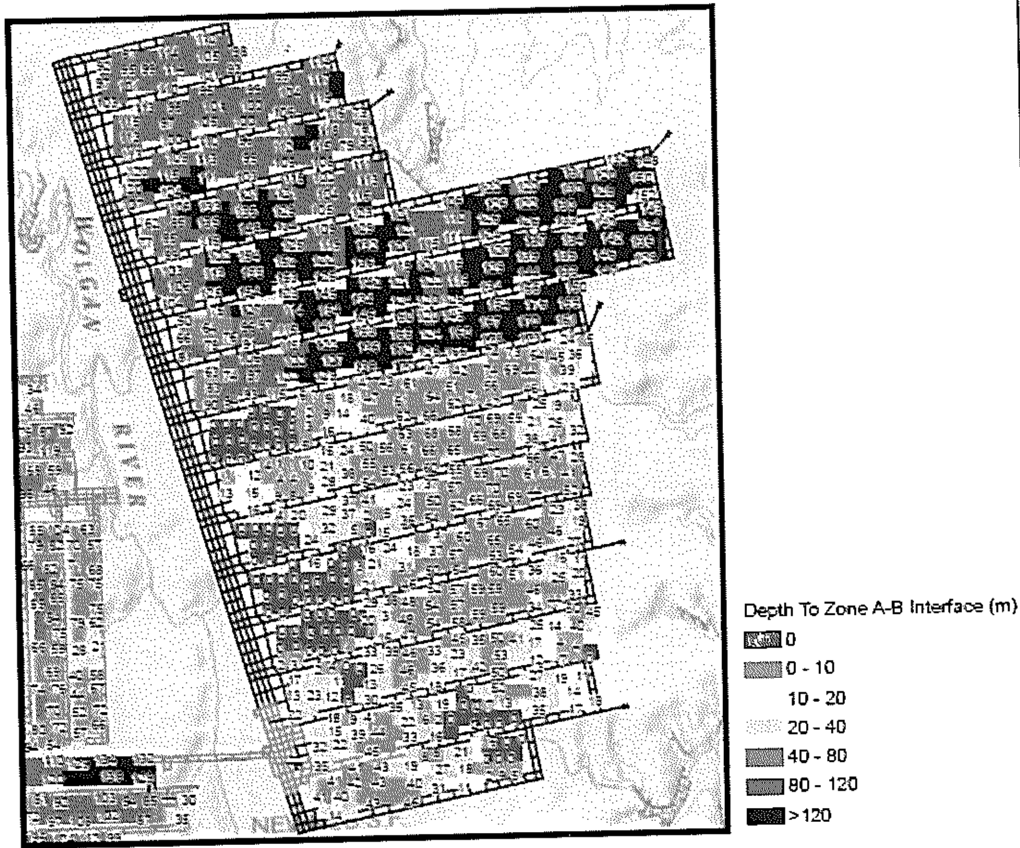


Figure 2. Examples of hydrographs showing probable compression effects which cannot be simulated



Source: JBS&G (2019) Figure 4.11

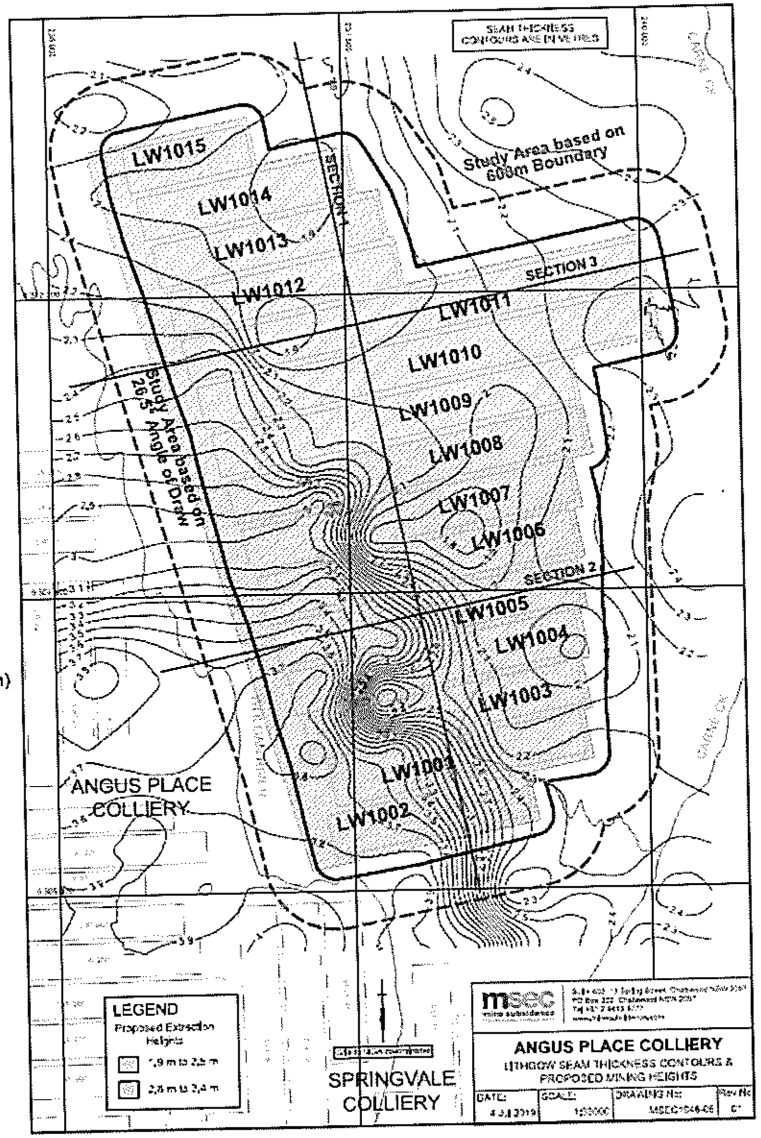


Figure 3. Comparison of depth to top of fracture zone with seam thickness

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Document Status

Rev No.	Author	Reviewer	Approved for Issue		
		Name	Name	Signature	Date
A	Dr Justin Bell	Dr Lyndon Bell, Dr Greg Dasey	Dr Justin Bell	n/a	9 July 2019
B	Dr Justin Bell	Dr Lyndon Bell	Dr Justin Bell	n/a	30 July 2019
0	Dr Justin Bell	Dr Lyndon Bell	Dr Justin Bell		27 August 2019
1	Dr Justin Bell	Dr Lyndon Bell	Dr Justin Bell		18 October 2019

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L02Rev0

11 September 2019

Dr Nagindar Singh
Centennial Angus Place Pty Ltd
Locked Bag 198
WALLERAWANG NSW 2845
Via email: nagindar.singh@centennialcoal.com.au

Change in Groundwater Contribution from Hydrogeological Model at Points of Interest

Dear Nagindar,

Introduction

As requested, JBS&G Australia Pty Ltd (JBS&G) have extracted output from the numerical groundwater model at additional locations within the Wolgan River catchment to provide information for other technical studies associated with the Angus Place Mine Extension Project: Amended Project.

Details of the construction and calibration of the numerical groundwater model are presented in JBS&G (2019).

Model Output

The location of model output (from median rainfall condition simulations) at the requested points of interest is presented in **Figure 1**.

Details of the locations of model output are summarised in **Table 1**. It is noted that the numbering of the locations listed in **Table 1** is made consistent with output from the swamp water balance model, therefore not all numbers are used.

It is noted that, depending on the location of the point of interest, the nearest upstream or downstream node has been selected. The coordinate information presented in **Table 1** is with respect to the downstream edge of identified model node.

Table 1: Summary of Model Output Locations

ID.	Node	Easting[1] (mMGA56)	Northing[1] (mMGA56)	Description
Carne Creek				
CC01	PAS423a	238610	6316450	Carne Creek
CC01A	NAT342a	237240	6311890	Trail Six Swamp
CC02	NAT490a	240860	6311600	Carne Creek, east of LW1011
CC03	NAT497a	239950	6308470	Birds Rock Swamp
CC04a	NAT562a	239993	6306761	Crocodile Swamp
CC06	NAT526a	239790	6303750	Carne Creek Swamp
Wolgan River				
WR02	PAS421a	239790	6319020	Wolgan River below Carne Creek
WR03	PAS428a	237490	6317160	Wolgan River above Carne Creek
WR04	PAS431a	232200	6313000	Wolgan River
WR05	NAT462a	235330	6309600	Wolgan River below Twin Gully Swamp
WR05a	NAT332a	235749	6308088	Wolgan River between Twin Gully Swamp and Tri-Star Swamp
WR06	NAT322a	235800	6308670	Twin Gully Swamp
WR08	NAT324a	236610	6307050	Tri-Star Swamp

Notes. 1) Eastings and Northings are of the Model Node at downstream point.

References

JBS&G, 2019. *Angus Place Mine Extension Project (SSD 06_0021): Amended Project – Hydrogeological Model Report*. Consultant report prepared by JBS&G Australia Pty Ltd for Centennial Angus Place Pty Ltd. Reference No. JBS&G56421-123003/R02Rev0, dated 27 August 2019.

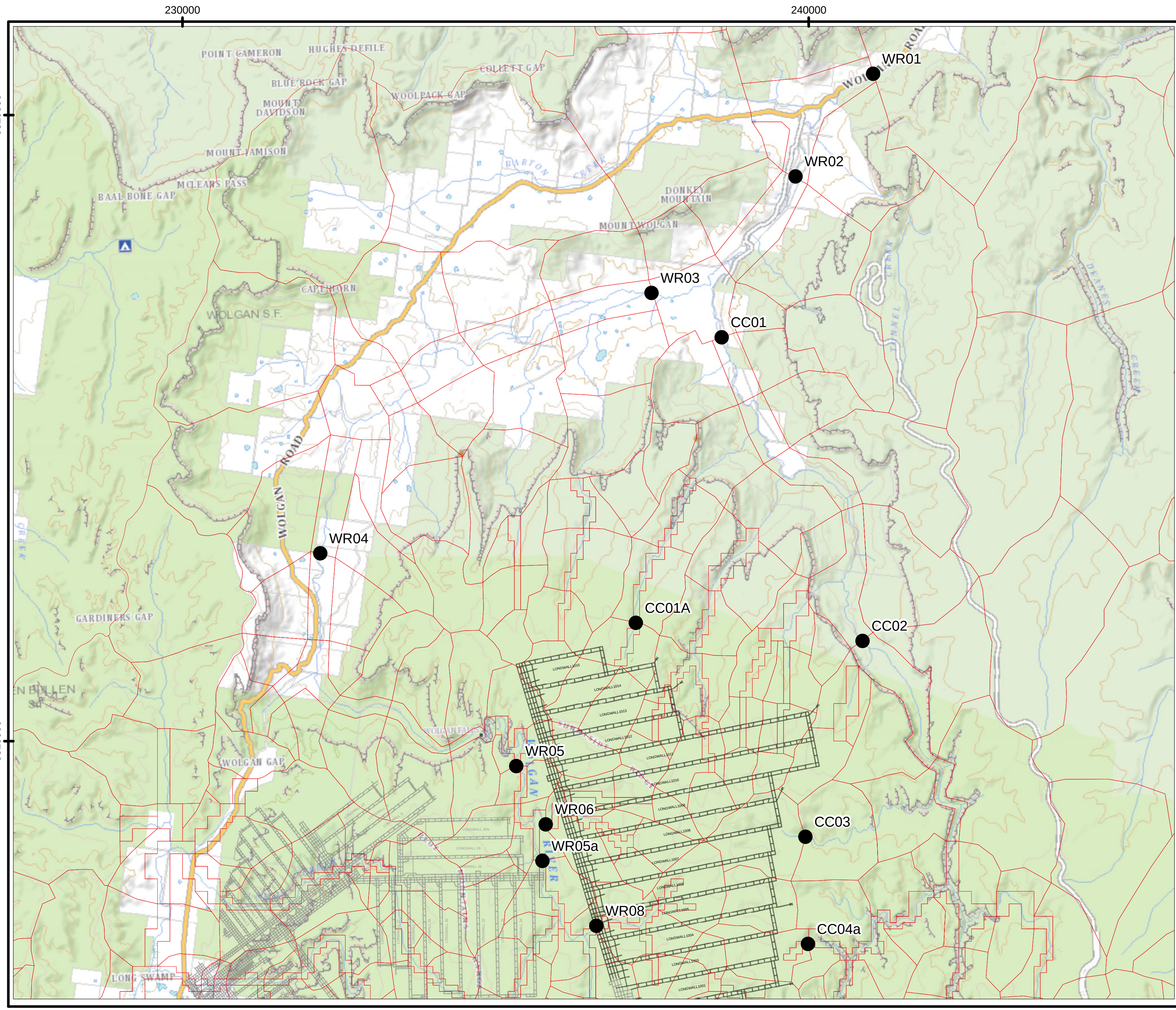
Closing

Should you require clarification, please contact the undersigned on 02 8245 0313 or by email jbell@jbsg.com.au.

Yours sincerely:

Justin AW Bell

Dr Justin Bell
Principal Environmental Engineer
JBS&G Australia Pty Ltd



Legend:

- Model Output Locations
- SAPSWBM Catchments
- Proposed Extension
- Existing Mine

JBS&G

Job No: 56339

Client: Centennial Angus Place Pty Ltd

Version: L02Rev0	Date: 11-Sep-2019
Drawn By: JZ	Checked By: JB

Scale 1:80,000

0 1,600 3,200

Meters

Coor. Sys. GDA 1994 MGA Zone 56

Groundwater Model Output Locations

FIGURE: 1

File Name: N:\Projects\JacobsGroupAustraliaPtyLtd\56339_AngusPlaceMineExtensionProject\Figures\GIS\Maps\L02Rev0_D001_LocationOfModelOutput.mxd

Reference: © Department of Finance, Services & Innovation 2018

Attachment A

A1. Hydrogeological Model Output – Carne Creek Catchment

Figure A.1: Time-Series Model Output (CC01) – Carne Creek (Node PAS423a): Baseflow and Change in Baseflow (m3/d) (Upper is 10th percentile; Middle is 90th percentile; Bottom is SIM0)

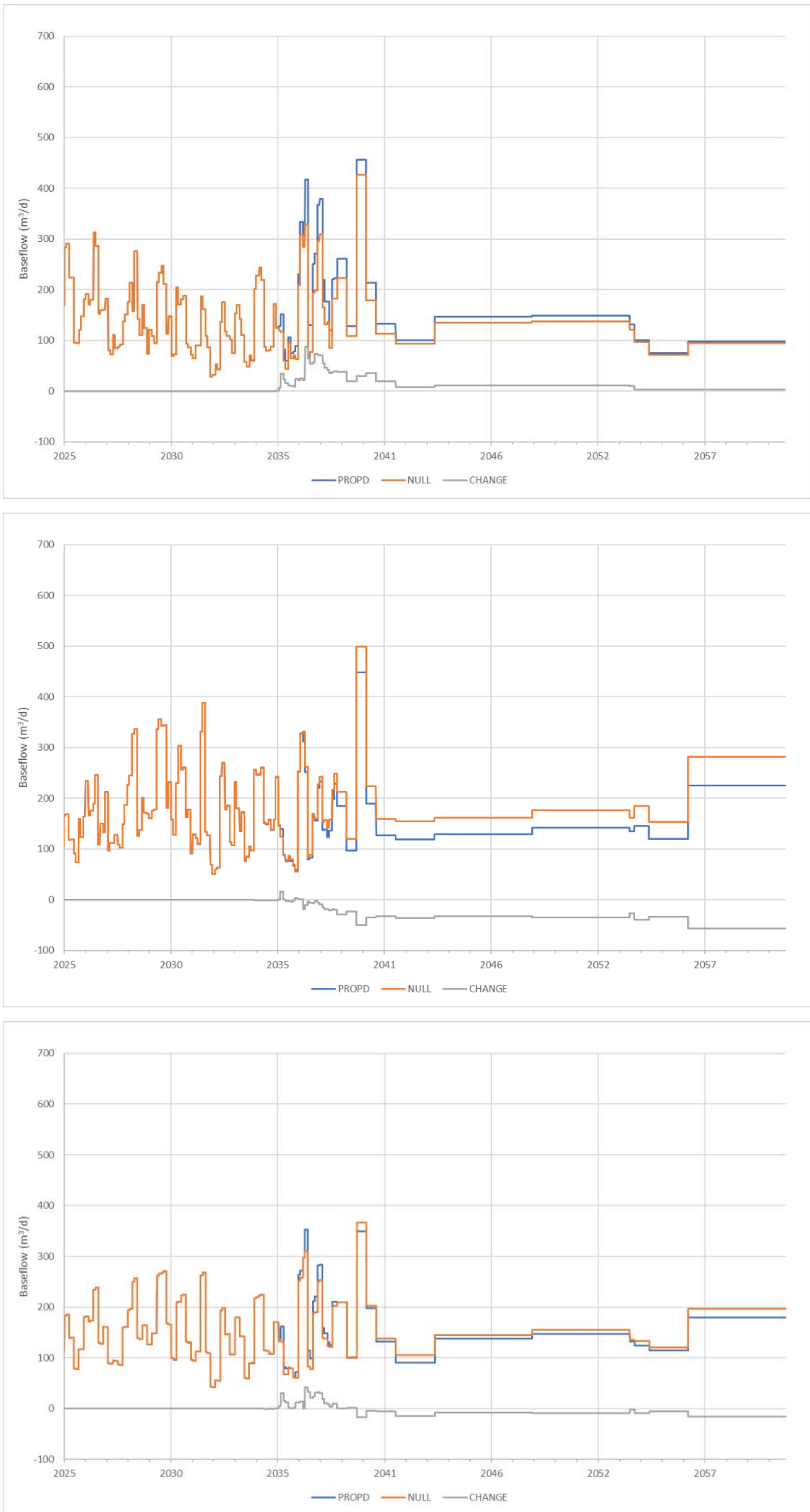


Figure A.2: Time-Series Model Output (CC01A) – Trail Six Swamp (Node NAT342a): Baseflow and Change in Baseflow (m3/d) (Upper is 10th percentile; Middle is 90th percentile; Bottom is SIM0)

Figure A.3: Time-Series Model Output (CC02) – Carne Creek, East of LW1011 (Node NAT490a): Baseflow and Change in Baseflow (m3/d) (Upper is 10th percentile; Middle is 90th percentile; Bottom is SIM0)

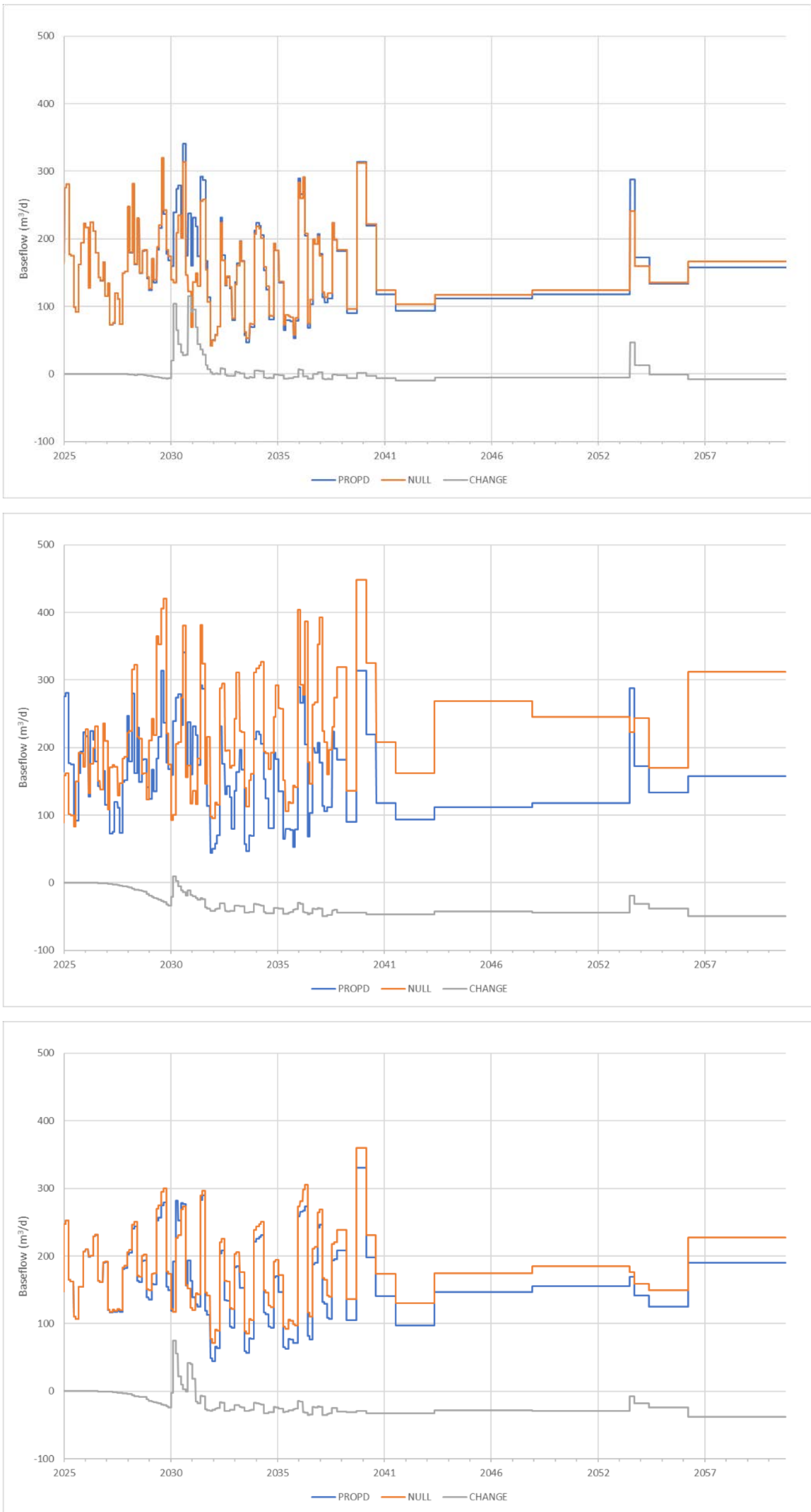
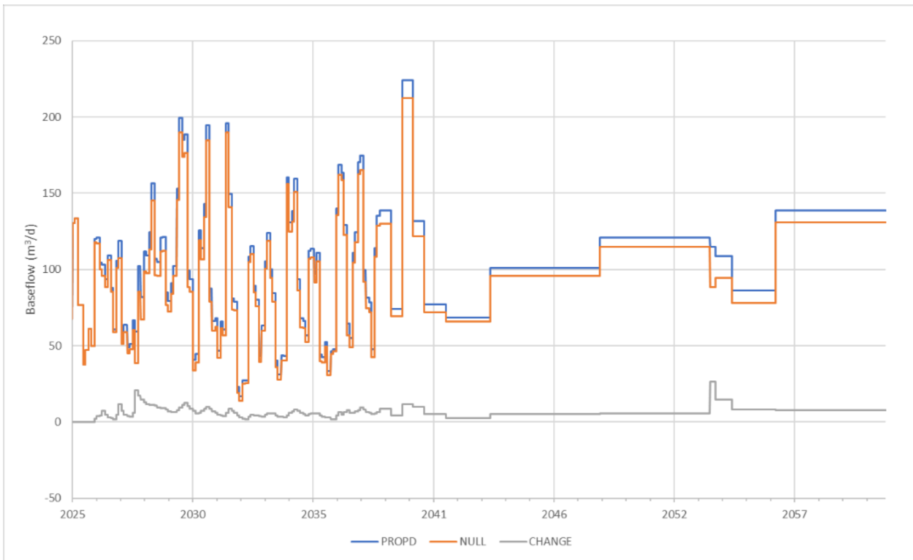
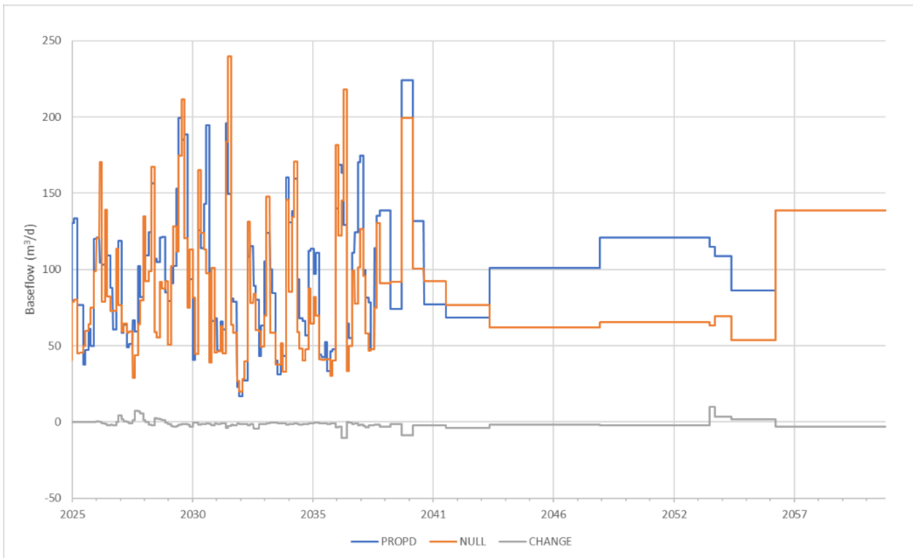


Figure A.4: Time-Series Model Output (CC03) – Birds Rock Swamp (Node NAT497a): Baseflow and Change in Baseflow (m3/d) (Upper is 10th percentile; Middle is 90th percentile; Bottom is SIM0)





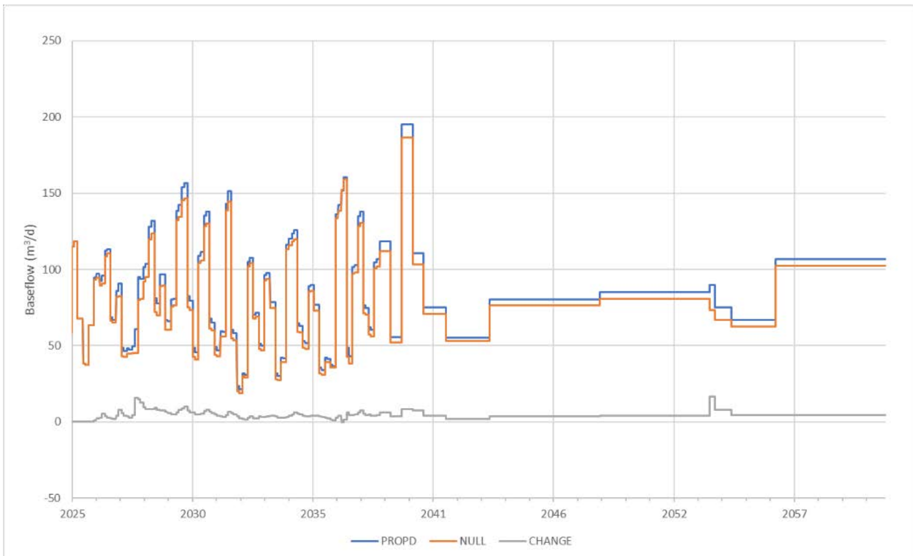


Figure A.5: Time-Series Model Output (CC04a) – Crocodile Swamp (Node NAT562a): Baseflow and Change in Baseflow (m3/d) (Upper is 10th percentile; Middle is 90th percentile; Bottom is SIM0)

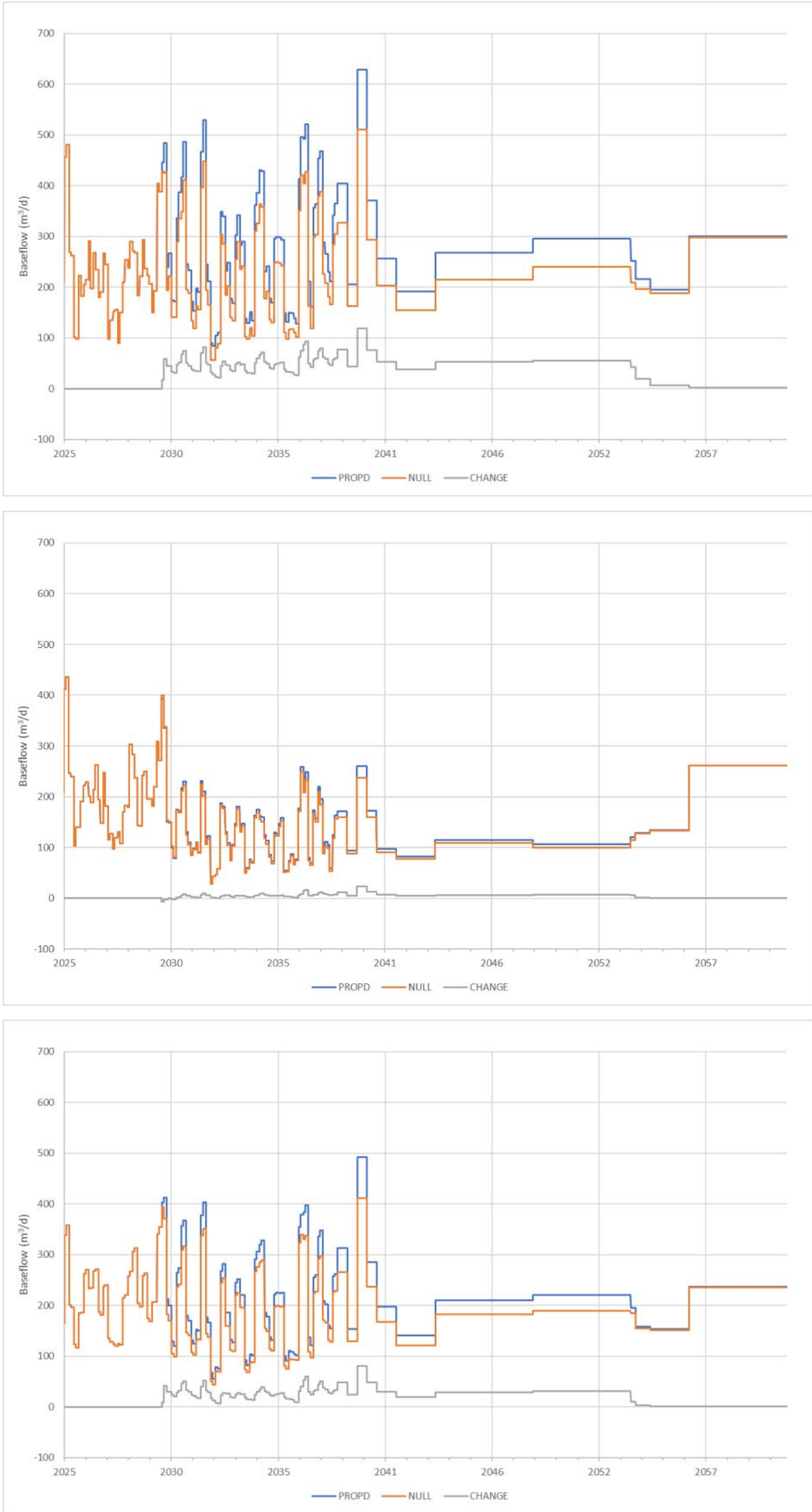
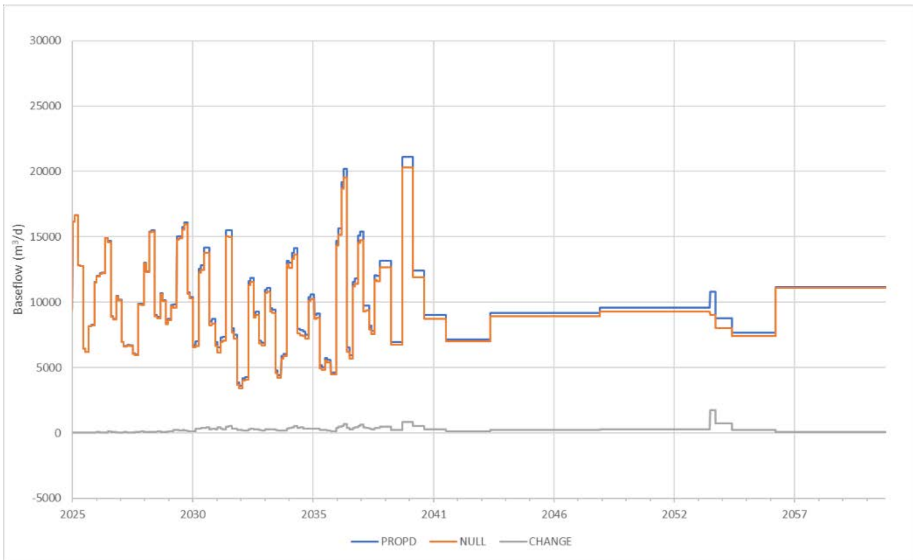
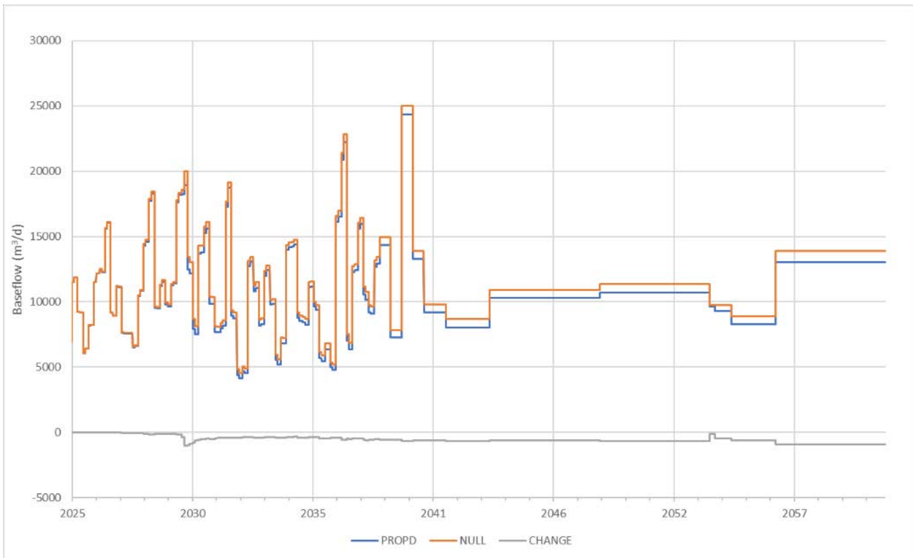


Figure A.6: Time-Series Model Output (CC06) – Carne Creek Swamp (Node PAS526a): Baseflow and Change in Baseflow (m3/d) (Upper is 10th percentile; Middle is 90th percentile; Bottom is SIM0)

Attachment B

B1. Hydrogeological Model Output – Wolgan River Catchment





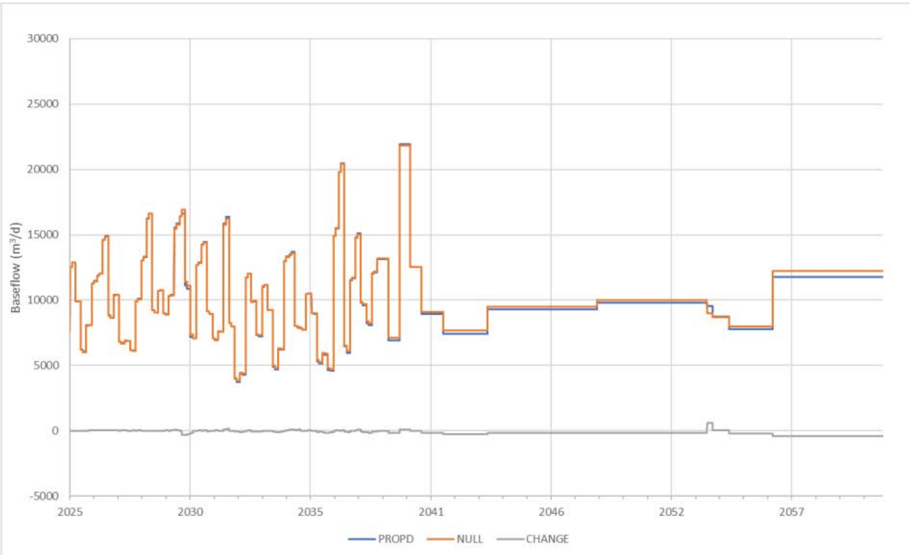


Figure B.1: Time-Series Model Output (WR02) – Wolgan River below Carne Creek (Node PAS421a): Baseflow and Change in Baseflow (m3/d) (Upper is 10th percentile; Middle is 90th percentile; Bottom is SIM0)

Figure B.2: Time-Series Model Output (WR03) – Wolgan River above Carne Creek (Node PAS428a): Baseflow and Change in Baseflow (m3/d) (Upper is 10th percentile; Middle is 90th percentile; Bottom is SIM0)

Figure B.3: Time-Series Model Output (WR04) – Wolgan River (Node PAS431a): Baseflow and Change in Baseflow (m3/d) (Upper is 10th percentile; Middle is 90th percentile; Bottom is SIM0)

Figure B.4: Time-Series Model Output (WR05) – Wolgan River below Twin Gully Swamp (Node NAT462a): Baseflow and Change in Baseflow (m3/d) (Upper is 10th percentile; Middle is 90th percentile; Bottom is SIM0)

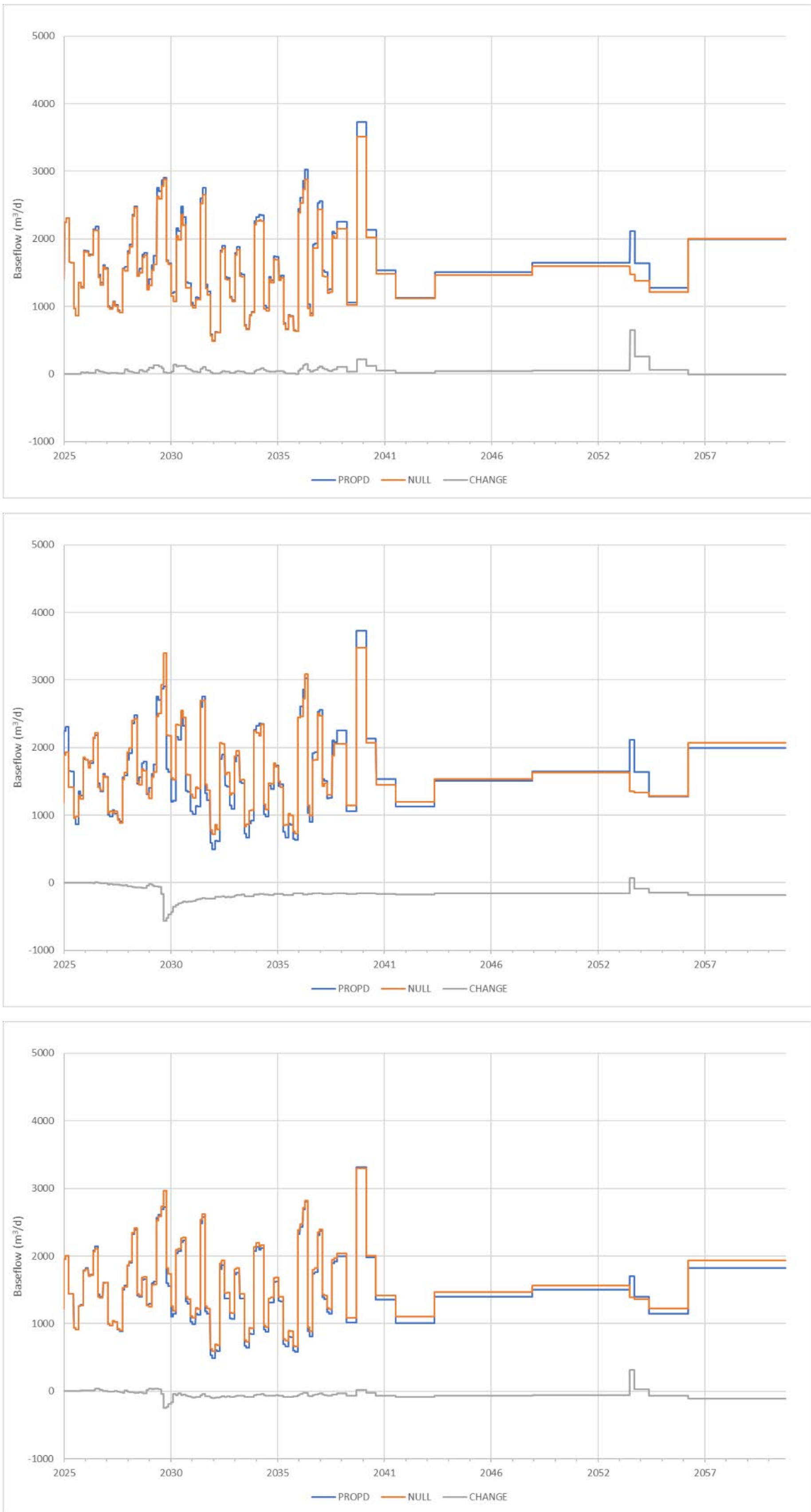
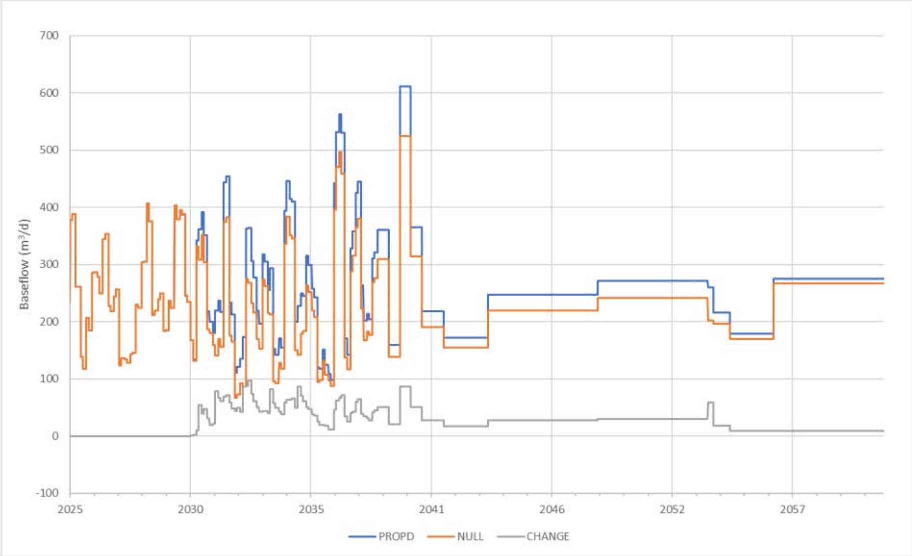
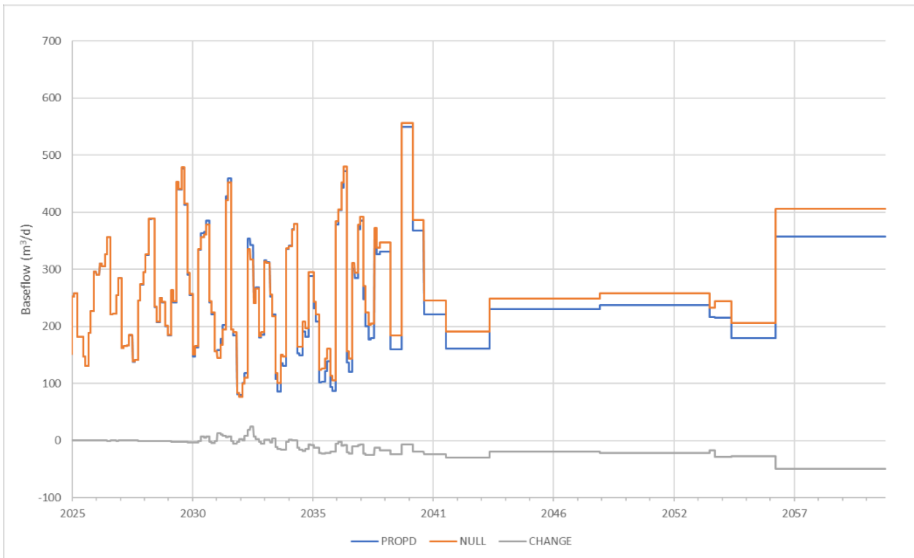


Figure B.5: Time-Series Model Output (WR05a) – Wolgan River between Twin Gully Swamp and Tri-Star Swamp (Node NAT332a): Baseflow and Change in Baseflow (m3/d) (Upper is 10th percentile; Middle is 90th percentile; Bottom is SIM0)





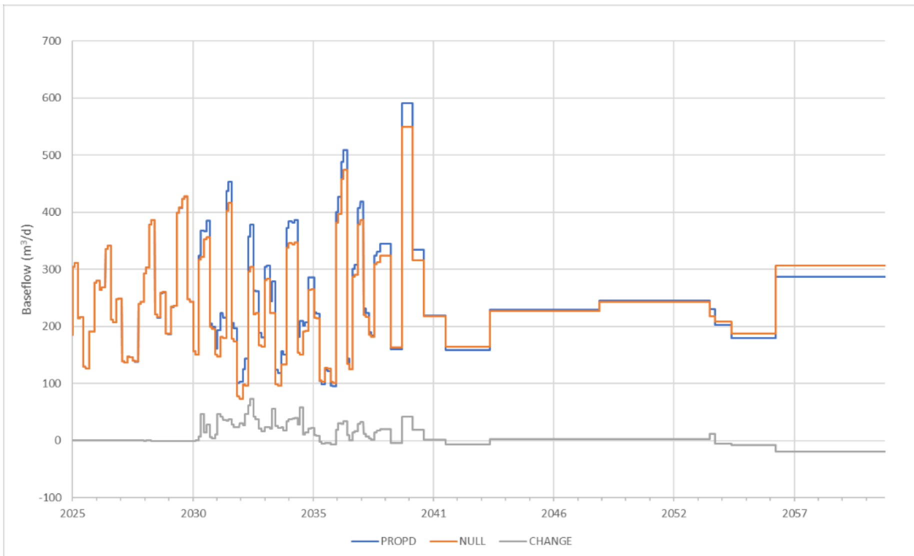
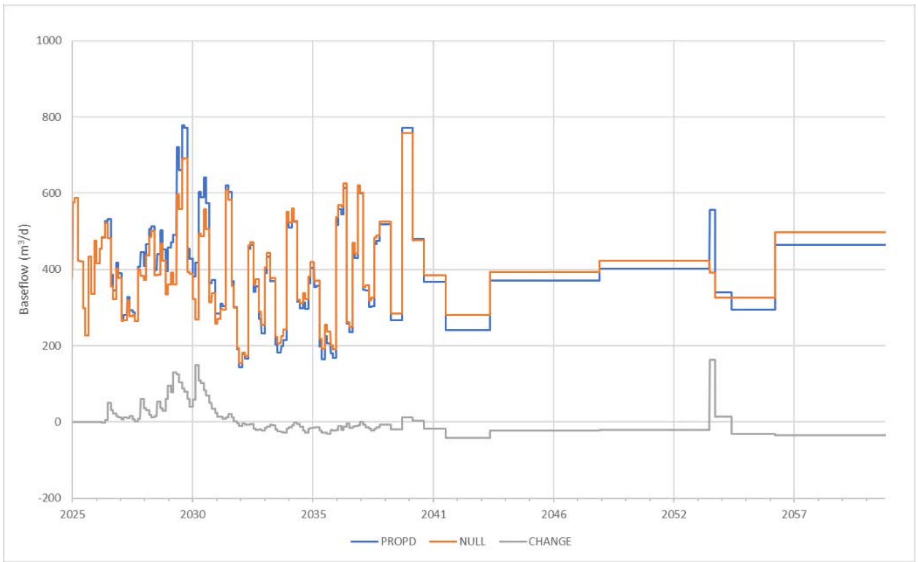
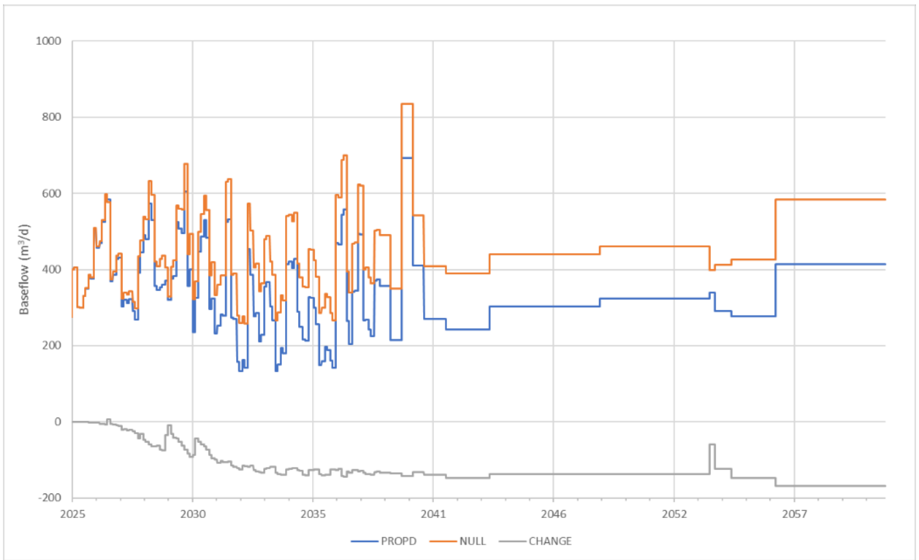


Figure B.6: Time-Series Model Output (WR06) – Twin Gully Swamp (Node NAT322a): Baseflow and Change in Baseflow (m3/d) (Upper is 10th percentile; Middle is 90th percentile; Bottom is SIM0)





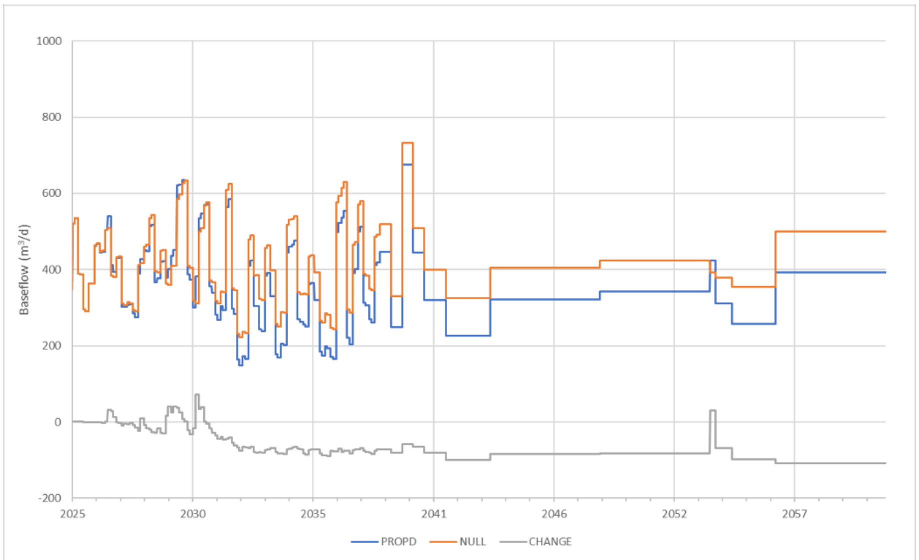


Figure B.7: Time-Series Model Output (WR08) – Tri-Star Swamp (Node NAT324a): Baseflow and Change in Baseflow (m3/d) (Upper is 10th percentile; Middle is 90th percentile; Bottom is SIM0)