Hydrology and Water Quality Assessment for Huntly Mine

Pinjarra Alumina Refinery Revised Proposal

Alcoa of Australia Limited

06 December 2024

The Power of Commitment

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Executive summary

Introduction

Alcoa of Australia Limited (Alcoa) is proposing to increase production at the Pinjarra Alumina Refinery (Refinery) by 5 per cent from 5.0 million tonnes per annum (Mtpa) to 5.25 Mtpa and transition the Huntly Bauxite mine to the proposed Myara North and Holyoake mine regions and re-enter the O'Neil mine region (the Proposal). The Proposal is located in the Peel region of Western Australia (WA), approximately 100 km south-east of Perth.

The Proposal will be subject to environmental impact assessment under Part IV of the WA Environmental Protection Act 1986 (EP Act), and the Environment Protection Biodiversity Conservation Act 1999 (EPBC Act). The environmental impact assessment will be via a Public Environmental Review (PER).

The Myara North development envelope lies adjacent and north of the existing Myara mining operations. The Holyoake development envelope lies north-east of Dwellingup, approximately 20 km south of Myara North. The O'Neil development envelope lies adjacent and southeast of the existing Myara mining operations, 5 km south of Myara North and 10 km north of Holyoake. Collectively, the three development envelopes are referred to as Mine Development Envelopment (DE).

The proposed Myara North, Holyoake and O'Neil development envelopes (DE) (collectively referred to as the Mine DE) is located in State Forest, which is managed for multiple uses including drinking water production, timber harvesting (noting native timber harvesting in the state ceased as of 2024), pine plantation, and recreation.

Assessment scope

This Hydrology and Water Quality Assessment has been prepared to support the EPA assessment and focuses on the Myara North, Holyoake, and O'Neil DEs of the Proposal.

The aim of the Hydrology and Water Quality Assessment is to establish a preliminary baseline understanding of surface water and groundwater conditions along with the values these systems support within the Mine DE. It also supports the assessment of the Proposal's potential impacts on these inland water systems, informing mine and infrastructure planning, as well as environmental mitigation measures for the Proposal.

The scope of works to support this assessment comprised the following:

– Complete a comprehensive desktop assessment comprising review of databases, existing studies and geospatial information for the Huntly Mine, and proposed Mine DE to inform the baseline monitoring program and development of conceptual and numerical models
– Develop a baseline monitoring program - including development of a surface water and groundwater Sampling and Analysis Quality Plan, installation of surface water monitoring equipment, and drilling and installation of groundwater monitoring bores and equipment - and undertake baseline surface and groundwater monitoring
– Carry out catchment scale modelling groundwater surface water interaction using updated Mine DE conceptualisation from field investigations including outcomes from the baseline monitoring program
– Complete technical reports for the various supporting studies including:
    - Baseline Surface and Ground Water Monitoring Report and the associated Sampling Analysis and Quality Plan and Surface and Groundwater Monitoring Installation Report – Myara North and Holyoake
    - Hydrological setting and Understanding – Myara North and Holyoake
    - Groundwater Modelling Report for Huntly Mine – Myara North
    - Groundwater Modelling Report for Huntly Mine – Holyoake
    - Baseline Surface and Ground Water Monitoring Report – O'Neil including Bore Completion Report

A Drinking Water Risk Assessment was conducted for the Serpentine, Serpentine Pipehead, South Dandalup, and Wungong Brook catchments, evaluating potential contaminants from both mining and non-mining activities and

their potential impacts on human health. A separate report addresses the drinking water risks associated with the Proposal, and as such, these risks are not covered in this report.

This report is subject to, and must be read in conjunction with the limitations, assumptions and qualifications contained throughout the report.

Mine DE baseline assessment

Regional setting

Western Australia's southwest has experienced a 15-20% decrease in rainfall since the 1970s, with further reductions of 2-14% predicted by 2030. Temperature is expected to rise by 0.7°C, and potential evapotranspiration is forecast to increase by 2-3%. Rainfall decreases with distance inland, with historical rainfall isohyets including the 1,100 mm annual rainfall isohyet (referred to as the High Rainfall Zone (HRZ)) and the historical 900 to 1,100 mm annual rainfall isohyet (referred to as the Intermediate Rainfall Zone (IRZ)) defining different hydrological effects across the Huntly Mine area where the Proposal is located.

The Huntly Mine (including proposed Myara North, Holyoake DEs and historic O'Neil DE) lies within the Darling Plateau, an undulating lateritic plateau. Soils have developed over the granitic terrain in a typical laterite profile with sand and gravelly topsoils which transition into a saprolite zone of weathering. The landforms across the Myara North, Holyoake, and O'Neil DEs share significant similarities, with Dwellingup lateritic uplands being predominant in all regions. Other commonly occurring landforms across the Mine DE also include Cooke upland hills and rock outcrops, Yarragil minor valleys with swampy floors and Murray major valleys.

Bauxite is naturally occurring in the region, primarily within the lateritic profile developed over the bedrock. This laterite, formed from the weathering of parent rock, includes a ferruginous or aluminous hard cap above a kaolinitic saprolite zone. The bauxite resources, particularly concentrated along the flanks and tops of ridges, are typically 2 to 3 meters thick in granite-derived areas. The presence of bauxite is integral to the region's geology, with its formation being a key natural process linked to weathering and lateritisation.

Hydrological and hydrogeological setting

The groundwater in the Mine DE is hosted in weathered and fresh Archaean basement crystalline rocks, with additional sediments in incised drainage lines. Key aquifer units include:

– Shallow weathered zone: A seasonal aquifer with significant storage and flow capacity, comprising lateritic caprock and gravely/sandy sediments.
– Deep weathered zone: Limited permeability with some storage potential, primarily clay-rich.
– Saprock: A transition zone with enhanced permeability.
– Fractured bedrock: Permeability depends on fracture development and connectivity.

Groundwater flows generally follow topography, discharging into creek lines and feeding surrounding reservoirs, including Serpentine and South Dandalup dams. Groundwater discharge contributes to streamflow, with baseflow varying significantly across years, potentially being the dominant component in some catchments.

The Myara North, Holyoake and O'Neil DEs intersect the catchment areas of public drinking water supply reservoirs, including:

– Serpentine Dam (Myara North and O'Neil DEs) and Serpentine Pipehead Dam (Myara North DE);
– Wungong Brook Dam (Myara North DE); and
– South Dandalup Dam (Holyoake DE).

Within the Myara North DE the Serpentine Reservoir is fed by the Serpentine River, with other major tributaries including Big Brook and 39 Mile Brook. The South Dandalup Reservoir in the Holyoake DE is fed primarily by the South Dandalup River.

The Serpentine and South Dandalup reservoirs form part of the Water Corporation's Integrated Water Supply Scheme (IWSS) supplying drinking water to the Perth and Peel metropolitan region, the Goldfields and parts of the Great Southern. The dams are protected by a Reservoir Protection Zone (RPZ), which forms a 2 km buffer area

around the top water level of the reservoir, including the reservoir itself, but not extending outside the catchment area. The reservoirs are managed in accordance with their respective Drinking Water Source Protection Plan.

Surface water and groundwater characterisation in the proposed Mine DE is based on a combination of historic monitoring data (e.g., surface water gauging stations installed since 1980s, groundwater monitoring bores installed since 1970s) primarily in and around the Myara North mine region (and Holyoake mine region to a lesser extent) along with recent monitoring by GHD (2020 - 2024) in the three Proposal mine regions. It is noted that there is no historical monitoring data for the O'Neil DE, and large areas of the proposed mining catchment in each region currently lack streamflow gauging or groundwater data.

The drying climate in southwestern Western Australia has led to a decline in groundwater levels, reducing connectivity with stream beds and causing a shift from perennial to ephemeral streamflow. Long-term data shows a decline of 1-10 metres in Myara North and around 9 metres in Holyoake since the 1990s. This is reflected in streamflow data, with a marked reduction in annual streamflow and a delay in flow commencement, especially after 2000. Similarly, in Holyoake, streamflow has decreased, and flow seasonality shows delays in flow start and earlier cessation, mirroring trends in Myara North.

Surface water and groundwater are interconnected through drainage lines, wetlands, and reservoirs. Surface water flow is typically short-lived, lasting 2-3 weeks after rainfall, with contributions from runoff, near-surface flow, and groundwater. Shallow subsurface flows, influenced by rainfall, temporarily resaturate permeable materials, creating localised flow which merges with baseflow during winter rains. Baseflow, primarily from groundwater, sustains streamflow and riparian zones (including wetlands) during dry periods provided groundwater levels remain sufficiently high. Major rainfall events affect streamflow salinity, with higher TDS values correlating with reduced streamflow. The connectivity of surface water and groundwater is considered similar across the three Proposal mine regions, though deeper groundwater in the Holyoake and O'Neil regions may reduce baseflow and streamflow duration. Three main water sources support streamflows and riparian zones: surface runoff, near-surface lateral flow, and baseflow from groundwater discharge.

Surface water across the Myara North, Holyoake, and O'Neil mine regions is generally fresh, non-saline, and minimally impacted by human activities. Key characteristics include neutral to slightly acidic pH, low turbidity, low total suspended solids, and low nutrient levels. Some occasional exceedances in metals (zinc, copper) and nutrients were observed, particularly in the Holyoake and O'Neil mine regions. Recorded PFAS levels within the Proposal mine regions were low and well below drinking water criteria. Microbiological parameters were present at all Proposal mine regions, with higher concentrations in the Holyoake compared to Myara North. No significant contamination from PAHs, BTEX, or other chemicals were found within the Proposal mine regions, except for minor occurrences in select samples.

Groundwater quality across the Myara North, Holyoake, and O'Neil mine regions is generally fresh, with salinity levels mostly below 500 mg/L TDS. The Myara North and Holyoake mine regions exhibit occasional salinity increases, with Myara North having a few bores reaching up to 2,000 mg/L and Holyoake up to 1,500 mg/L. In O'Neil, groundwater ranges from fresh to brackish, with an average EC of 1,910 µS/cm, varying from 248 µS/cm to 5,450 µS/cm. pH levels were consistent, averaging 5.3 in Myara North, 6.3 in Holyoake, and varying in O'Neil. All regions show low nutrient levels and metal concentrations typical of natural conditions, with occasional exceedances for zinc and cadmium. No BTEX or PFAS were detected in any of the Proposal mine regions, and minor detections of TRH and PAH were observed, likely due to drilling or bushfire activity. No seasonal changes in groundwater quality were noted across the Proposal mine regions.

Water use and environmental values

The Myara North, Holyoake, and O'Neil mine regions support various water use and environmental values, including drinking water supply (within catchment areas of public reservoirs), potential groundwater-dependent ecosystems (GDEs) such as riparian and phreatophytic vegetation, aquatic ecosystems reliant on groundwater, recreational and aesthetic values, and cultural heritage, with the Serpentine River being a registered Aboriginal ethnographic heritage site.

Potential GDEs were delineated from detailed flora and vegetation assessment across the Mine DE by Mattiske (2021, 2024). In summary, a total of 6,238 ha (26.1 per cent) of the Mine DE comprise of potential GDEs, including 3,485 ha (32.6 per cent) of the Myara North DE, 1,480 ha (19.4 per cent) of the Holyoake DE, and 1,273 ha (22.8 per cent) of the O'Neil DE.

The Myara North, Holyoake, and O'Neil DEs provide important fauna habitats, including drainage lines with low-density vegetation preferred by medium-sized mammals like Quenda and Quokka. Aquatic fauna in both Myara North and Holyoake are dominated by seasonal creeklines and ephemeral swamps, with high species endemism and seasonality. Carter's Freshwater Mussel (CFM) is unlikely to occur in both Myara North and Holyoake DEs due to seasonal streams and dry summer conditions. The O'Neil DE lacks suitable habitat for CFM and does not support aquatic fauna communities.

Hydrological effects of mining

A literature review of previously cleared and mined areas analogous to the Proposal indicates increased stream flows of 7% to 20% of rainfall during mining. In addition, an assessment of a former mining area adjacent to the Myara North DE indicates increased groundwater levels of on average 5.5 metres (but as much as 14 metres) as a response to mining and land clearing. This supports the assertion that local rises in groundwater levels (mounding) will progressively dissipate towards the groundwater discharge boundaries during mining. Changes in groundwater recharge and quickflow dynamics due to vegetation removal and subsequent bauxite mining has the potential to increase the groundwater level by several metres, with variations reflecting local hydrogeological conditions and properties. The potential rise in groundwater levels and associated increase in groundwater discharge may temporarily alter the water regime that supports environmental values in the Mine DE including riparian and swamp vegetation, aquatic ecosystems and reservoir/drinking water and recreational beneficial uses associated with the drainage lines and streams.

Modelling results and predictions

Catchment-scale numerical modelling for the Myara North and Holyoake mine regions was conducted to estimate groundwater level changes due to the Proposal for indicative mining periods comprising clearing/mining and rehabilitation periods. No modelling was completed for O'Neil mine region.

Myara North

Numerical modelling suggests an average increase in streamflow to the Serpentine Reservoir of 1.3 GL/year during the mining and rehabilitation period (2023–2033). Groundwater level mounding could range from 1-10 metres, particularly during wetter periods. After mining, streamflow is expected to decrease by 0.3 GL/year in the base climate case and 0.2 GL/year in the drying climate case.

Holyoake

Similar to Myara North, modelling predicts increased groundwater levels and streamflows in the Holyoake mine region. Streamflow to the South Dandalup Reservoir is expected to increase by 0.1 GL/year during the mining period (2029–2033) and 0.2-0.3 GL/year in the post-mining period. Groundwater level mounding in the Holyoake mine region may range from 1-10 metres, with lesser extents of mounding farther from cleared areas.

Streamflow Salinity Changes

Modelling predicts variable salinity changes during the mining period in both Myara North and Holyoake, with average reductions in TDS ranging from 1 mg/L to 10 mg/L for the current climate case and 1 mg/L to 7 mg/L for the drying climate case. In the post-mining period, TDS is expected to increase by 3-20 mg/L in Myara North and 11-24 mg/L in Holyoake, with slightly smaller impacts under drying climate conditions.

Climate Scenario Impact

Under current and drying climate scenarios, the impact of mining on salinity is relatively minor. In the Myara North mine region, the increase in TDS is between 3-20 mg/L for the current climate and 3-24 mg/L under the drying scenario. In the Holyoake mine region, salinity increases are similarly minor, with an average increase in TDS between 11-24 mg/L in the current climate and 6-13 mg/L under drying conditions.

Groundwater changes within potential GDEs

In both the Myara North and Holyoake DEs, groundwater mounding is predicted to be localised to mined areas, with the magnitude decreasing towards low-lying areas and potential GDEs. Mounding in most GDE-associated areas is expected to be under 1 m but can reach 1-5 m in some areas. Post-mining, mounding effects recede, with

residual mounding predicted to be 1-5 m in Myara North and up to 20 m in Holyoake, especially in dense mining areas.

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Appendix F Inland Waters Baseline Report Year 1 – O'Neil

Terminology

Terminology	Definition
Alcoa of Australia Limited (Alcoa)	The proponent of the Proposal.
GHD Pty Ltd (GHD)	Consultant engaged by Alcoa to prepare environmental approvals documentation and supporting technical studies for the Proposal.
Myara North Development Envelope (DE)	Myara North mine DE (9,997 ha) and associated infrastructure corridor (708 ha) within the Huntly mine region. 10,705 ha total
Myara North Infrastructure Corridor DE	Corridor adjacent to Myara North mine DE in which a haul road and other infrastructure may be developed. May also be referred to as a transport study area or haul road corridor. 708 ha
Holyoake Development Envelope	Holyoake mine DE (6,421 ha) and associated infrastructure corridor (1,203 ha) within the Huntly mine region. 7,624 ha total
Holyoake Infrastructure Corridor DE	Corridor adjacent to Holyoake DE region in which a conveyor, haul road, access road and other infrastructure may be developed. May also be referred to as a transport study area or conveyor/haul road corridor. 1,203 ha
O'Neil Development Envelope	O'Neil mine DE (5,571 ha) within the Huntly mine region. No infrastructure corridor is proposed for the O'Neil DE.
Mine Development Envelope	Total Mine Development Envelope (DE) for the Proposal, this being Myara North, Holyoake and O'Neil DEs and associated infrastructure corridors. 23,900 ha
Mining region	Sub-regions that comprise the Huntly Mine, including current (Myara), historic (O'Neil, McCoy) and future (Myara North, Holyoake), etc.
Haul Road	Truck and mine infrastructure access road linking into existing corridors.
Huntly Mine	Huntly Bauxite Mine within ML1SA. This includes the previous and current mine regions of Del Park, Huntly, White Road, McCoy, O'Neil, and Myara, and the transition to the future mine regions of Myara North, Holyoake and re-entering of O'Neil.

Abbreviations

Abbreviations	Definition
ADWG	Australian Drinking Water Guidelines
AEP	Annual Exceedance Probability
ANZG	Australia New Zealand Guidelines
BoM	Bureau of Meteorology
BSEC	Bauxite Strategic Executive Committee
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
CAR	Comprehensive Adequate Representative
CRD	Cumulative Rainfall Departure
DE	Development Envelope
DWER	Department of Water and Environmental Regulation
EC	Electrical Conductivity
EPA	Environmental Protection Authority Western Australia
EP Act	Environmental Protection Act 1986
EPBC Act	Environmental Protection and Biodiversity Conservation Act
ERD	Environmental Review Document
ESD	Environmental Scoping Document
FPC	Forest Products Commission
GDE	Groundwater Dependent Ecosystem
ha	Hectares
HRZ	High Rainfall Zone
IRZ	Intermediate Rainfall Zone
km	Kilometres
LTRMS	Long Term Residue Management Strategy
MBAS	Methylene Blue Active Substances
mBGL	Metres Below Ground Level
MMPLG	Mining Management Planning Liaison Group
MOG	Mining Operations Group
µS/cm	Microsiemens Per Centimetre
mg/L	Milligrams Per Litre
ML	Megalitre
NTU	Nephelometric Turbidity Units
PAH	Polycyclic Aromatic Hydrocarbons
PER	Public Environmental Review
PDWSA	Public drinking water source area
PFAS	Per- and Polyfluoroalkyl Substances
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctane Sulfonate

Abbreviations	Definition
RPZ	Reservoir Protection Zone
SWL	Standing Water Level
TDS	Total Dissolved Solids
TMP	Trial Mining Project
TRH	Total Recoverable Hydrocarbons

Introduction

Project background

Alcoa of Australia Limited (Alcoa) is proposing to increase production at the Pinjarra Alumina Refinery (Refinery) by 5 per cent from 5.0 million tonnes per annum (Mtpa) to 5.25 Mtpa and transition the Huntly Mine to the proposed Myara North, and Holyoake mine regions, and re-enter the O'Neil mine region (the Proposal). The Proposal is located in the Peel region of Western Australia (WA), approximately 100 km south-east of Perth.

The Proposal will be assessed by the Environmental Protection Authority (EPA) under Part IV of the *WA Environmental Protection Act 1986* (EP Act), and the *Environmental Protection Biodiversity and Conservation Act 1999* (EPBC Act) via the bilateral agreement. The Proposal will be assessed via Public Environmental Review (PER).

One of the key environmental factors to be assessed in the PER is Inland Waters. The EPA (2018) define Inland Waters as:

> *The occurrence, distribution, connectivity, movement, and quantity (hydrological regimes) of inland water including its chemical, physical, biological and aesthetic characteristics (quality)*.

This Hydrology and Water Quality Assessment has been prepared to support the PER assessment and focuses on the characterisation of hydrological regimes and water quality for the Mine component of the Proposal.

Purpose of this report

This Hydrology and Water Quality Assessment draws on several technical studies commissioned by Alcoa (section 3.5) for the Mine DE to establish a preliminary baseline understanding of surface water and groundwater hydrological regimes and water quality. It also evaluates the Proposal's potential changes to hydrological regimes and water quality, to inform the assessment of impacts to the associated environmental values in the PER.

This assessment has been prepared in accordance with the Environmental Scoping Document (ESD) under Part IV of the EP Act and aligns with the EPA's 2018 *Environmental Factor Guideline for Inland Waters*.

The purpose of this report is to provide an understanding of the hydrological and hydrogeological conditions across the three Proposal mine regions and assess the potential changes in groundwater levels and quality (salinity), streamflow rates, and streamflow salinity, considering past mining activities and the Proposal.

Table 0.1 outlines the EPA scoping requirements as outlined in the ESD.

Table 0.1 EPA scoping requirements

EPA scoping requirements	Where addressed in this assessment
47. Characterise the surface water and groundwater systems in a local and regional context and describe recharge and discharge mechanisms, aquifer connectivity, surface water/groundwater interaction and water chemistry. This should include identifying and mapping groundwater and surface water dependent ecosystems, including the catchment interactions with the Peel-Yalgorup System Ramsar Site.	Sections 0, 0, 0 and 7
48. Undertake surveys to establish baseline water quality and the environmental values identified.	Sections 0, 0 and 7
51. Analyse, describe and assess surface water and groundwater impacts, including direct and indirect impacts, from the Proposal. This should include, but not limited to: a. changes to groundwater levels and surface water flows associated with the Proposal; b. changes to water quality; c. the nature, extent and duration of impacts; and d. impacts on environmental values of ground and surface water dependent ecosystems*;	Section 8 Item (a) and (b)

EPA scoping requirements	Where addressed in this assessment
e. impacts to aquatic fauna species or communities*; f. impacts to Peel-Yalgorup System – Ramsar Site*; g. cumulative impacts with existing operations, and other development and activities in the region including mining, timber harvesting, rehabilitation activities, fire, and interactions under projected climate change.	

*c, d, e, and f are addressed in the Environmental Review Document (ERD).

Scope of works

The scope of works is to:

- Complete a comprehensive desktop assessment comprising review of databases, existing studies and geospatial information for the Huntly Mine, and proposed Mine DE to inform the baseline monitoring program and development of conceptual and numerical models
- Develop and install a baseline monitoring program, including development of a surface water and groundwater Sampling and Analysis Quality Plan, installation of surface water monitoring equipment and groundwater monitoring bores, and completion of baseline surface and groundwater monitoring
- Carry out catchment scale modelling groundwater surface water interaction, using updated Mine DE conceptualisation from field investigations including the baseline monitoring program
- Complete technical reports for the various supporting studies including the Baseline Surface and Ground Water Monitoring Report and the associated Sampling Analysis and Quality Plan and Surface and Groundwater Monitoring Installation Report – Myara North and Holyoake (Appendix B), Hydrological setting and Understanding – Myara North and Holyoake (Appendix C), Groundwater Modelling Report for Huntly Mine – Myara North (Appendix D), Groundwater Modelling Report for Huntly Mine – Holyoake (Appendix E), and Baseline Surface and Ground Water Monitoring Report – O'Neil including Bore Completion Report (Appendix F).
- Provide a Hydrology and Water Quality Assessment technical report that consolidates the results and findings of the various supporting studies (this report).

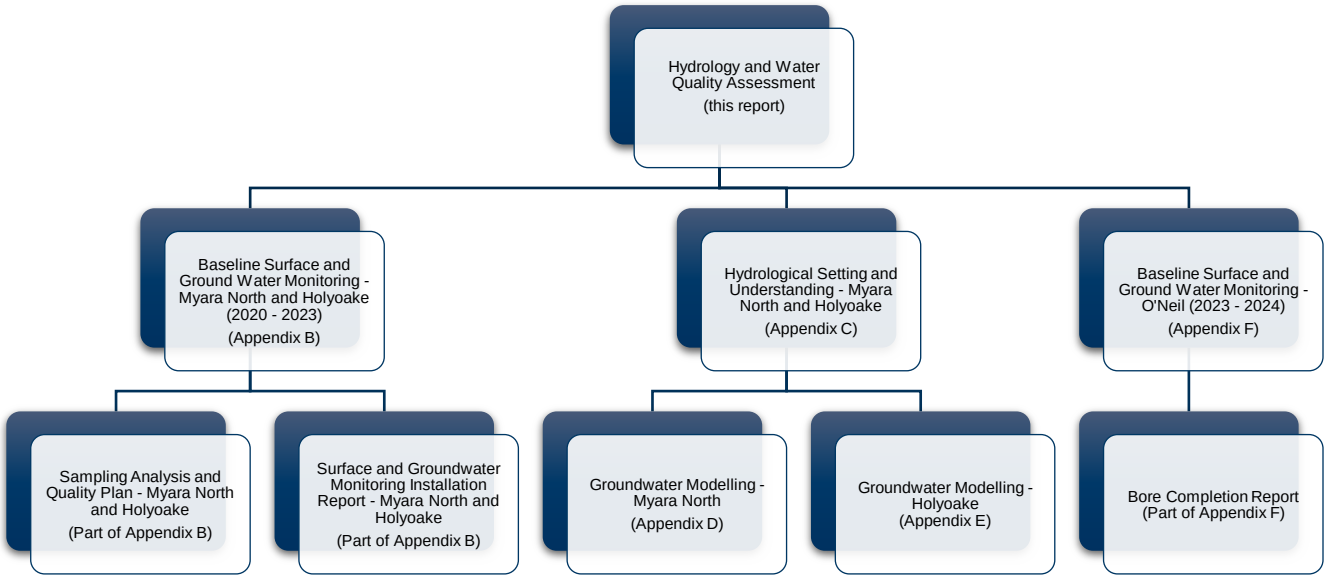


Figure 0.1 Reporting structure

Limitations and assumptions

This report has been prepared by GHD for Alcoa of Australia Limited and may only be used and relied on by Alcoa of Australia Limited for the purpose agreed between GHD and Alcoa of Australia Limited as set out in section 0 of this report.

GHD otherwise disclaims responsibility to any person other than Alcoa of Australia Limited arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Alcoa of Australia Limited and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

The opinions, conclusions and any recommendations in this report are based on information obtained from, and testing undertaken at or in connection with, specific sample points. Site conditions at other parts of the site may be different from the site conditions found at the specific sample points.

Investigations undertaken in respect of this report are constrained by the particular site conditions. Site conditions (including the presence of hazardous substances and/or site contamination) may change after the date of this Report. GHD does not accept responsibility arising from, or in connection with, any change to the site conditions. GHD is also not responsible for updating this report if the site conditions change.

Assessment methodology

Desktop assessment

A hydrological desktop assessment was completed to inform the various technical studies that were completed as part of the Hydrology and Water Quality Assessment.

The hydrological desktop assessment comprised a review of various literature and data sources related to the surface water and groundwater hydrology and water quality of the proposed Mine DE. The hydrological desktop assessment also incorporated a review of the existing Huntly Mine operations and management relevant to hydrology and water quality, including mine water use and water supply.

Data sources and previous studies

Alcoa has supported studies to assess the potential impacts of its mining activities on the environment since the 1970s, previously in association with the former Water and Rivers Commission as part of the *Joint Intermediate Rainfall Zone Research Program*. This research was overseen by the Bauxite Hydrology Committee, formerly a subcommittee of the Mining Management Planning Liaison Group (MMPLG), which was suspended in 2014. In 2024, the MMPLG was superseded by the Bauxite Strategic Executive Committee (BSEC).

The following generalised information sources were reviewed, the reference and details of which are presented in section 0:

– Alcoa Environmental Research Bulletins No 16 and No 22, relating to salinity research within mining exploration boreholes across the Darling Range
– Reports prepared by and for the Bauxite Hydrology Committee (Section 3.4)
– Published technical journals and research papers
– Geotechnical and hydrogeological reports and data including for soils and groundwater
– Flora and fauna surveys of the Proposal area, conducted as part of this study or previously conducted.

Groundwater and surface water related reports for historical, current, and future mining operations were also reviewed, including:

– Triennial Environmental Review 2015-2017; Alcoa WA Mining Operations, September 2018 (Alcoa of Australia Limited 2018)
– Annual Environmental Review 2018; Alcoa WA Mining Operations, July 2019 (Alcoa of Australia Limited 2019)
– Alcoa/DEC Working Arrangements; Bauxite Mining Operations, 2011-2015 (2011)
– Water Working Arrangements, Version 5 Effective Years of Operation 2018-2023(2019)
– Alcoa Mining and Management Program, 2019-2023 Inclusive, Huntly and Willowdale Mines, Western Australia Mining Operations, January 2019 (Alcoa of Australia Limited 2019)
– Draft Alcoa Mining and Management Program 2020-2024 Inclusive, Huntly and Willowdale Mines, Western Australia Mining Operations, December 2019 (2019)
– Huntly Mine Operations 10 Year Mine Plan 2019-2028 (1st edition May 2019)
– The following data have also been reviewed within the Mine DE and wider region:
– Data relating to sensitive environmental receptors, such as wetlands, threatened flora and fauna from published reports and Government of Western Australia databases
– Water monitoring data, including quality, levels, flows, and abstraction rates from Alcoa database and DWER Water Information Reporting and Water Register databases.
– Spatial and temporal data, including topography, drainage, vegetation, land use from Government of Western Australia databases.

A summary of the findings of key studies is chronicled in section 0, along with their gaps and limitations with respect to the proposed mining areas.

Baseline surface and groundwater monitoring program overview

A targeted monitoring program commenced on August 2020 to characterise the baseline surface water and groundwater conditions of the Myara North and Holyoake mine regions. For the O'Neil mine region a targeted monitoring program commenced from July 2023. In each Proposal mine region, the monitoring programs were built on previous Alcoa and DWER monitoring data (where available across the proposed Mine DE) and site characteristics, and designed to be commensurate with the key potential risks associated with existing and proposed activity.

While it is acknowledged that the monitoring period and spatial coverage are neither extensive nor fully representative of the unique geomorphology and catchment hydrology of the Darling Plateau, the collected data to date provides a valuable starting point for developing a preliminary understanding of site conditions within the proposed Mine DE. It is noted that Alcoa is in the process of establishing a wider network of surface water and groundwater monitoring sites across each of the three Proposal mine regions.

The Pinjarra Alumina Refinery Revised Proposal – Myara North and Holyoake Regions Baseline Hydrology Monitoring Program and Sampling Analysis and Quality Plan (SAQP) (GHD 2020a) documents the development of the baseline monitoring program, the sampling program and analytical work for the collection and validation of field data for Myara North and Holyoake. The O'Neil Inland Waters Baseline Report Year 1 and Bore Completion Report (GHD 2024b) outlines the development of the baseline monitoring program, the sampling program and analytical work for the collection and validation of field data for the O'Neil.

The scope of the baseline surface water and groundwater monitoring program for the Myara North and Holyoake DEs is summarised in Table 0.2, and the scope for O'Neil DE is outlined in Table 0.2. For Myara North and Holyoake DEs, the monitoring period extends from August 2020 to February 2023, while for O'Neil monitoring extends from July 2023 to June 2024.

Table 0.1 Groundwater and surface water monitoring locations – Myara North DE and Holyoake DE

Study Area	Groundwater monitoring*		Surface water monitoring	
	Existing bores	New bores	Surface water grab sample	Surface water logger^
Myara North DE	7 (25*)	18	20	6
Holyoake DE	4 (8*)	17	15	3
Note:	* Groundwater monitoring locations where groundwater quality samples were taken. Values in parentheses are total number of sites that groundwater level measurements were taken from			
	^ Surface water logger locations comprised water level logger, and turbidity and/or electrical conductivity logger			

Table 0.2 Groundwater and surface water monitoring locations – O' Neil DE

Study Area	Groundwater monitoring		Surface water monitoring	
	Number of monitoring wells	Number of loggers installed[1]	Number of surface water grab sample locations	Number of surface water loggers installed[2]
O'Neil DE	15	7	8	6
Note:	[1] Refers to number of groundwater level loggers, each area also includes one location with barometric logger [2] All surface water logger locations included a water level logger, with some also having a turbidity logger			

The monitoring locations were selected to establish baseline conditions, considering historical and existing monitoring locations (where available), and with selected reference locations using existing groundwater monitoring bores (Alcoa bores).

A summary of the baseline monitoring results across the three mine regions is presented in section 0 for Myara North, section 0 for Holyoake, and section 7 for O'Neil.

Detail of the baseline monitoring program is provided in the following supporting technical reports:

– GHD (2023a) Baseline Surface Water and Groundwater Monitoring Report – Myara North and Holyoake 2020-2023 (Appendix B)
– GHD (2024b) Inland Waters Baseline Report Year 1 - O'Neil (Appendix F)

Model development

Numerical modelling was completed for Myara North DE and Holyoake DE to:

– Estimate changes to the watertable due to mining and rehabilitation, to inform the potential Groundwater Dependent Ecosystem (GDE) impact assessment.
– Estimate changes in surface flows due to mining and rehabilitation.
– Evaluate those changes in a model uncertainty framework for risk analysis.

Conceptual model development informed numerical model build, simulation, and calibration, and is detailed in Appendix C.

The catchment-scale hydrological system responds to natural variability in climate, with spatial differences in response controlled by the topography, recharge and discharge mechanisms, and the variability in the subsurface material properties. The hydrological response in the study area is to be further affected by the effects of progressive clearing, mining, and rehabilitation. The combined effects of these spatially and temporally varying stressors result in hydrological responses that can be complex and highly variable.

While replicating such complex behaviour with a high degree of accuracy is often not feasible, the modelling provides an important mechanism for closely examining the cause-effect relationship observed in the field data. For example, the incremental effects of mining can be easily discerned from the natural variability simulated by the model. Where this is supported by data, the numerical modelling can provide a sensible basis for projecting potential impacts of future mining activities. The goal of numerical modelling is to simulate the overall system behaviour and incremental effects of mining, using the data collected over a period of several decades and knowledge gained from relevant prior studies.

The overall approach to the modelling is centred around assimilation of as much data of relevance to the required predictions of interest as is possible (and based on availability). This is implemented in a framework that recognises model input and process representation uncertainties, in such a way that they are carried through to their effects on model predictions.

This regional scale, spatially distributed groundwater flow model is required to answer questions relating to changes in the watertable (and associated impacts on potential GDEs) and baseflow impacts of bauxite mining.

Detail of the numerical modelling is provided in the following supporting technical reports:

– GHD (2021a) Pinjarra Alumina Refinery Revised Proposal; Hydrological Setting and Understanding Report – Myara North and Holyoake (Appendix C)
– GHD (2021b) Pinjarra Alumina Refinery Revised Proposal; Groundwater Modelling Report for Huntly Mine – Myara North (Appendix D)
– GHD (2021c) Pinjarra Alumina Refinery Revised Proposal; Groundwater Modelling Report for Huntly Mine Myara North – Holyoake (Appendix E)

Project site setting

Project location and overview

This surface water and groundwater study relates to the transition of the Huntly Mine to the Myara North and Holyoake mine regions, and the re-entering of the O'Neil mine region. The proposed Mine DE comprising these three mine DEs and adjacent infrastructure corridors is presented in Figure A-1 (Myara North) and Figure A-2 (Holyoake) and Figure A-3 (O'Neil) in Appendix A. The Avoidance Zone (AZ), Low Disturbance Area (LDA), and Mine Development Zone (MDZ) within the proposed Mine DE are presented in Figure A-4 (Myara North), Figure A-5 (Holyoake) and Figure A-6 (O'Neil) in Appendix A.

The proposed Myara North DE lies north of the existing Myara mine region. It is bounded by State Forest to the west, Serpentine Dam to the south west, Monadnocks Conservation Park to the east, and the former Jarrahdale Mine to the north. The Myara North DE is predominantly zoned as State Forest, which is managed for multiple uses including drinking water production, pine plantation and recreation. Alcoa mined in this vicinity, near Jarrahdale, from 1963 to 1998.

The proposed Holyoake DE lies south of the McCoy mine region, which retains operating mine facilities. It is bounded by Lake Banksiadale (South Dandalup Dam) to the north-west and Pinjarra-Williams Road immediately to the south. The Holyoake DE is predominantly zoned as State Forest, which has historically been managed for multiple uses including drinking water production, timber harvesting (until 2024), and recreation.

The proposed O'Neil DE lies east of the existing McCoy mine region, south of the proposed Myara North mine region (and south of the Serpentine Dam) and is bounded by Monadnocks Conservation Park to the north-east. The O'Neil DE is predominantly zoned as State Forest with multiple historical land use including timber harvesting (until 2024), recreation, conservation, firewood collection and apiaries.

A description of the Development Envelopment for each mine region is provided in Table 0.1.

Table 0.1 Mine DE breakdown

Development Envelope	Myara North	Holyoake	O'Neil
Mine DE	9,997 ha	6,421 ha	5,571 ha
Infrastructure Corridor DE	708 ha	1,203 ha	-
Total DE	**10,705 ha**	**7624 ha**	**5,571 ha**

Construction in the proposed Myara North DE is scheduled to occur from approximately 2026, with operations taking place from 2028 to 2034. The transition to Holyoake DE is scheduled to commence around 2028, post construction activities. From approximately 2026 to 2032, mining operations at Huntly Mine are proposed to transition to the previously mined O'Neil mine region.

Two infrastructure corridors are proposed to facilitate operations within the Myara North DE. An infrastructure corridor is proposed within the Myara North DE to support the development of a water pipeline extending to the Serpentine Dam and a pumping station at the dam. A second infrastructure corridor will extend into the Myara mine region to enable the construction of the Kisler Transfer Station and primary haul road linking the Myara crusher to the new mine facility within the Myara North mine DE.

A conveyor is proposed for the Holyoake mine region. extending from the historic White mine region to a new mine facility within the Holyoake DE. The proposed haul road network within the Holyoake DE will connect the proposed mine facility within the DE to the pre-existing haul road within the McCoy mine region.

No infrastructure corridor is proposed for the O'Neil DE. A haul road network will be developed within the O'Neil DE and link up to the proposed primary haul road within the McCoy mine region. A new office/crib facility and

primary haul road is proposed outside but adjacent to the O'Neil DE and is captured outside of the scope of the Proposal[1].

Overview of the bauxite mining process

Alcoa's bauxite mining process involves:

- Pre-mining environmental and heritage surveys.
- Exploration drilling (120 m or 60 m grid, subsequently refined to 30 m and 15 m grids) to identify ore bodies suitable for mining.
- Salvage of timber by the Forest Products Commission (FPC).
- Vegetation clearing.
- Removal of topsoil and overburden and separate stockpiling for re-use later or immediate re-use on an area undergoing rehabilitation.
- Drilling and blasting of caprock (and bulldozing in some areas).
- Establishment of drainage protection measures to capture runoff and sediment from the mine pit, where required.
- Mining of bauxite, haul road transport and associated crushing and conveying to the refineries.
- Rehabilitation to jarrah forest by regrading and contouring of pits to be compatible with the surrounding terrain, followed by ripping (undertaken up to 1.5 m depth) to remove compaction.
- Further ripping (post-replacement of topsoil and overburden in sequence) of the area (up to 0.8 m depth) to prepare for seeding and to facilitate infiltration and reduce erosion.
- Seeding and planting of nursery raised seedlings and fertilising.

Bauxite is found in the form of tabular ore bodies averaging 4 to 5 m thick and in aerial extent varying from approximately 0.5 to 150 ha. Mining of bauxite is characterised by a mosaic of shallow and widespread mine voids linked to a centrally-located crusher by a network of haul roads.

The topsoil and overburden vary in depth from 0 to 1.5 m, with the underlying bauxite ore consisting of 1 to 4 m of friable material and, in some cases, a cemented layer or duricrust.

Mine clearing is integrated with forest harvesting through Alcoa's working arrangements with the FPC, along with other third parties, to maximise wood residue re-use practices. Alcoa completes removal of forest residue through burning, scraping and excavation.

After mining, the area is rehabilitated with the intention of restoring a functioning jarrah forest ecosystem that can support pre-mining land uses. The process of vegetation re-establishment and the return to pre-mining hydrological trends typically spans up to 10 years. Around 40 to 50 different plant species are planted as seeds sourced from the surrounding forest within defined provenance zones or from nursery-raised recalcitrant plants.

Potential effects of bauxite mining on hydrological systems

Bauxite mining activities have the potential to cause increased rainfall recharge to groundwater due to the reduced evapotranspiration (vegetation removal) and increased soil disturbance (increase in soil surface area and possible increase in permeability). The hydrologic function of bauxite layers plays an important role in regulating the local groundwater system. Bauxite layers, which are typically porous and often underlain by clay or impermeable layers, act as a natural aquifer. They help to retain water and facilitate slow and steady groundwater recharge by allowing water to infiltrate and move vertically through the soil profile. This process is key in maintaining groundwater levels and regulating flow into surrounding systems, such as wetlands, streams, and aquifers.

[1] The scope of the proposed O'Neil mine facility forms part of the scope of two proposals that are being assessed under Part IV of the EP Act: *Pinjarra Alumina Refinery Revised Proposal* (Assessment No. 2253) and *Bauxite mining on the Darling Range in the southwest of WA for the years 2023 to 2027* (Assessment No. 2385).

During this process, bauxite mining typically causes a rise in groundwater levels and changes surface water quantity (flow rate) and potentially quality (e.g., salinity). This may affect environmental receptors including potential GDEs comprising swamps, wetlands, springs and rivers and creeks, the ecology of which may be sensitive to changes in groundwater levels, changes in surface water flows / volumes / flow regime and salinity.

Given reduced evapotranspiration and increased infiltration, bauxite mining has been recognised as potentially causing a site-based or off-site based rise in groundwater levels that may have the following effects:

– Waterlogging of surface soils causing salt build-up in soils through increased evaporation (dryland salinity)
– Waterlogging or saturation of dispersive soils – causing increase erosion and sediment load to rivers and creeks
– Waterlogging or saturation of vegetation and root systems – limiting oxygen availability to roots, leading to root failure and increased risk of dieback.
– Mobilisations of salts, where stored within the soil profile / unsaturated zone into the groundwater flow systems which could discharge into creeks or other surface water features in the area
– Changes in volumes of groundwater discharge (baseflow contribution) into rivers and creeks – causing alteration to streamflow regime
– Changes in streamflow salinity due to changing proportion of groundwater discharge
– Changes in quality of groundwater – change in groundwater salinity may cause stress to groundwater dependent vegetation

These changes to the groundwater flow regime and water quality have potential to impact the following receptors, where confirmed as present within areas potentially affected by mining:

– Riparian vegetation
– Potential GDEs
– Streams to which groundwater is discharging
– Aquatic fauna and flora
– Drinking water quality and irrigation/stock water use.

Following successful rehabilitation and establishment of pre-mining conditions, rainfall recharge and groundwater levels, previously raised during mining, should reduce and return to pre-mining conditions, which is anticipated to occur over decadal timeframes.

Bauxite Strategic Executive Committee

All Alcoa mining operations are currently conducted under the supervision of the Bauxite Strategic Executive Committee (BSEC), which superseded the MMPLG in 2024.

Prior to the MMPLG, the Steering Committee on Research into the Effects of Bauxite Mining on the Water Resources of the Darling Range was established in 1973 to research effects on water resources and provide advice to a Bauxite Policy Committee (Croton *et al.* 2011).

The BSEC has three subcommittees:

– Worsley Environmental Management Liaison Group (S32), which conducts technical review of mine management documents environmental reports, other reports (including LTRMS) and assessment of proposed CAR informal reserve incursions (when required) and provides advice to BSEC.
– Alcoa Independent Technical Advisory Group (ITAG) which co-designs and implements technical studies and reports (as required in MMP approval conditions or by BSEC) and provides advice to BSEC.
    – The ITAG has two functions:
        1. Technical review of mine management documents, environmental reports, other reports (including Long Term Residue Management Strategy (LTRMS)), and assessment of proposed Comprehensive, Adequate, and Representative (CAR) Informal Reserve incursions (when required). Prevision of advice to BSEC.

2. Co-design and implementation of technical studies and reports (as required in MMP approval conditions or by BSEC). Provision of advice to BSEC.

– Mining Operations Group (MOG), which oversees and reports to the BSEC regarding environmental and community issues of its operations.

Previous studies

Alcoa has undertaken and supported research to assess the potential impacts of its mining activities on water resources and the environment since the 1970s. A number of studies were completed in association with the former Water and Rivers Commission as part of the Joint Intermediate Rainfall Zone Research Program, and overseen by the Bauxite Hydrology Committee, a former subcommittee of the MMPLG. Following the transition from the MMPLG, these responsibilities are now assumed by the BSEC.

A summary of the findings of this research and other key studies is chronicled in Table 0.2 along with gaps and limitations with respect to the proposed mining areas.

The research has had a significant focus in understanding the relationship between rainfall, runoff, groundwater levels, and salinity in the region with respect to mining and other land uses.

Table 0.2 Technical documents reviewed

Title	Key features	Findings	Gaps/limitations/comments
Hydrology			
(Ruprecht & Stoneman, 1993) (Bari & Ruprecht, Water yield response to land use change in south-west Western Australia, 2003) (Croton & Reed, 2007)	Mining in public drinking water catchments	Mining initially caused increases in stream flow, followed by a return to pre-mining levels or below after rehabilitation.	
Hydrological Response of the O'Neil to McCoy Mining Area (Water & Environmental Consultants, 2013a)	Six year groundwater (GW) /surface water (SW)/salinity monitoring Mining in public drinking water catchment and control catchment Some mining areas within IRZ	Mining-related stream-salinity response observed, albeit much less than had previously been modelled.	Given mining-related stream-salinity response observed, there may be cumulative impacts from other areas in Myara yet to be mined or rehabilitated within Serpentine catchment.
Review of the Trial Mining Project (Water & Environmental Consultants, 2011) (Water & Environmental Consultants, 2013b)	10 year GW/SW/salinity monitoring in IRZ Mined catchments compared to control catchments	Experimental catchments in IRZ dominated by below-average rainfall conditions since 1974, with groundwater recharge processes essentially at zero or reducing. Streamflow and stream-salinity records not attributed to mining. Little to no potential for significant streamflow or stream-salinity response in experimental catchments to mining as long as below-average rainfalls continue.	
Hydrological response to bauxite mining and rehabilitation in the jarrah forest in south west Australia (Grigg, Hydrological response to bauxite mining and rehabilitation in the jarrah forest in south west Australia, 2017)	36-year monitoring period Mined, thinned, control catchments compared	Mining caused peak streamflow response of 225 mm or 18% rainfall, returned to pre-disturbance levels 11 years after mining commenced. Changes in groundwater level related to rainfall and LAI, indistinguishable between rehabilitated and unmined areas. Response to mining could not be distinguished from responses to other catchment disturbances which do not disrupt the regolith including forest thinning, clearing or clear-felling. No shallow-subsurface flow processes beyond valley floor and immediately adjacent slopes. Catchment disconnection observed such that paired catchment approach may be ineffective for future forecasts.	Localised impacts of short-term events (significant storm events) immediately after clearing.

Title	Key features	Findings	Gaps/limitations/comments
A standardised Landsat time series (1973–2016) of forest leaf area index using pseudoinvariant features and spectral vegetation index isolines and a catchment hydrology application (McFarlane, Grigg, & Daws, 2017)	Remotely sensed imagery from Landsat dating back to 1972	Standardised time series of LAI was developed that could inform future hydrological modelling in the area, as previous modelling has typically been based on rainfall only. For long-term annual average rainfall of 1,200 mm their model predicts zero streamflow when catchment average LAI reaches 2.	Potential for application of LAI time series in new models in the area.
On the contribution of groundwater to streamflow in laterite catchments of the Darling Range, south-western Australia (Grigg and Kinal 2020)	Estimation of baseflow proportion to streamflows. Groundwater contributions to streamflows	Groundwater contributions to streamflows have a large variability. Contributions from quickflow components vary primarily linearly with annual rainfall.	Applied to catchments outside of MDEs, however the approach is applicable to MN and HO MDEs.
Nonstationarity driven by multidecadal change in catchment groundwater storage: A test of modifications to a common rainfall–run-off model (Grigg & Hughes, Nonstationarity driven by multidecadal change in catchment groundwater storage: A test of modifications to a common rainfall-run-off model, 2018)	GR8J Model 21,000 individual groundwater records 40 year dataset Model incorporates “catchment memory”	Improved rainfall-runoff model	Not applied to proposed mining areas
Salinity			
Environmental Research Bulletin No. 16. Salt Storage in the Bauxitic Laterite Region of the Darling Range, Western Australia (Slessar, Murray, & Passchier, 1983)	327 bores drilled in Darling Range	Darling Range exhibits low soil salt storage west of 1,100 mm isohyet (0.16±0.15 kg/m^3) Near-exponential increase in soil salt content with distance inland (0.79 ± 0.84 kg/m^3)	Limited resolution within proposed mining areas, and in close proximity east of 1,100 mm isohyet
Environmental Research Bulletin No. 22. Estimation of Soil Salinities East of the Huntly Mine, Darling Range, WA (Tsykin, 1989)	70 bores drilled east of Huntly mine (south-east of Myara North), predominantly in IRZ Soil salt content estimated in grid-cells based on rainfall, terrain type, vegetation “greenness” and position in landscape.	High rainfall areas had low soil salt contents (<0.4 kg/m^3), lower rainfall areas had high salt contents.	Limited resolution within proposed mining areas
Hydrology and Bauxite Mining on the Darling Plateau (Croton & Reed, 2007)	Literature review	Under current rainfall regimes, it is unlikely that there will be a significant salinity response due to Alcoa’s mining, but it is inadvisable to discount the salinity issue in the lower rainfall zone, and research will need to consider the possibility of further climate change.	Water quality issues only discuss salinity. Myara North has specific setting in a drinking water catchment and would require assessment beyond salinity.

Title	Key features	Findings	Gaps/limitations/comments
Salinity Risk Assessment for the O'Neil to McCoy Mining Area (Water & Environmental Consultants, 2010)	Mining in public drinking water catchment Application of a simple (unknown) groundwater flow model (data from 1970 to 2007) Application of salinity risk methodology	Stream salinities below average for the period of low rainfall post 1999, likely driven by falling groundwater levels. Modelling (using WEC-C) concluded that there will be streamflow, stream salt-load and stream salinity increases due to the mining of O'Neil to McCoy.	Limited information on the model and its spatial domain.
Modelling long-term flow and salinity response to bauxite mining in the upper Serpentine catchment (DWER, 2019)	Mining/rehab in dam catchment LUCICAT SW/salinity modelling	Regardless of mining case or future climate, change in inflows due to mining was <~2 GL/year, or five per cent of flow on an annual average basis. Effects on reservoir salinity of mining within Upper Serpentine were within acceptable limits (within 3% of no-mining case).	Dynamics of simulated groundwater levels in context of strong drought years not well understood in model (flows in these instances are overestimated). Model is suited to large catchment areas, however, the proposal area includes one large catchment (Upper Serpentine), and two smaller separate catchment areas (Lower Serpentine, and Wungong Brook). Model data is 10 years old. Landsat LAI data from 1963 to 1972 is linearly extrapolated. Short term impacts are either not captured by the model, or not described in the report.
Waterlogging			
Kreuzwieser, J., & Rennenberg, H. (2014). Molecular and physiological responses of trees to waterlogging stress. Plant, Cell & Environment, 37(10), 2245-2259.	Carbon metabolism in both, leaves and roots of trees.	Main physiological responses of trees to waterlogging include the stimulation of fermentative pathways and an accelerated glycolytic flux. Many energy-consuming, anabolic processes are slowed down to overcome the energy crisis mediated by waterlogging. A crucial feature of waterlogging tolerance is the steady supply of glycolysis with carbohydrates, particularly in the roots; stress-sensitive trees fail to maintain sufficient carbohydrate availability resulting in the dieback of the stressed tissues.	Limited studies available investigating the transcriptome and metabolome (i.e., genetic and chemical changes) of waterlogged trees
van der Moezel, P., Watson, L., Pearce-Pinto, G., Bell, D., 1988. The Response of Six Eucalyptus Species and Casuarina	Tolerance of seven tree species (*Eucalyptus camaldulensis, E. comitae-vallis, E. kondininensis, E.*	*Eucalyptus camaldulensis* and *Casuarina obesa* developed specialised roots with aerenchyma,	More research is needed on the long-term performance of these

Title	Key features	Findings	Gaps/limitations/comments
obesa to the Combined Effect of Salinity and Waterlogging. Functional Plant Biology 15, 465-474.	*lesouefii, E. platycorys, E. spathulata,* and *Casuarina obesa*) to saline and non-saline waterlogged conditions in a controlled glasshouse experiment Growing seedlings under four conditions: non-saline drained, saline drained, non-saline waterlogged, and saline waterlogged for three months. Measurement of seedling height, survival, and ion concentrations (Na, K, Ca, Mg, Cl).	allowing them to tolerate non-saline waterlogged conditions. All species showed reduced growth under saline, drained conditions, with *E. kondininensis* as the only species to experience seedling death. *C. obesa* was the most tolerant of saline waterlogged conditions, with no seedling deaths and minimal growth reduction compared to the Eucalyptus species. Exclusion of Na and Cl, along with specialised roots, likely contributed to *C. obesa*'s high tolerance to saline waterlogging. Species that tolerated non-saline waterlogging also performed better in saline waterlogged conditions.	species under varying environmental conditions. Findings are important for rehabilitating secondary salinised land in Australia
Shishkova, S., Rost, T. L., & Dubrovsky, J. G. (2008). Determinate root growth and meristem maintenance in angiosperms. Annals of Botany, 101(3), 319-340.	Focus on root growth and development in flowering plants (angiosperms) and understanding how root development is regulated, especially during periods of stress or environmental changes like waterlogging.	Root growth is tightly controlled, with the meristem playing a critical role in maintaining root growth and ensuring it happens in a structured way. It identifies mechanisms that help plants maintain healthy root systems, even under conditions where growth could be challenged (such as waterlogged or low-oxygen soils).	Limited to certain species angiosperms (flowering plants) and findings may not apply to all plant species, such as gymnosperms or non-flowering plants. Focus on growth, not function of roots in environmental stress (like how roots help plants survive in waterlogged soils) No real-world application (theoretical insight).

Regional setting

This section provides a summary of the desktop assessment of the regional and groundwater and surface water systems of the Mine DE. It includes a summary of the Aquatic Fauna Desktop Assessment completed for the Mine DE.

Climate

Western Australia's southwest region has a 'Mediterranean' type climate characterised by typically high winter rainfalls and an intense summer drought. A summary of the nearest Bureau of Meteorology (BoM) to the Mine DE is provided in Table 0.1.

Table 0.1 Summary of nearest BoM climate stations

BoM Station	Station number	Distance from Mine DE	Data range
Serpentine Main Dam Station	009115	5 km west of Myara North DE 15 km northeast of O'Neil DE 21 km north of Holyoake DE	1963 to 2016 Rainfall
Karnet Station	009111	10 km southeast of Myara North DE 16 km north of Holyoake DE 14 km north-west of O'Neil DE	1963 to 2021 Rainfall, evaporation and solar radiation data
Dwellingup Station	009538	5 km southeast of Holyoake DE 23 km southeast of O'Neil DE 36 km south of Myara North DE	1935 to 2021 Rainfall, evaporation and solar radiation data

Given the proximity of the three stations, this review presents data from Karnet Station as representative of the Mine DE. Monthly statistics for the site since its inception are shown in Figure 0.1. Additionally, SILO[2] point data and annual rainfall are plotted in Figure 0.2. Dwellingup rainfall data has been used for site-specific comparison for Holyoake DE surface water and groundwater datasets.

The mean monthly maximum temperature ranges from 15.8°C in July to 30.9°C in January. Average annual evaporation (1,520 mm) typically exceeds average annual rainfall (1,153 mm), albeit rainfall exceeds evaporation during winter and shouldering months.

Western Australia's south west region has undergone a 15 to 20% reduction in rainfall since the 1970s, as illustrated in Figure 0.2 (Petrone, Hughes, Van Niel, & Silberstein, 2010). This trend has been forecast to continue with a further 2% to 14% reduction predicted by 2030. Temperature is projected to increase by 0.7°C, and potential evapotranspiration is expected to rise by 2 to 3% (CSIRO, 2009; DoW, 2015).

Rainfall is also known to decline with increasing distance inland. Historical rainfall isohyets including the 1,100 mm annual rainfall isohyet (referred to as the High Rainfall Zone or HRZ) and the historical 900 to 1,100 mm annual rainfall isohyet (referred to as the Intermediate Rainfall Zone or IRZ) have been identified in research as defining features for differing hydrological effects across the Huntly Mine.

[2] Rainfall, temperature, and evaporation data sourced from the SILO data downloaded from https://legacy.longpaddock.qld.gov.au/silo/ppd/ on 5 June 2020. Point data from the SILO climate database (Queensland Department of Science, 2015) provides a continuous daily climatic record for a given point with gaps infilled based on interpolation of records from nearby weather stations.

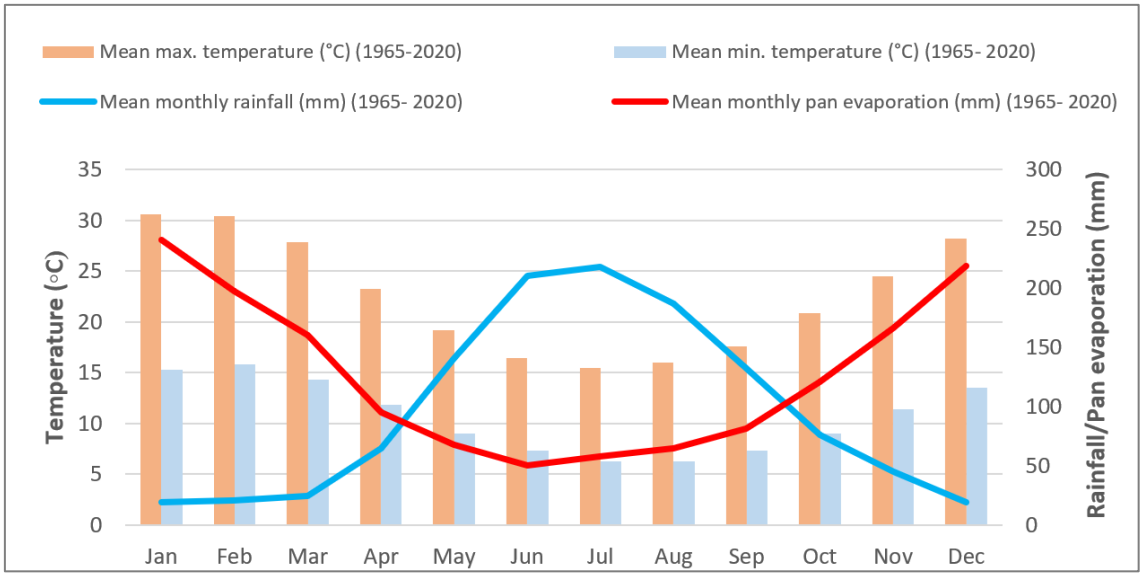


Figure 0.1 *Monthly climate statistics at Karnet Station (1965 to 2020)*

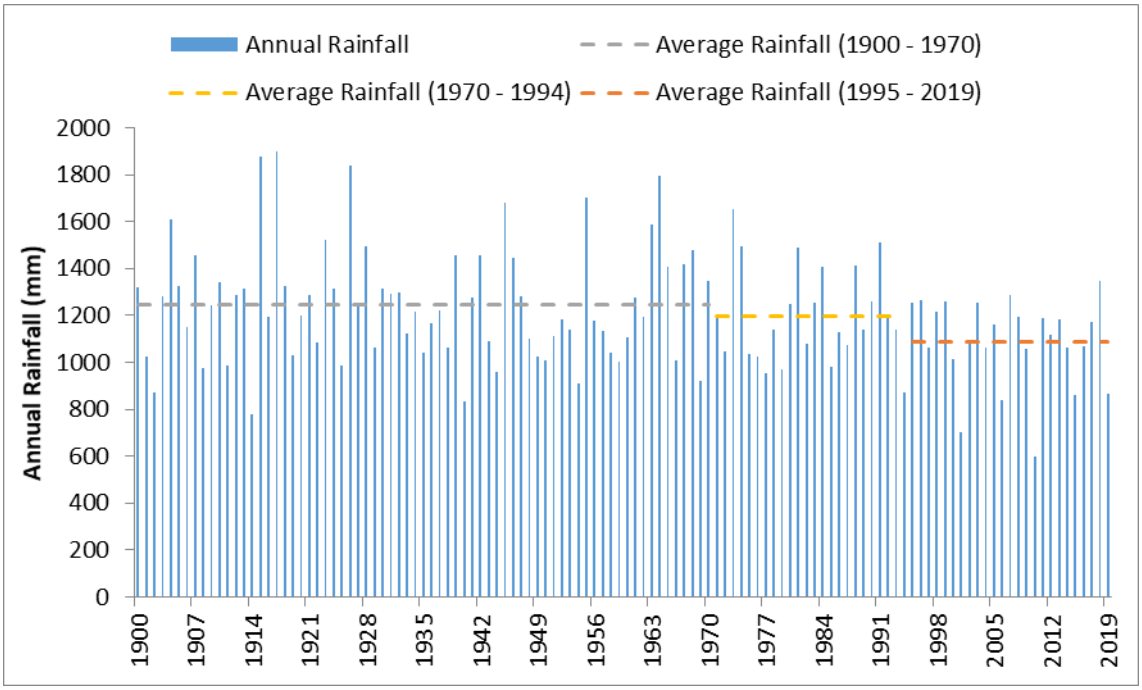


Figure 0.2 *Annual rainfall at Karnet Station*

Landforms and topography

The Huntly Mine is situated within the Darling Plateau, at 240 m AHD to 370 m AHD. Topography across the Mine DE is presented in Figure A-4 (Myara North), Figure A-5 (Holyoake) and Figure A-6 (O'Neil) in Appendix A.

The Huntly Mine is characterised by lateritic profiles (>30 m depth), formed from the in-situ weathering of basement rock. The laterite surface is undulating, dissected by streams and extending through a zone of variable thickness to weathered bedrock.

Landforms have been described by Churchward and McArthur (1980) and mapped as part of vegetation complexes of the South West forest region (Mattiske and Havel 1998). Table 0.2 presents the landform descriptions and mapped extent over the Myara North, Holyoake and O'Neil DEs.

Table 0.2 Soil landscape mapping in the Mine Development Envelope

Landform name	Landform Description	Myara North DE (ha)	Holyoake DE (ha)	O'Neil DE (ha)	Proportion of current extent in Mine DE (%)
Cooke	Hills rising above general plateau level; mainly mantled by laterite but with some rock outcrop	416	0	300	3.6
Dwellingup	Gently undulating landscape with duricrust on ridges; sands and gravels in shallow depressions	4,501	4,527	3,205	2.9
Goonaping	Shallow upland valleys with grey sands and some swamps	56	0	0	2.3
Murray	Deeply incised valleys with red and yellow earths on slopes; narrow alluvial terraces.	272	121	0	0.7
Yarragil	Valleys of the western part of the plateau; sandy gravels on the slopes; orange earths in swampy floors.	5,461	2,976	714	5.5
Pindalup	Gently undulating landscape with lateritic duricrust on ridges and slopes; sandy and gravelly soils in shallow depressions.	0	0	1,351	1.2
Total		10,705	7,624	5,571	-

As presented in Table 0.2, the landforms over the Myara North DE are predominantly Dwellingup lateritic uplands interspersed by Yarragil minor valleys with swampy floors. Murray landform major valleys occur along the Serpentine River on the southern boundary of the region. Goonaping sandy upland valley occurs in a shallow depression in the headwaters of Honour Brook north of Jack Rocks. Cooke upland hills and rock outcrops occur as pockets along the eastern portion of the region.

The landforms over the Holyoake DE are less diverse than in the Myara North DE and comprise almost totally (59%) Dwellingup lateritic upland and Yarragil minor valley landforms (39%). A small area of Murray major valley (2%) occurs in the headwaters of the Murray River on the southern boundary.

The landforms over the O'Neil DE are limited to Dwellingup lateritic uplands (70%) interspersed by Yarragil and Pindalup minor valleys with swampy floors (35%). The proportion of Yarragil complex present in the O'Neil DE is significantly less than the Myara North DE and Holyoake DE as Pindalup minor valleys become present moving east. Cooke upland hills and rock outcrops occur as pockets throughout the O'Neil DE.

Regional geology

The Myara North, Holyoake and O'Neil DEs are located in the Yilgarn Craton, a predominantly granitic geological terrain. The regional geology of the study area has been mapped by the Geological Survey of Western Australia (GSWA) and is presented in Figure A-7 in Appendix A.

The bedrock outcrops over less than 10% of the region, as there is an extensive layer of Cainozoic laterite developed. A typical lateritic profile in the Darling Range is distinctly zoned. The laterite has been derived from the weathering of parent rock and consists of a ferruginous or aluminous hard cap layer which overlies a pallid, and often mottled kaolinitic zone of varied thickness (saprolite). The transition zone between the fresh rock and saprolite is referred to as saprock.

The laterite layer includes the bauxite resources which are proposed to be mined. Bauxitisation has been especially pronounced along the flanks and tops of ridges. The lateritic (bauxite) horizon is on average 2 to 3 m thick for granite-derived bauxite.

The younger-age tholeiitic quartz dolerite dykes intrude the Precambrian basement. The dykes are generally 10 m thick although the width can vary widely. These dykes generally follow east-west to northwest to southeast directions.

Observations of outcrops along the railway cutting near Jarrahdale suggest significant differences between the profile developed over metagranites and dolerites. These are related to the dominance or preservation of quartz in

the profile developed over the metagranite whereas it is almost totally absent from the profile developed over the dolerite.

Hydrogeology

The groundwater host rocks of the Myara North, Holyoake and O'Neil DEs predominantly comprise the weathered and fresh Archaean basement crystalline rocks. In addition, more recent sediments are incised into the basement rocks, coincident with existing drainage or palaeodrainage lines.

The understanding of the generalised hydrogeology of the Mine DE comprises the following main aquifer units:

– Shallow weathered zone aquifer: comprising lateritic caprock and shallow gravely to sandy sediments with represents a seasonal aquifer with significant storage, infiltration and flow capability
– Deep weathered zone aquifer (lower saprolite), an aquifer of some storage potential, but limited bulk permeability (comprising clays). The clayey nature of this zone can be interspersed by macropore features developed along deep root systems which were subsequently filled with more clastic material
– Transition zone between the fresh basement and saprolite, referred to as saprock, which typically has enhanced permeability
– Fractured bedrock aquifer, permeability and yields are dependent on facture development and connectivity of the fractures.

Groundwater has been an active part of lateritisation process, particularly in development of cemented ferruginous hardcap (duricrust) often seen on the surface. Formation of duricrust has been driven by groundwater flow and capillary action which led to precipitation of iron minerals leached from the weathered bedrock. Duricrust can also form in valley floors due to accumulation of iron brought by groundwater flow and its precipitation due to evapotranspiration or exposure to the surface.

In addition to the above, where drainage lines are sufficiently developed, and have eroded the basement material, sediments, typically alluvial, have accumulated in the lower lying areas. The permeability of the sediments is variably distributed and related to lithology, depth and degree of weathering.

Broadly, groundwater levels within all aquifers appear to follow the topography, such that groundwater level is highest in areas of highest topography and lowest in areas of lowest topography. Where groundwater levels intersect the base of the creek groundwater discharges provide baseflow following the winter rains (topped up aquifer storage and groundwater levels).

Given that topographical slopes reflect the groundwater gradient, the groundwater of the Mine DE is inferred as discharging into low lying creek lines when groundwater is in connection to the stream zone. These creek lines feed into, and discharge into the Serpentine Dam in the Myara North DE. The Myara North DE also includes several smaller catchments in the far north where the discharge is to the north towards the Wungong Dam, Gooralong Brook and some minor tributaries that drain towards the Pipehead Dam. In the Holyoake DE, groundwater predominantly discharges towards the South Dandalup Dam. In the far south of the Holyoake DE, the catchments drain to the south of the South Dandalup Dam and towards the Murray River. In the O'Neil DE, groundwater predominantly discharges towards the Serpentine River and Big Brook. The two perennial rivers drain in a north-westerly direction toward Serpentine Dam, located 17 km north-west of O'Neil DE. Several non-perennial unnamed tributaries merging with either the Serpentine River or Big Brook flow though the O'Neil DE.

Previous work from the Darling Range catchments suggested that groundwater was a minor contributor to streamflows (e.g., Bari and Ruprecht, 2003, and others). This has been recently disputed (e.g., Grigg and Kinal, 2020). The most recent analysis found that groundwater contribution, as baseflow component of streamflows, varies within a wide range, and it includes years in which groundwater is the dominant proportion of streamflows (shown in tested Lemon, Wights and Yarragil 4X catchments).

Soils

The Huntly Mine (including Myara North, Holyoake and O'Neil DEs) lies within the Darling Plateau, an undulating lateritic plateau. Soils have developed over the granitic terrain in a typical laterite profile with sand and gravelly topsoils which transition into a saprolite zone of weathering.

Soils typically comprise gravels, sands and loams including a discontinuous cemented layer or duricrust mostly in mid- to upper-slopes, merging with underlying mottled and pallid clays of the saprolite zone. Coarse gravels can be found on the upper slopes, trending to finer gravels downslope and sands near the valley floor, dominated by loams and clay loams (Churchwood and Dimmock, 1989), (Figure 0.3).

Of hydrological significance, root channels penetrating vertically via fissures and discontinuities in the cemented layer and deep into the clay zones are a consistent feature in the lateritic profiles. These channels form preferential flow paths and are understood to form significant vertical fluxes into groundwater systems (Grigg, 2017; McFarlane and Williamson, 2002; Turner et el. 1987).

The ‘dry flats’ and ‘wet flats’ are broadly consistent with alluvial deposits, developed along major drainage lines and creeks which may contain finer fraction especially in their downstream sections. The ‘dry flat’ term includes both the edge of the valley floor and permanently dry’ slightly elevated part of the flat. The ‘wet flat’ is the part of the valley floor which is waterlogged during winter. The soil profile is sometimes missing along the deeply incised drainage lines or at elevated highs which are often the granite outcrops.

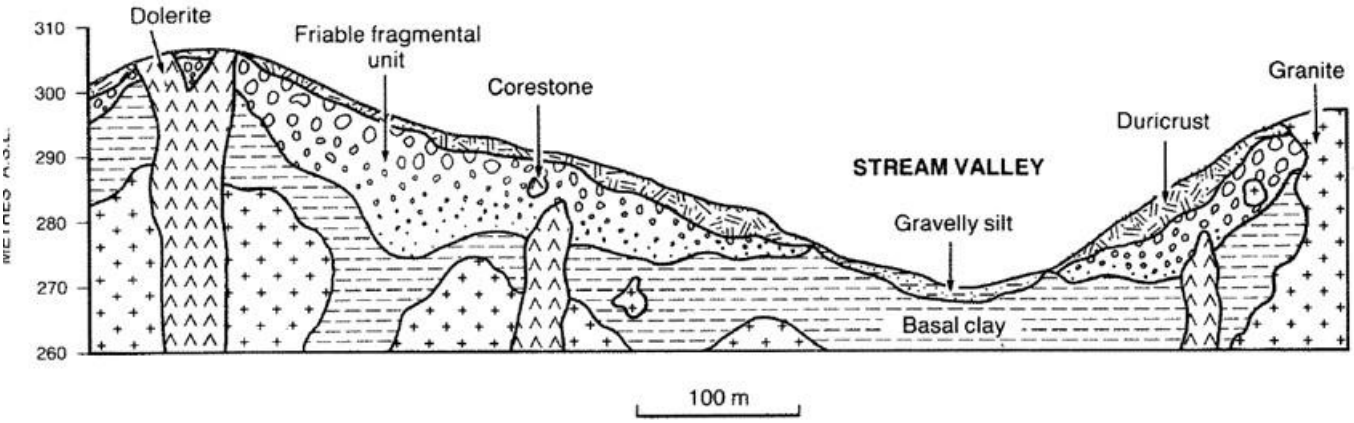


Figure 0.3 Typical textural changes in soils along the slopes (Hickman et al 1992)

Surface water hydrology

The Darling Plateau is characterised by sharply incised drainage lines forming dense drainage networks in the western, higher rainfall zone (HRZ), with these transitioning to open, flat-floored valleys in the eastern, intermediate rainfall zone (IRZ) (Churchward & Dimmock, 1989).

Some of the larger streams in the HRZ have previously exhibited perennial baseflows (Reed et al. 2012). However, the drying climate discussed in section 0 has caused a significant reduction in streamflow, leading to a shift from perennial to ephemeral streams and a decline in the runoff coefficient in recent decades. These declines have been observed as a step-change response to below-average rainfall years (Petrone, Hughes, Van Niel, & Silberstein, 2010; Hughes, Petrone, & Silberstein, 2012). For the Upper Serpentine catchment, a further decline in streamflow of 24%, from the historical average (1997-2007), has been forecast by 2030 (Silberstein, et al., 2012).

Groundwater storage is a key factor influencing the step-change response in streamflow, as it acts as the catchment “memory”. Where permanent groundwater levels fall below the stream bed and become ‘disconnected’ after low rainfall years, this step-change in streamflow is observed as a result of reduction in soil-water storage (Reed, et al. 2012). Unless above-average annual rainfalls persist, these streams will thereafter only flow after saturation has occurred causing runoff and infiltration to occur (Petrone, Hughes, Van Niel, & Silberstein, 2010; Hughes, Petrone, & Silberstein, 2012).

Myara North development envelope surface watercourses

The Myara North DE lies predominantly within the Serpentine River catchment and lies adjacent to the Serpentine River, and Serpentine Dam and Pipehead Dam Reservoirs (Figure A-8, Appendix A). The Serpentine River, originates to the east of the Myara North DE, flowing north-west along the southern boundary towards the

Serpentine Dam. Drainage floors occur in areas of alluvial deposits along the Serpentine River and tributaries and form ephemeral waterlogged damplands during the winter and spring.

The Myara North DE comprises three dominant catchment areas:

– The majority of the Myara North DE (94 km^2 or 88%) lies within the Serpentine Dam catchment area, including the main tributaries 39 Mile Brook, Banksia Gully and Goldmine Gully. The Serpentine River runs adjacent the southern boundary of the Myara North DE. Linear hydrographic mapping of the Myara North DE identifies a further eight tributaries that are second order streams and above, and a further twelve first order tributaries that discharge directly into the Serpentine River and Serpentine Dam.
– The northern portion of the Myara North DE (4 km^2, 4%) includes the Chandler Road sub-catchment and Cobiac sub-catchments which flows in a north and north-westerly direction, converging as the Wungong Brook. Wungong Brook flows north-west through State Forest, including the former Jarrahdale Mine (operating 1963 to 1998), and discharges into the Wungong Reservoir.
– The north-western portion of the Myara North DE (2 km^2, 2%) is drained by Gooralong Brook which flows west through Jarrahdale townsite then south-west through Serpentine National Park and discharges into the Serpentine River approximately 5.5 km downstream of the Serpentine Pipehead Dam.

The Myara North DE excludes the Serpentine Pipehead Dam catchment.

Holyoake development envelope surface watercourses

The Holyoake DE lies predominantly within the South Dandalup River catchment (Figure A-9, Appendix A). The South Dandalup River has multiple tributaries that contribute flows that originate from within and outside the Holyoake DE.

The Holyoake DE comprises two dominant catchment areas:

– The majority of the Holyoake DE (48 km^2 or 64%) lies within the South Dandalup Dam catchment. This part of the Holyoake DE drains either into the main tributary of South Dandalup River or one of four of its tributaries. The South Dandalup Dam catchment extends well beyond the Holyoake DE boundary.
– The south-western portion of the Holyoake DE (23 km^2, or 31%) drains south to the Murray River catchment, in one of two tributaries, Davis Brook and Swamp Oak Brook.

O'Neil development envelope surface watercourses

The O'Neil DE lies entirely within the Serpentine River catchment (Figure A-10, Appendix A). Two perennial rivers; Serpentine River and its major tributary Big Brook, occur within the O'Neil mine region but outside the DE, with both rivers draining in a north-westerly direction toward Serpentine Dam.

The O'Neil DE does not intersect the catchment areas of other public drinking water supply reservoirs (i.e., Serpentine Pipehead Dam, Wungong Brook Dam, and South Dandalup Dam).

Public drinking water supply reservoirs

The Myara North, Holyoake and O'Neil DEs intersect the catchment areas of public drinking water supply reservoirs, including:

– Serpentine Dam (Myara North and O'Neil DEs);
– Wungong Brook Dam (Myara North DE); and
– South Dandalup Dam (Holyoake DE).

Two infrastructure corridors within the Myara North DE lies within the Reservoir Protection Zone (RPZ) of the Serpentine Dam reservoir. The Holyoake infrastructure corridor DE in proximity to its central western boundary intersects a portion of the South Dandalup RPZ.

The reservoirs form part of the Water Corporation's Integrated Water Supply Scheme (IWSS) supplying drinking water to the Perth and Peel metropolitan region, the Goldfields and parts of the Great Southern. The reservoirs are managed in accordance with their respective Drinking Water Source Protection Plan.

The Mine DE is primarily located within the Murray River basin, with a small portion of the Myara North DE located in the Swan Coastal basin. Approximately 21,364 ha (89.4 per cent) of the Mine DE lies within the catchments of six water supply dams, of which four dams impound all flows with no downstream release and two dams (North Dandalup Dam and Conjurunup Pipehead Dam) release limited flows (<10 per cent of inflow) to maintain downstream beneficial uses (Table4.3). The six dams are used for drinking water and their catchments comprise Priority Drinking Water Source Protection Areas (PDWSAs). The majority of the Mine DE (83.0 per cent of total) lies within the regulated subcatchments of Serpentine and South Dandalup dams. An additional 6.4 per cent of the Mine DE is located within regulated catchments, flows from which are impounded at Conjurunup Pipehead Dam, North Dandalup Dam, Canning Dam and Wungong Dam (Table 4.3).

An approximate 2,536 ha (10.6 per cent) of the Mine DE lies within the un-regulated catchments of the Serpentine and Murray Rivers, which discharge into the Peel Inlet near Mandurah (Table 4.3). The Peel Inlet forms part of the Peel-Harvey Estuary and Peel-Yalgorup System Ramsar site.

Table 0.3 Mine Development Envelope breakdown by catchments

Basin	Subcatchment	Holyoake DE		Myara North DE		O'Neil DE	Total Mine DE Within catchment (ha)	Proportion of Mine DE (per cent)	Approximate catcment area (ha)	Mine DE proportion of catchment (per cent)	Approximate catchment area (ha)	Mine DE proportion of catchment (per cent)	Priority Drinking Water Source Area	Downstream release to rivers
		Mine DE (ha)	ICDE (ha)	Mine DE (ha)	ICDE (ha)	Mine DE (ha)								
Un-regulated catchments														
Peel Estuary – Murray River Catchment														
Murray River	Davis Brook	1,739	0	0	0	0	1,739	7.3	6,565	26.5	-	-	No	Yes
Murray River	Swamp Oak Brook	592	0	0	0	0	592	2.5	7,097	8.3	-	-	No	Yes
	Catchment total	**2,332**	**0**	**0**	**0**	**0**	**2,332**	**9.8**	**-**	**-**	**811,064**	**0.3**	**-**	**-**
Peel Estuary – Serpentine River Catchment														
Murray River	Gooralong	0	0	204	0	0	204	0.9	2,151	9.5	-	-	No	Yes
	Catchment subtotal	**0**	**0**	**204**	**0**	**0**	**204**	**0.9**	**-**	**-**	**168,341**	**0.1**	**-**	**-**
	Un-regulated catchments subtotal	***2,332***	***0***	***204***	***0***	***0***	***2,536***	***0.6***	**-**	**-**	**-**	**-**	**-**	**-**
Regulated catchments														
Peel Estuary – Murray River Catchment														
Murray River	Conjurunup Pipehead	0	133	0	0	0	33	0.6	3,085	4.3	-	-	Yes	Yes – overflow to South Dandalup River, Murray River
Murray River	North Dandalup Dam	0	297	0	0	0	297	1.2	7,866	3.8	-	-	Yes	Yes – managed release to North Dandalup River, Murray River
Murray River	South Dandalup Dam	4,079	764	0	0	0	4,843	20.3	30,977	15.6	-	-	Yes	No
	Catchment subtotal	**4,079**	**1,194**	**0**	**0**	**0**	**5,273**	**22.1**	**-**	**-**	**811,064**	**0.7**	**-**	**-**
Peel Estuary – Serpentine River Catchment														
Murray River	Serpentine Dam	11	9	8,686	708	5,571	14,984	62.7	65,727	22.8	-	-	Yes	No
	Catchment subtotal	**11**	**9**	**8,686**	**708**	**5,571**	**14,984**	**62.7**	**-**	**-**	**168,341**	**8.9**	**-**	**-**
Swan Avon – Canning River Catchment														
Swan Coastal	Canning Dam	0	0	61	0	0	61	0.3	34,698	0.2	-	-	Yes	No
Swan Coastal	Wungong Dam	0	0	1,046	0	0	1,046	4.4	8.086	12.9	-	-	Yes	No
	Catchment subtotal	**0**	**0**	**1,108**	**0**	**0**	**1,108**	**4.6**	**-**	**-**	**137,826**	**0.87**	**-**	**-**
	Regulated catchments subtotal	***4,090***	***1,203***	***9,793***	***708***	***5,571***	***21,364***	***89.4***	**-**	**-**	**-**	**-**	**-**	**-**
	Total	**6,421**	**1,203**	**9,997**	**708**	**5,571**	**23,900**	**100.0**	**-**	**-**	**-**	**-**	**-**	**-**

Surface water bodies

The Landgate Medium Scale Topo Water Polygon dataset identifies several water bodies within and in proximity to the Myara North mine region (Figure A-8, Appendix A). The largest of these are the Serpentine Dam and Serpentine Pipehead Dam, both perennial reservoirs, which form part of the Water Corporation's Integrated Water Supply Scheme (IWSS) supplying drinking water to the Perth and Peel metropolitan region, the Goldfields and parts of the Great Southern.

Non-perennial marshes are mapped as occurring within the mid and upper 39 Mile Brook valley floors, in the mid catchment valley floor of Goldmine Gully and in the unnamed eastern tributaries. A non-perennial swamp is also mapped in the unnamed eastern tributaries.

Within the Holyoake mine region, the largest mapped water body is the South Dandalup Dam (Figure A-9, Appendix A), a perennial reservoir, and part of the Water Corporation's IWSS. Other water bodies distributed primarily through the central part of the Holyoake DE are described as non-perennial swamps.

There are no known or recorded permanent water bodies / reservoirs within the O'Neil mine region (Figure A-10, Appendix A). Water bodies occur in limited areas with the DE, with small seasonal not permanent streams occurring (GHD 2024c).

Mapped wetlands

The Holyoake mine region is located approximately 30 km to the east of the Peel-Yalgorup System which is the closest Ramsar Wetland of International Importance and is also mapped under the Directory of Nationally Important Wetlands (Figure A-2, Appendix A).

The Myara North mine region lies approximately 35 km north-east of the Peel Yalgorup System whilethe O'Neil mine region is located around 50 km to the east.

The Myara North mine region is located at the eastern extent of the Department of Biodiversity Conservations and Attractions *Geomorphic Wetlands Swan Coastal plain* dataset. The mapping classifies wetlands present within valley floors as palusplain or floodplain flats, and headwater swamps as sump or dampland basins. The geomorphic wetland mapping classifies wetlands as conservation category where they are relatively intact, and resource enhancement where they partially cleared for development.

The north-western portion of the Myara North mine region includes some mapped geomorphic wetlands which are summarised in Table 0.4 and presented in Figure A-6, Appendix A. The wetlands mapped as conservation category reflect the absence of clearing and relatively intact nature.

Unmapped valley floors and swamps that occur within the Myara North, Holyoake and O'Neil DEs are similarly expected to be of similar environmental values as those classified as conservation category, reflecting the absence of clearing of the wetlands except for occasional roads or access tracks.

Table 0.4 Myara North geomorphic wetland mapping

Management category	Wetland type	UFI number	Myara North DE sub-catchment
Conservation	Palusplain	12,396	Gooralong Brook
Multiple use	Dampland	12,398	Gooralong Brook
Resource enhancement	Palusplain	13,483	Gooralong Brook
Resource enhancement	Palusplain	12,525	Gooralong Brook
Multiple use	Dampland	12,300	Gooralong Brook
Multiple use	Palusplain	12,315	Gooralong Brook
Conservation	Dampland	12,330	Serpentine Pipehead Dam
Conservation	Dampland	12,325	Serpentine Pipehead Dam
Conservation	Dampland	12,312	Serpentine Pipehead Dam
Conservation	Dampland	12,316	Serpentine River
Resource enhancement	Sumpland	12,314	Serpentine River

Comprehensive Adequate Representative (CAR) Reserves

The Comprehensive Adequate Representative (CAR) Reserves system were a series of reserves delineated as part of the Regional Forest Agreement in 1999. The CAR reserves include a series of formal and informal reserves, the majority of which are identified along streamzones within the Myara North, Holyoake and O'Neil DEs.

Ephemeral damplands occur within the valley floors of some tributaries (section 0), which contain vegetation communities that are distinct from the upland Jarrah forest and provide important habitats for terrestrial fauna. The CAR reserves are also considered to support vegetation communities important to terrestrial fauna.

Water use and environmental values

The water use and environmental values in the vicinity of the Myara North, Holyoake and O'Neil DEs were identified through review of existing mapping and published information, site survey of vegetation types and desktop assessment of aquatic fauna ecological values.

The surface water resources in the vicinity of the Myara North, Holyoake and O'Neil DEs support a wide range of social and environmental values including:

– Drinking water supply – Both existing and proposed Huntly Mine Operations occur within the catchment areas of public drinking water supply reservoirs (section 0, **Error! Reference source not found.**).
– GDE which include terrestrial ecosystems that rely on the subsurface presence of groundwater – This is considered to include riparian and phreatophytic terrestrial vegetation (where depth to groundwater is less than 10 m bgl), where vegetation has a seasonal or occasional dependence on groundwater.
– Aquatic ecosystems that rely on surface expression of groundwater which include the surface watercourses that receive groundwater flow, groundwater fed springs and swamps within the study area and their respective biological and environmental values.
– Recreational use including aesthetic values.
– Cultural heritage values – Within the Myara North mine region the Serpentine River is a registered mythological/ethnographic Aboriginal heritage site.

This report includes a brief summary of the environmental values of the Mine DE, with detail of the ecology, drinking water and recreational values provided in the relevant Proposal Environmental Review Document chapters; chapter 5 (flora and vegetation), chapter 6 (terrestrial fauna), chapter 8 (inland waters) and chapter 11 (social surroundings).

Myara North hydrological setting

This section summarises the results of the historical surface and groundwater data review, baseline surface and groundwater monitoring program and supporting environmental technical investigations that were completed across the Myara North mine region.

Hydrogeological characterisation

Alcoa has collected groundwater level and groundwater quality data within the Myara North mine region since the 1970s, with available groundwater data typically concentrated within the eastern areas of the mine region. As part of the baseline monitoring program GHD installed 18 new groundwater bores at 16 locations within the Myara North mine region, to supplement 25 existing Alcoa groundwater bores (Figure A-8, Appendix A).

The location of the monitoring bores was selected to provide site wide coverage of groundwater conditions. Since the eastern side of the Myara North DE already had a significant groundwater monitoring network, the new bores were primarily focused on the central and western areas. Two of the 16 sites included installation of paired bores (shallow and deep), providing data on groundwater for the upper 'perched' unit and the underlying more regional groundwater.

The baseline groundwater monitoring program comprised monthly water level dips and physico-chemical parameter measurements between August 2020 and February 2023., with groundwater samples collected for laboratory analysis of a broader suite of parameters in October 2020 and February 2023. The timing of events was aligned to represent the seasonal periods of later winter annual groundwater level maximum, and the late summer groundwater level minimum. Groundwater level data loggers were installed at Myara North mine region to monitor two paired bores (one site). Continuous groundwater level data (hourly) was recorded between October 2020 and February 2023.

Aquifer units

Hydrogeological information on the aquifer system units was confirmed from installation and hydraulic testing of groundwater monitoring bores by GHD at Myara North. Data on bore depths and screen interval were reviewed to interpret the lithology profile (i.e. to infer depth to basement rock). A summary of the geological logs is provided below and monitoring bore locations are presented in Figure A-8, Appendix A. Detailed geological logs of GHD bores are provided in GHD (2020b) (Appendix B).

A review of the GHD geological logs indicates a broadly uniform lithology across Myara North mine region with a typical weathering profile as follows:

- **Lateritic/ duricrust caprock:** 1 to 4.5 m thick, comprising of minor soils with pea-gravel and cemented duricrust or laterites. Caprock is hard to very hard and often strongly cemented with pisolitic nodules. In valley floors this can be overlain or replaced by relatively thin alluvial sediments.
- **Saprolite**: Highly variable depths from 1 to 29 m thickness, comprising clays derived from weathered basement. Clays are mottled or pallid towards the top becoming less pallid with depth reflecting the weathered bedrock lithology.
- **Weathered basement:** Weathered basement zone is characterised by decreasing clay content, an increasing rock texture/relict features which grades sharply into basement rocks, with a thickness of less than 2 to 4 m. Most active groundwater flow occurs in this zone and was often pressurised.
- **Fractured (fresh) basement**: Depth to fractured basement varies from 6 to 28.5 m below ground level (m BGL) and extended to end of bore hole. Basement rocks were dominantly granite interspersed with a few occurrences of dolerite.

The results of slug testing GHD (2023a) (Appendix B) are summarised and presented in Figure 0.1. The monitoring bore slotted intervals were set along water strikes, which were generally identified within the transition zone from weathered bedrock to basement materials.

Figure 0.1 indicates an average hydraulic conductivity (K) of approximately to 0.6 m/day for the transition zone, and the range of hydraulic conductivity is relatively high (<0.05 to 1.2 m/day). The saprolite clays which overlie the transition zone are inferred to be less permeable at less than 0.001 m/day (saprolite clays were not hydraulically tested).

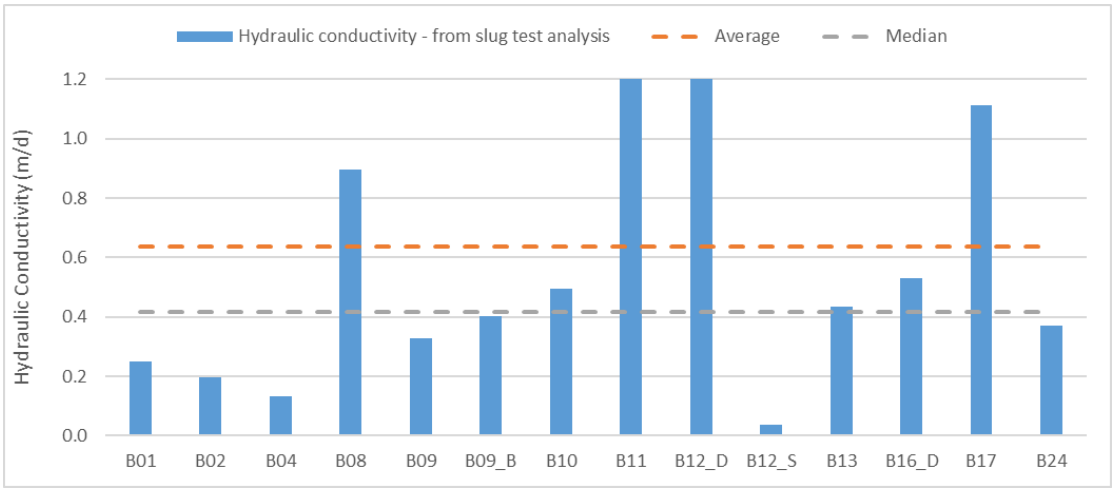


Figure 0.1 ***Myara North slug test results (hydraulic conductivity)***

Alcoa's internal report (Raper and Croton, 1996) provides a regional summary of hydraulic conductivity data which provides information on various horizons of the weathering profile with wider range of K values (0.001 to 16 m/d) dependent on lithological textures and the geomorphological position. The average storativity was stated to be 0.013, with a range of values between 0.0037 to 0.1.

Groundwater levels and flow

Groundwater levels and flow

The groundwater level surface for the Myara North DE is a subtle replica of the topography. There is an understandably strong correlation between the topographic elevation and measured water levels of all monitoring bores (see for comparison between maximum water levels and terrain elevation in Figure 0.2).

Groundwater flows from topographical highs towards the groundwater discharge boundaries of the region which, based on the regional groundwater flow direction, is generally to the west and southwest, but can be locally modified in response to topographic and drainage trends.

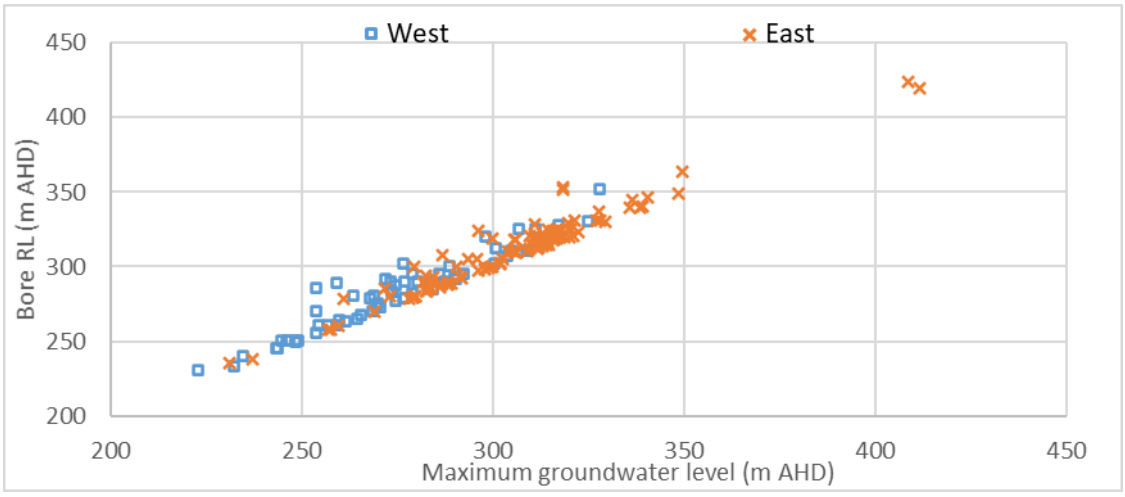


Figure 0.2 ***Comparison of measured maximum groundwater levels and ground elevation***

Groundwater level trends and observations

A review to determine trends of the historical monitoring data collated for monitoring bores within the Myara North mine region was undertaken with results presented in the Hydrological Setting and Understanding Report – Myara North and Holyoake (GHD 2021a) (Appendix C) and summarised in Table 0.1. The table identifies the following key features and long-term trends in groundwater levels (groundwater salinity discussed in section 0):

– A strong seasonal variation in groundwater levels, typically varying over an annual cycle by between 1 to 5 m, in response to natural recharge events, confirming that recharge occurs during every winter season.
– Monitoring bores that have a relatively greater depth to groundwater (i.e. more than 10 m BGL) have a tendency to have a less significant seasonal variation.
– Most monitoring bores show declining groundwater levels since the 1990s which is considered to reflect the reducing rainfall pattern. This can be seen when groundwater levels are compared to cumulative rainfall departure (CRD) plots (GHD 2021a, Appendix C). These plots shown a declining trend in rainfall over the same period as the reduction in groundwater levels. Bore hydrographs are included in the Baseline Surface and Groundwater Monitoring Report – Myara North and Holyoake 2020 – 2023 (Appendix B).
– The summary data presented in Table 0.1 indicates that all but two monitoring bores show declining groundwater levels of between 1 to 10 m since the 1990s, with an average decline close to 4.5 m over 30 years (or 0.15 m/year).

Table 0.1 ***Myara North mine region - summary of groundwater level trends and salinity from selected Alcoa long term monitoring bores (GHD 2021a; Appendix C)***

Monitoring well ID	Groundwater levels			Groundwater Salinity		
	1990 SWL[1] (mBGL)	2020 SWL[1] (mBGL)	Change SWL (m)	1990 TDS[1] (mg/l)	2020 TDS[1] (mg/L)	Change TDS (mg/L)
MJ38033A	3	4	-1	500	800	300
MJ38034A	6	10	-4	400	200	-200
MJ39222A	4	10	-6	200	400	200
MJ40121A	2	6	-4	2000	500	-1500
MJ41081A	7	5.5	1.5	NA	NA	NA
MK382511A	3	3	0	1500	500	-1000
MK39171A	1	2	-1	200	200	0
MK39181A	4	8	-4	400	400	0
MK39191A	2	10	-8	400	500	100
MK40102A	5	15	-10	NA	NA	NA
MK40111A	4	8	-4	300	300	0
MK40181A	2	10	-8	250	300	50
MK40182A	5	15	-10	100	250	150
MK40191A	2	8	-6	400	500	100
MK40251A	10	14	-4	NA	NA	NA
MK40252A	15	25	-10	NA	NA	NA
MK40261A	3	5	-2	150	100	-50
MK41041A	2	5	-3	200	200	0
MK41061A	10	15	-5	1550	1590	0
ML40092A	3	4	-1	400	300	-100
ML40093A	2	4	-2	300	300	0
ML40131A	4	6	-2	250	300	50
ML40271A	20	25	-5	NA	NA	NA

Monitoring well ID	Groundwater levels			Groundwater Salinity		
	1990 SWL[1] (mBGL)	2020 SWL[1] (mBGL)	Change SWL (m)	1990 TDS[1] (mg/l)	2020 TDS[1] (mg/L)	Change TDS (mg/L)
ML41011A	10	20	-10	NA	NA	NA
Notes	SWL - Standing Water Level					
	TDS – Total Dissolved Solids					
	1 - average values estimated from graphs observations (semi-quantitative)					
	NA - Not applicable, no data or unreliable data					

Installation of the new groundwater bores within the Myara North mine region provided further spatial representation and enabled refinement of groundwater level understanding across the proposed mine region. Key observations from the new groundwater bores over the monitoring period between October 2020 and February 2023 include:

– Groundwater is generally shallow (<10 m BGL), with groundwater at depths of more than 10 m only observed in the far south (B02, B03 and B04), and B10 in the far east of the mine region.
– Groundwater levels are generally seen to reduce over the monitoring period (September 2020 to February 2023), consistent with a seasonal change from late winter groundwater highs to summer groundwater lows. Seasonal reduction in groundwater levels resulted in the drying out of five of the monitoring bores. Of these, two (B12S and B16S) are shallow screened bores, with the paired deep bore also observing a decline in groundwater level though not drying out.
– Average seasonal groundwater level decline for all new bores is 1.9 m, with over 3.5 m range recorded in four bores (B12D, B13, B18 and B24). The least seasonal variation is seen in the bore with the greatest depth to groundwater (B02, B03 and B04).
– Bores B01, B09, B18 also dry out during the summer monitoring, however these bores are installed just above the granite basement rock, indicating the absence of a saturated profile in these areas during summer periods.

Groundwater level data loggers installed at monitoring bores B12S (shallow bore) and B12D (deep bore) highlight the reduction in groundwater levels between the end of the winter and the summer (see Figure 0.3). For the deep bore, screened from 18.5 m to 24.5 m BGL, groundwater levels are seen to reduce by 6 m over the two years of monitoring. The groundwater level in the shallow bore (screened between 0.3 to 3.5 m below ground level) also recedes at the same rate as the deep bore. This results in the bore being recorded as dry from late December onwards. The logger data also indicates a slightly confined deeper aquifer with groundwater elevations being marginally higher in the deep bore with comparison to the shallow bore. Both bores show a similar response to rainfall events, with levels seen to rise by up to around 1 m after rainfall events of 10+ mm.

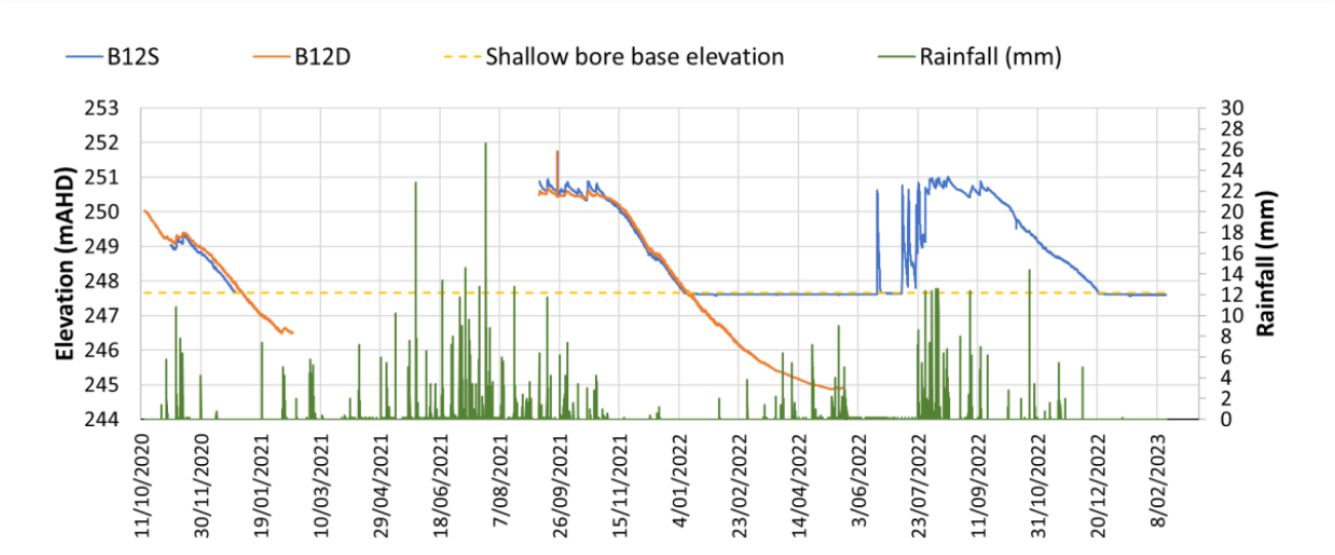


Figure 0.3 Groundwater levels (logger data) in B12 and rainfall (2020 – 2023) (GHD 2023a, Appendix B)

Groundwater quality

Groundwater salinity trends and observations

Groundwater quality within the Myara North mine region is typically fresh. The majority of the monitoring data for the study area, available for some sites since the 1970s, indicates generally fresh conditions with an average salinity of around 450 mg/L. However, as shown by the salinity trend data in Table 0.1 there is some variability within the salinity dataset with isolated bore locations having salinities around 2,000 mg/L. Unlike the long-term groundwater level data, the long-term salinity dataset does not show any site-wide trends in groundwater salinity (i.e., generally stable or variable up or down).

Within the limited spatial extent of the data, there does not appear to be a relationship between bore salinity and location with salinity ranges within each catchment being as variable as those between catchments. Whereas there has been a definite reduction in site-wide groundwater levels, the groundwater quality data, albeit less comprehensive, does not show any widespread long-term trends. This may be partly explained by fewer salinity observations available for the last decade.

Groundwater quality field data was collected at existing historical bores, and at the new monitoring bore sites on up to seven sampling rounds between September 2020 and February 2021, October 2022, and February 2023. Groundwater is consistently fresh (< 500 mg/L TDS) in the majority of bores and across most sampling rounds. The average maximum salinity per bore is 474 mg/L, compared to an average minimum salinity per bore of 260 mg/L (GHD 2023a, Appendix B).

Other groundwater quality parameters

Of the above described sampling events, two included more comprehensive monitoring rounds when a full groundwater laboratory suite was analysed. The data indicated no discernible seasonal change in groundwater quality, however some effects of sampling soon after drilling of the bores was noted.

The results showed low nutrient levels, typical for the land-use, suggesting lack of applied nutrients or sources. Dissolved metal concentrations were typical of ‘natural’ conditions and representative of the geological setting. Low concentrations of per- and polyfluoroalkyl substances (PFAS) were detected in four of the sampled bores, however all detections were significantly below the drinking water assessment criteria. Minor detection of total recoverable hydrocarbons (TRH) and polycyclic aromatic hydrocarbons (PAH) was noted, with concentrations reducing in the second sampling round, possibly indicating that the drilling was the source, or alternatively the low levels are associated with bushfire effects (GHD 2023a, Appendix B).

Surface water characterisation

Surface water flow

Myara North gauging stations

There are several stream gauging stations (GS) relevant to the Myara North mine region and DE (Appendix A, Figure A-8), details of which are summarised in **Error! Not a valid bookmark self-reference.**. The River Road (Serpentine River) upstream of the Myara North DE and Jack Rocks (39 Mile Brook) gauging stations provide a robust annual flow dataset from the early 1980s to 1998, and again from the mid to late 2000s through to late 2010s (Figure 0.4). Vardi Road (Wungong Brook) has a near continuous flow dataset from 1981 to present (Figure 0.5).

It is noted that there are large areas of the proposed mining catchment in which no stream gauging data exists and additional gauging stations will be installed as part of the mine expansion.

Table 0.2 Gauging stations relevant to Myara North mine region

Site ID	Site name	Flow record	GS catchment area (km^2)	Annual average rainfall (mm) [2]	Annual average streamflow (ML) [3]	Runoff (mm)
Serpentine Catchment - regulated						
614035	River Road	1982 to 1998	243	840.7	5,572	22.9

Site ID	Site name	Flow record	GS catchment area (km^2)	Annual average rainfall (mm) [2]	Annual average streamflow (ML) [3]	Runoff (mm)
		2008 to 2019				
614031	Jack Rocks	1981 to 1998 2006 to 2016	55	1,025.7	3,660	66.5
Serpentine Catchment - unregulated						
614073 [1]	Gooralong Brook - Mundlimup	1951 to 1998	51	*1,144.4*	10,594	207.7
Wungong Brook Catchment						
616041 [1]	Wungong Brook – Vardi Rd	1981 to current	81	*1,144.4*	7,368	90.9
616124	Wungong Brook – Chandler Rd	2005 to 2013	18	*1,144.4*	1,208	67.1
616058	Wungong Brook – Cobiac Rd	1992 to 2016	4	*1,144.4*	202	50.5

Note:

[1] Gauging stations 614073 and 616041 are located > 5km downstream of the DE boundary

[2] Annual average rainfall for 614035 and 614031 derived from SILO 5 km daily grid data (1970-2020), remaining sites derived from SILO extraction for Karnet station (1970-2019)

[3] Average of available streamflow record

Long-term trends in annual flow

The step change in rainfall discussed in section 0 is reflected in observed step changes in streamflow, whereby annual average streamflows after year 2000 were considerably lower than the preceding period (Figure 0.4 and Figure 0.5). Average annual streamflow in the Serpentine River has declined by more than 50% at River Road (614035), from 6,810 ML (1982-1998) to 3,232 ML (2008-2018), with an 80% decline in the streamflow record at Jack Rocks (614031), from 5,432 ML (1981-1998) to 1,093 ML (2006-2016)

A similar decline in average annual streamflow (70%) is observed in the upper Wungong River catchment with flows at Vardi Road (616041) reducing from 11,172 ML (1981-2000) to 3,416 ML (2000-2020).

The impact of decline in groundwater levels on streamflows (discussed in section **Error! Reference source not found.**) is also apparent at Jack Rocks with average annual streamflows from 2012 to 2016 approximately 75% lower than the six years prior to 2012, despite average rainfall decreasing by only 8% over the same period.

Long-term trends in flow seasonality

The long-term flow data for the River Road and Jacks Rocks gauging sites was used to generate box and whisker plots of monthly flow data (Figure 0.6 and Figure 0.7). The plots group the monthly flow data by the observed step changes in annual streamflow (pre-2000, post-2000), with the post 2000 flow data demonstrating a delay in flow commencement and typically earlier cease to flow, in comparison to the pre-2000 flow data.

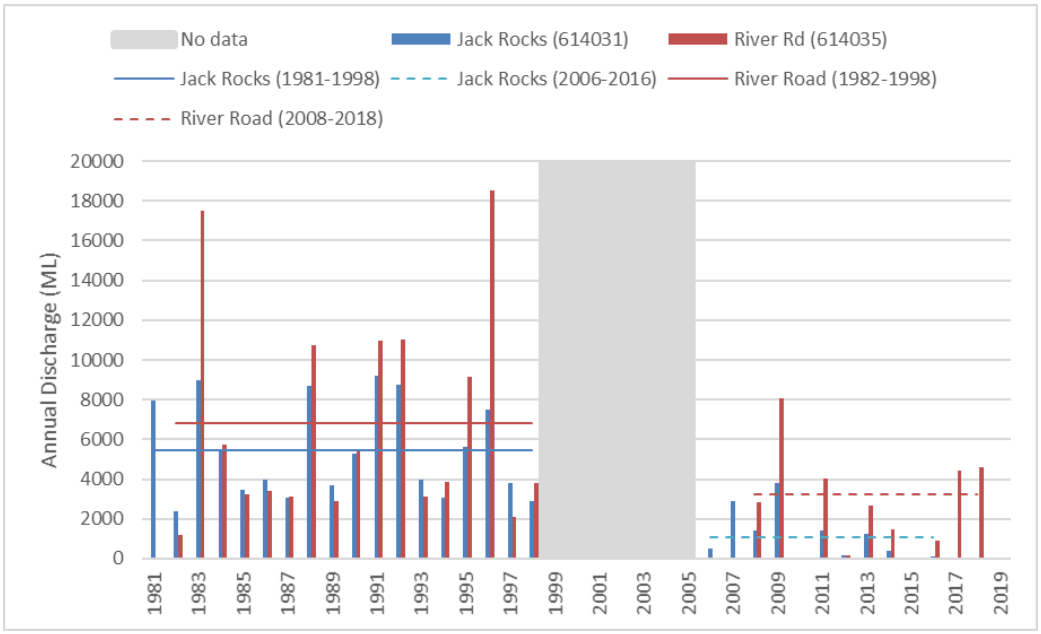


Figure 0.4 *Annual flows at relevant Serpentine catchment gauging stations*

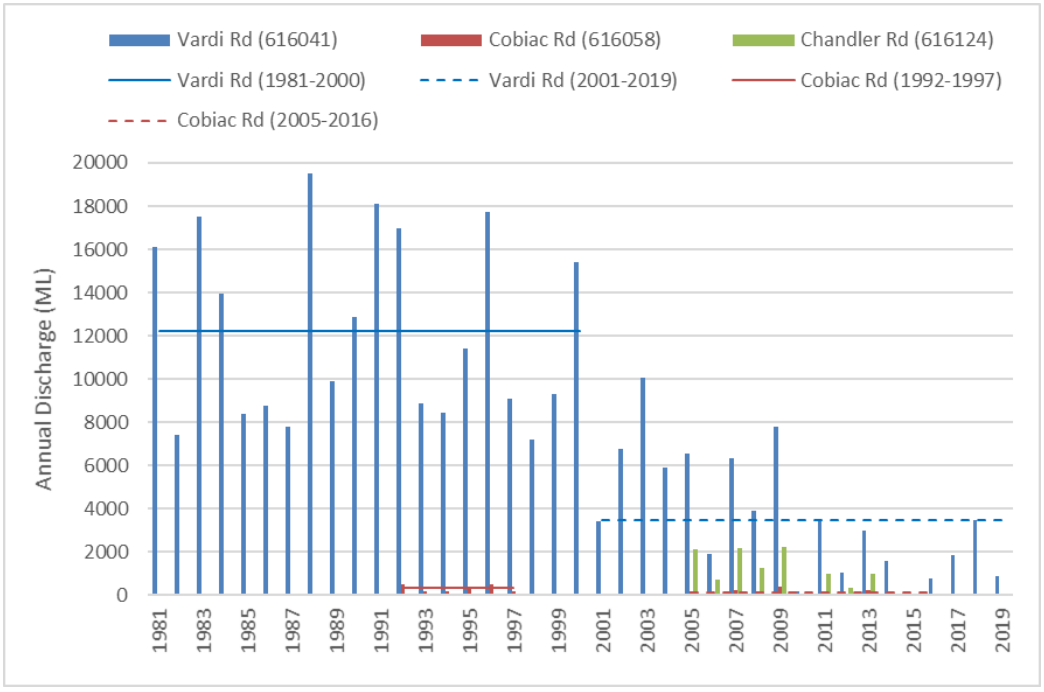


Figure 0.5 *Annual flows at relevant Wungong catchment gauging stations*

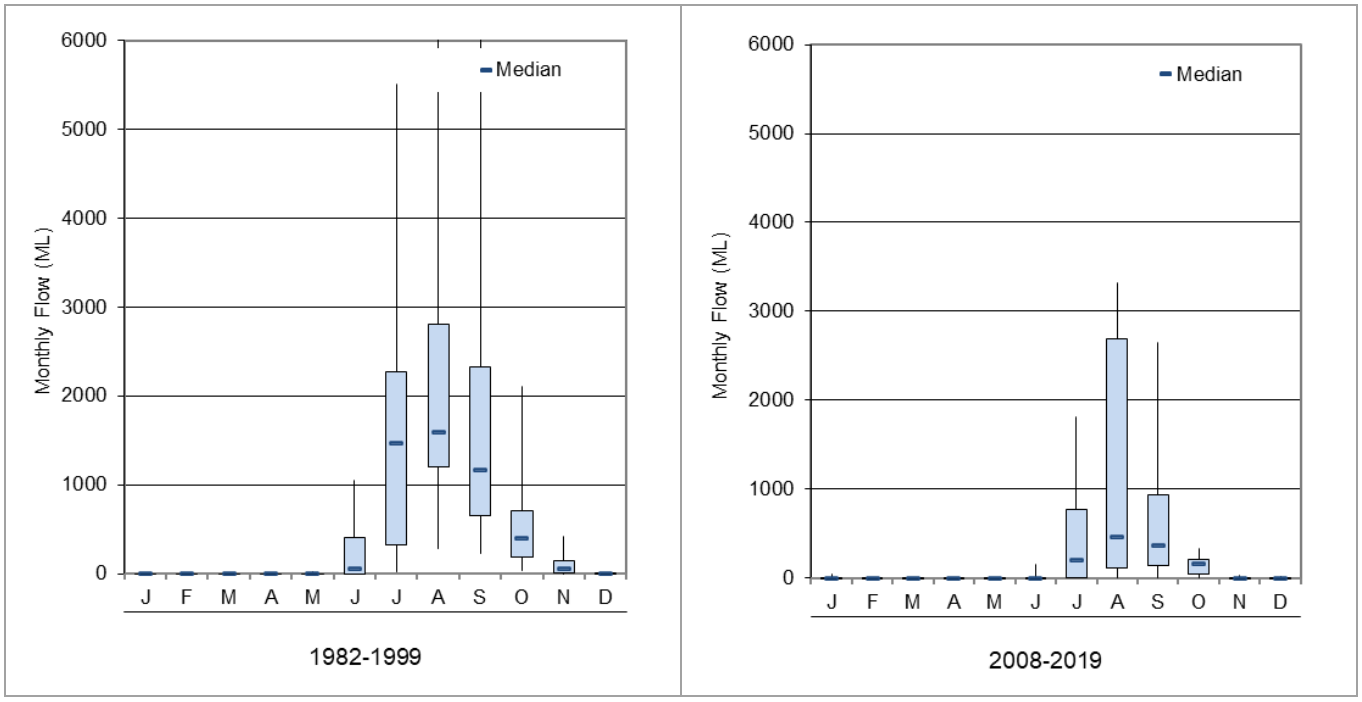


Figure 0.6 Flow seasonality – River Road (Serpentine River) for periods 1982-1999 and 2008-2019

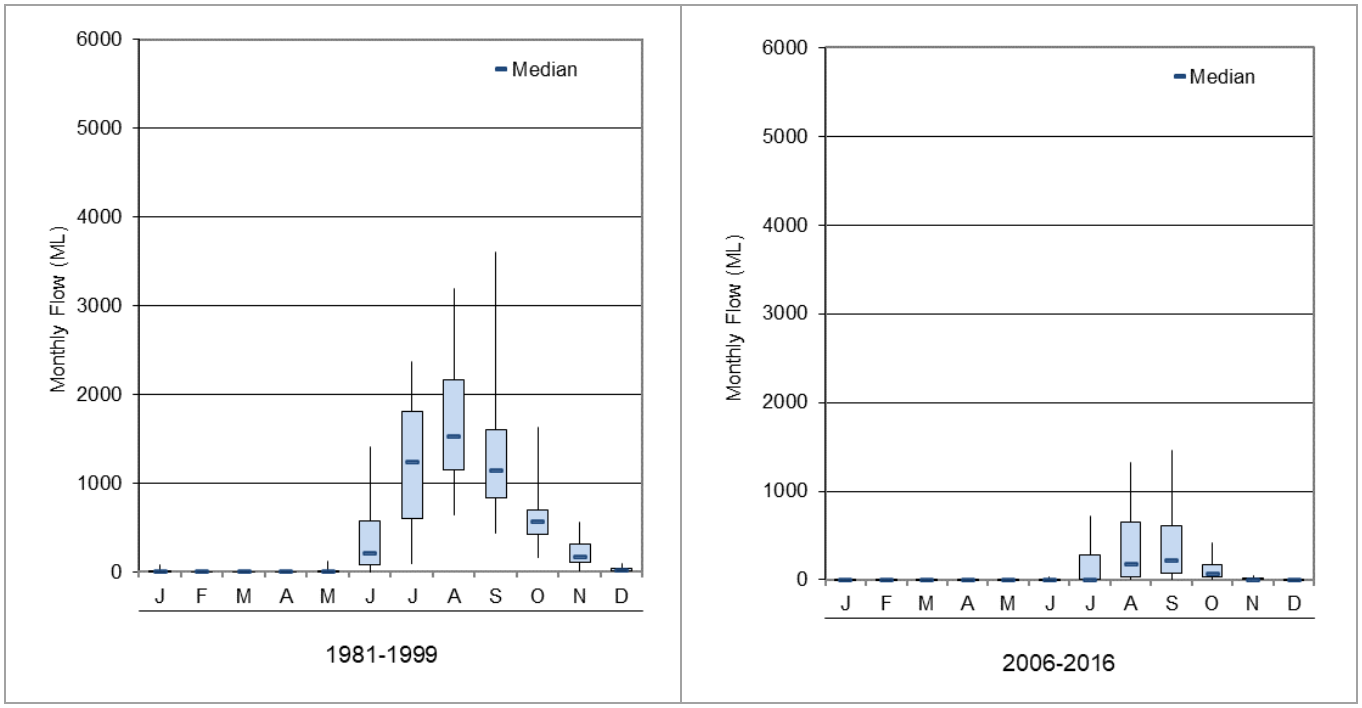


Figure 0.7 Flow seasonality – Jack Rocks (39 Mile Brook) for periods 1981-1999 and 2006-2016

Short-term trends in surface water levels and flow conditions

Surface water level loggers were installed in mid to late September 2020 at selected Myara North surface water monitoring locations, four at the downstream extent of representative catchments prior to discharge to the Serpentine River or Serpentine Dam, and one in the Serpentine River downstream of the proposed conveyor crossing (Table 0.3).

Table 0.3 Myara North surface water logger data summary

Site ID	Subcatchment	Installation date	Cease to flow (2020 season)	Cease to flow (2021 season)	Cease to flow (2022 season)
GG03	Gooralong Brook	September 2020	Mid -October 2020	December 2021	November 2022
SW04	Unnamed minor tributary of Serpentine Main Dam		October 2020	December 2021	October 2022
SW03	39 Mile Brook		October 2020	November 2021	December 2022
6141121	Banksia Gully		October 2020	November 2021	September 2022
6141125	Goldmine Gully		November 2020	November 2021	-

During the 2020 - 2022 baseline monitoring period flow conditions at surface water sampling locations were recorded during monthly surface water sampling events (GHD 2023a, Appendix B). The observed periods of flow during the baseline monitoring program align with historical seasonality of flow observed across the Myara North mine region. The key trends in the surface water flow data include:

– Varying water level response between Myara North sites following installation in mid to late September 2020. Flows in the minor unnamed tributary (SW04) are rapid and flashy. Flows at other locations are more sustained with a gradual decline towards cease to flow ranging from early October in Banksia Gully (6141121) and late October in 39 Mile Brook (SW03).
– One site (SW05, minor tributary to Serpentine Pipehead Dam catchment) sustained flows throughout the monitoring period, with upwelling water observed in the January 2021 monitoring round which may indicate a local groundwater source.
– Sustained flows were also observed at site SW06 (cease to flow in January and December 2021 and November 2022) within the upper Gooralong Brook catchment. This site was located in the catchment of a prescribed burn completed in late September 2020. Talau (2015) report increased stream flow responses within areas subject to prescribed burns, however these are generally of a smaller magnitude compared to wildfire responses.

The observed surface water flow conditions from 2020 to 2022 across the Myara North mine region and a summary of the five surface water logger data results (September 2020 – February 2023) are provided in GHD 2023a, Appendix B.

Baseflow and interflow

Baseflow is the portion of streamflow that is sustained between precipitation events but also forms part of the flow during rainfall events. Interflow represents lateral movement of water in the unsaturated zone. It is usually considered a component of baseflow, depending on the response time – and in this case in position with respect to the stream.

For the Serpentine catchment, Bari et al. (2010) used a model to estimate that interflow is the largest contributor to streamflow followed by groundwater connected baseflow and surface runoff.

Data analysis by GHD using methods described by Barlow *et al.*, (2014)) for the gauging stations located in the Myara North DE and study area indicates that baseflow represents between 45% and 67% of streamflow, depending on location and baseflow separation methodology. For the O'Neil Road station (Big Brook, located south of Myara North mine region), representing the largest catchment of the Serpentine River and longest record, the baseflow proportion of runoff has a weak downward trend.

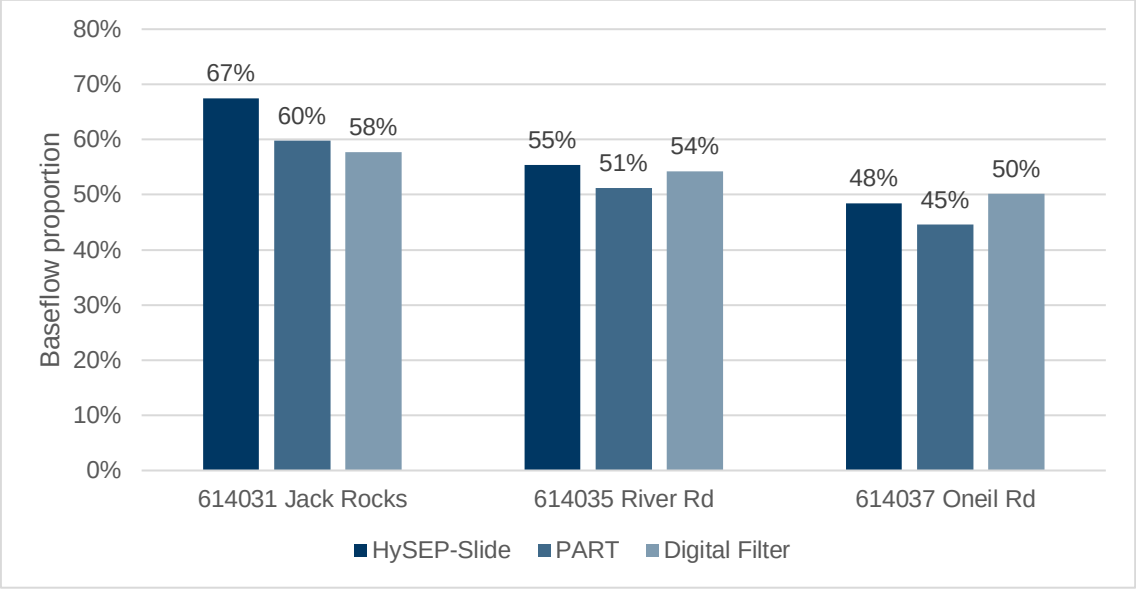


Figure 0.8 ***Baseflow contribution to runoff***

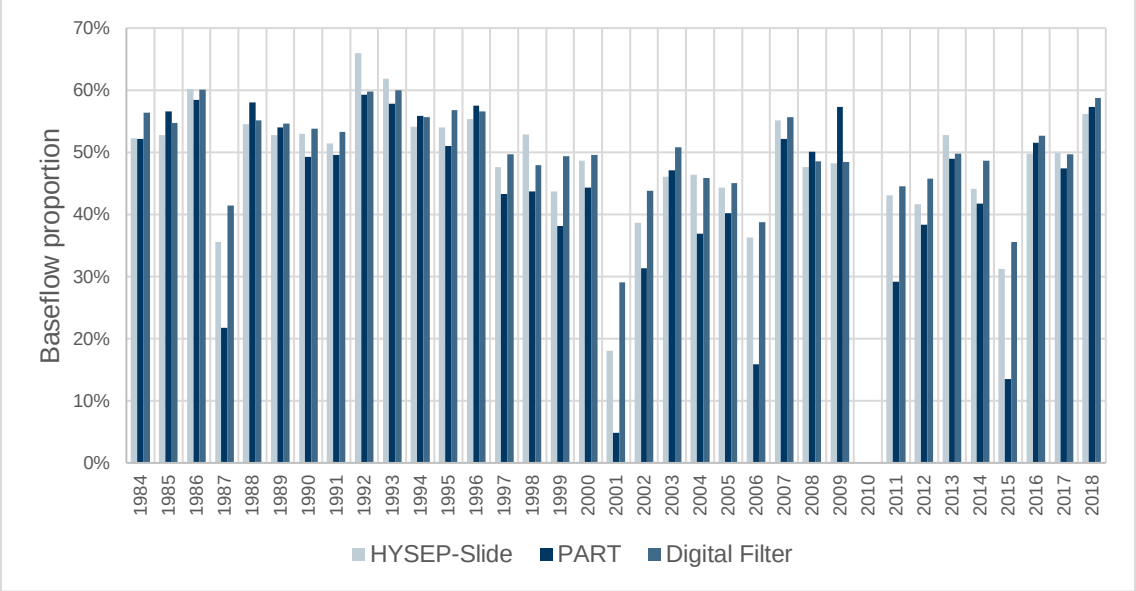


Figure 0.9 ***Baseflow trends***

Surface water quality

Historical water quality data

Surface water quality monitoring data across the Myara North mine region has historically been completed by Alcoa and DWER, and is limited to salinity, pH and some turbidity data.

The spatial distribution and frequency of Alcoa monitoring data varies widely across the Myara North mine region, with historical focus on research catchments and proposed mining catchments. Data for many sampling locations is not continuous. Data records range from short periods in the 1970s, with more extensive data from the mid-1970s through mid-1980s and mid-1990s.

The historical data identifies that surface water salinity is classified as fresh (0 to 500 mg/L TDS) in the surface water tributaries west of the 1,100 mm isohyet. Median salinity is comparable across all sampling locations, however maximum salinity values (as TDS and electrical conductivity (EC)) typically increase for tributaries east of the 1,100 mm isohyet.

Available pH data indicates that median pH of all tributaries is neutral, with some tributaries reporting minimum pH values in the acidic range (5 < pH < 8.6).

Historical turbidity data for surface water tributaries in the Myara North study area identify median turbidity values below 1.5 nephelometric turbidity units (NTU) with occasional values exceeding 25 NTU at some locations on Gooralong Brook, 39 Mile Brook and Banksia Gully. DWER monitoring of Serpentine River locations identifies marginally higher median turbidity values ranging from 1.6 to 2.6 NTU (GHD 2023a, Appendix B).

Short-term trends in surface water quality data (EC and turbidity logger data)

A short continuous EC logger record at two tributaries east of the 1,100 mm isohyet (Banksia Gully (site 6141121) and Goldmine Gully (site 6141125)) identified EC at the lower end of historically observed ranges.

During September 2020, EC at Banksia Gully was stable at an average of 167.1 µS/cm for four days, while Goldmine Gully saw a steady rise in EC from 236.2 to 377.6 µS/cm over four weeks. In July 2021, EC at Banksia Gully ranged from 50.2 to 201.3 µS/cm, and Goldmine Gully recorded a range of 49.5 to 338.66 µS/cm, increasing to 663.4 µS/cm in mid-October before returning to typical levels.

A trend has been observed between streamflow rates and salinity, with salinity increasing as the streamflow decreases (Figure 0.11).

Between September 2020 and February 2023, turbidity data were collected from multiple sites near the Serpentine Dam, where turbidity loggers were installed to monitor water quality. In September 2020, loggers were placed at the lower reach of 39 Mile Brook (SW03), a minor unnamed tributary (SW04), Goolagong Brook (GG03), and the main branch of the Serpentine River (SW08). At three of these sites, turbidity ranged from 0.4 NTU (GG03) to 1.9 NTU (SW03), with turbidity pulses reaching up to 138.7 NTU at SW03, typically associated with rainfall events. In the period from August 2022 to February 2023, turbidity loggers were installed at TN14, upstream of 39 Mile Brook, and at 614035, a DWER stream gauging site upstream of Serpentine River. At TN14, turbidity ranged from -0.9 to 98.9 NTU, with an average of 2.44 NTU, and at 614035, it ranged from -0.9 to 60.2 NTU, with an average of 3.92 NTU. Elevated turbidity pulses were recorded at both sites, often linked to rainfall, and some spikes were attributed to water disturbances (passing debris) during sampling, which were removed from the data (GHD 2023a, Appendix B).

Baseline surface water laboratory results

Surface water grab samples were collected from selected surface water monitoring locations when flowing water was present during the monthly surface water monitoring events between August 2020 to November 2022. The field and laboratory program included an extended field and laboratory parameter suite during the wetter months of August, September and October 2020, with a shorter field and laboratory parameter suite collected in subsequent years (2021 and 2022) and during the drier months (GHD 2023a, Appendix B).

The results of the baseline monitoring program identify that surface water quality is generally similar across the Myara North mine region, reflecting the similar hydrological and hydrogeological conditions. As with groundwater quality the surface water quality is typically fresh, unimpacted by anthropogenic activities and consistent with the site setting within state forest.

The salinity, pH and turbidity data observed during the baseline monitoring period is consistent with the historical data record for the various sub-catchments of the Myara North region.

Surface water is non-saline and moderately acidic, with marginally elevated surface water salinity observed in some samples during late season monitoring or when sampling occurred from pools.

Surface water samples typically had low turbidity and low total suspended solids. The low background turbidity was also observed in the short continuous turbidity logger record at four representative sites described above.

As with groundwater within the Myara North mine region the surface water results had low nutrient levels, and metal concentrations representative of the geological setting. During the 2020 monitoring events, microbiological parameters were detected at all sampling sites, with widespread detection consistent with the presence of fauna species within the national park setting.

Low concentrations of PFAS were detected at four sites, however all detections were significantly below the drinking water assessment criteria.

Detection of PAHs elevated above the drinking water guideline was recorded at site SW06 in October 2020, with PAH concentration dominated by naphthalene. Site SW06 is located in the catchment of a prescribed burn that occurred in late September 2020, and it is assumed that the elevated PAH concentration occurred due to natural introduction of PAHs from the prescribed burn. Dieldrin was detected in a single sample (SW01) in August 2020 at a concentration significantly lower than the drinking water assessment criteria.

For other contaminants of potential concern, including methylene blue active substances (MBAS) surfactants, Benzene, Toluene, Ethylbenzene and Xylene (BTEX) compounds, TRH and explosives, all samples analysed returned results less than laboratory limits of reporting.

Conceptual understanding of surface water and groundwater connectivity

Introduction

Surface water and groundwater are hydraulically connected through drainage lines (and potentially springs), valley floors (wetlands, damplands) and the water reservoir (the Serpentine Dam). Surface water is at least intermittently connected to both the regional (or in some instances perched) watertable and the interflow vadose zone.

This is supported by observations from the surface water flow monitoring data. An example of recorded observations is shown for the Jack Rocks gauge and the nearby bore MJ40122A which documents the correlation between elevated groundwater levels and surface flows (Figure 0.10). Surface flows occur at the same time when groundwater levels are elevated by several metres in response to winter rainfall.

Surface and near surface flow

Stream gauges within and in proximity to the Myara North DE (Appendix C), confirm that surface water flows are relatively short-lived following winter rains, ceasing to flow within two to three weeks following peak surface water flows.

The short duration of surface water flow following rainfall supports that the contribution to surface water flow from catchment runoff and other short-term storage such as shallow subsurface flow top up the baseflow contribution from groundwater in short term, following the winter rains.

The near-surface flow occurs in the variably saturated shallow subsurface where sufficient rainfall inputs can temporarily re-saturate permeable materials where these are present on top of less permeable substrate (for example clayey saprolite or basement subcrop) and cause short-term flows from these perched conditions downgradient. Due to the large heterogeneity of the weathering zone materials this component of flow can often exfiltrate to the surface when encountering a barrier such as a basement outcrop or where the shallow subsurface zone otherwise pinches out.

These flows are thought of as a patchwork of locally occurring flows, largely non-contiguous, but able to support – in short term – streamflows activated by winter rainfalls. This flow component is likely to merge with baseflow in the slopes surrounding the drainage lines where these sufficiently cut into the regional watertable.

Given the short duration, the streamflow flows carry the surface and near-surface flow contribution until it is exhausted, and the streamflow becomes dependent on contribution from groundwater (i.e., baseflow only). An examination of TDS values in Figure 0.11 between May 1990 and May 1991 suggests that winter rains at Jack Rocks gauge lead to low TDS values (around 150 mg/L) at the start of winter streamflows consistent with the initial larger proportion of surface runoff and near surface flow (and rain) contribution. As flow subsequently diminishes, TDS values rise to just below 350 mg/L, more typical of groundwater, i.e., dominated by baseflow.

Baseflow

Discharge in the form of baseflow or seepage, at smaller rates, is then present for the subsequent period typically extending some weeks or months following the winter rains and peak storage (when groundwater levels are highest).

Given the shallow depth to groundwater in areas beneath the potential GDEs and wetlands, the regional groundwater continues to support the potential GDEs and wetlands, particularly during the summer months in absence of surface water flows. As long as groundwater within the topographical slopes surrounding the drainage lines or creeks does not considerably fall below the creek level (which would lead to hydraulic disconnection), or the flow gradient reduces such that the incoming flow is completely removed by riparian evpotranspiration, groundwater continues to exfiltrate to the creek, or supporting sufficiently shallow watertable in the riparian zone accessible for support of vegetation communities.

Salinity changes during streamflow

Major rainfall events that produce streamflows lead to changes in streamflow salinity. These are interpreted to reflect changing proportions of more saline groundwater and less saline runoff and near surface flow. A relationship between streamflow rates and TDS (Figure 0.11) clearly demonstrates increase in TDS with falling streamflows and the importance of surface and near surface flows.

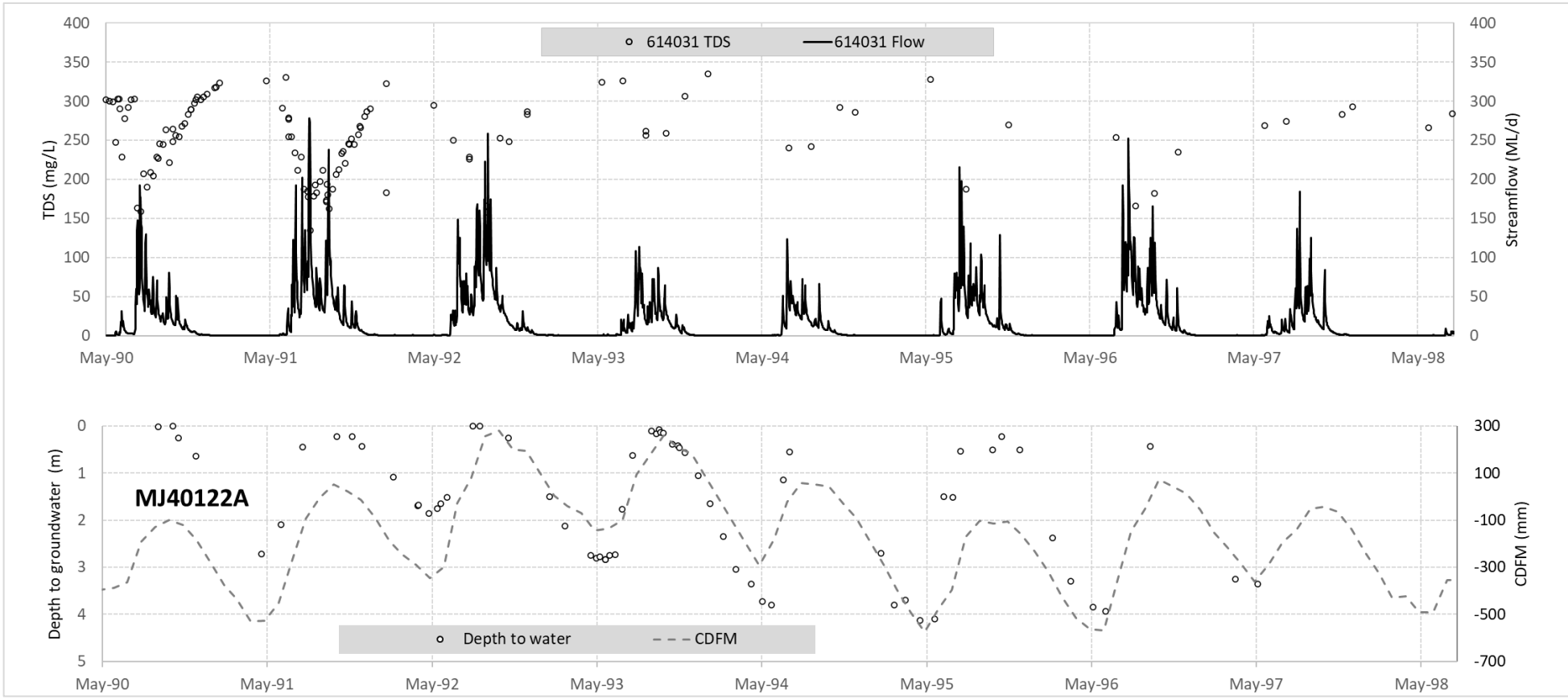


Figure 0.10 Example of streamflow and groundwater level response to seasonal rainfall (Jack Rocks gauge and bore MJ40122A)

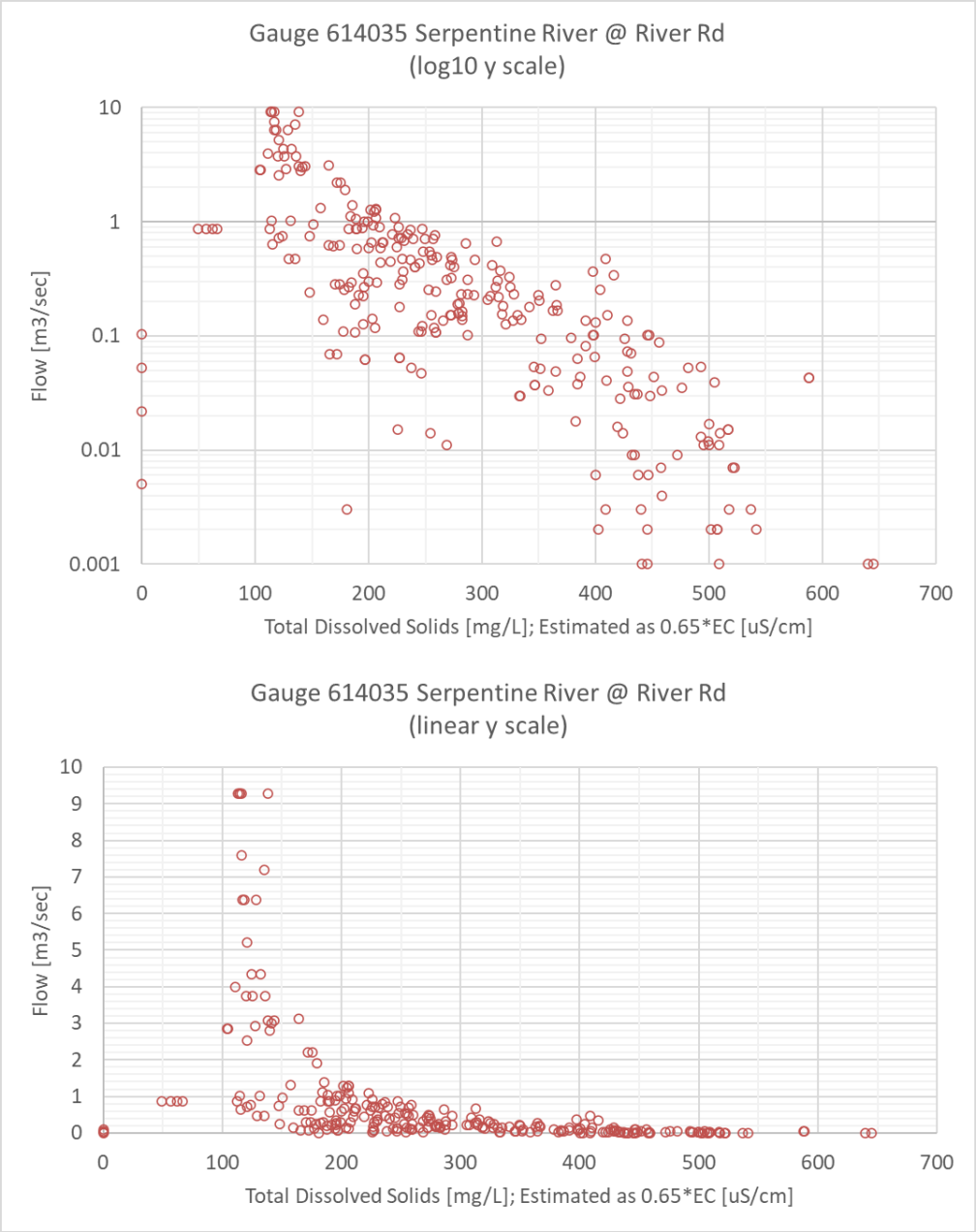


Figure 0.11 Example of relationship between streamflow rate and salinity (TDS)

Key components of stream-aquifer interaction

The key water components active during the stream aquifer interaction (occasionally including the top profile that is unsaturated for most times), and the conceptual model of this interaction are sketched in Figure 0.12.

In summary there are three potential sources of water which support streamflows and the riparian zones, including wetlands, areas where the potential GDEs are also mapped:

– **Surface runoff** – the proportion of rainfall flowing down-slope on the surface. It is short-term and proportionally small due to thick forestation.

– **Occasional near-surface flow in variably-saturated shallow subsurface** – a patchwork of shallow subsurface flow within lateritic material/sands/gravels, which eventually discharges into the creek or riparian zone or merges with baseflow. This component of flow represents occurrences of lateral flow through otherwise mostly unsaturated zone, perched above the less permeable saprolite clays or basement material of low permeability. The proportion of flow may occasionally exfiltrate (for example on encountering outcrop, or less permeable soil) and then infiltrate again, or removed by e.g., evaporation or evapotranspiration.

– **Baseflow - groundwater discharge** where the topographic low points (e.g., creeks, wetlands) intersect the regional groundwater table. For shorter periods after rainfalls the flow overcomes evapotranspiration in the riparian zone and discharges as baseflow into the stream.

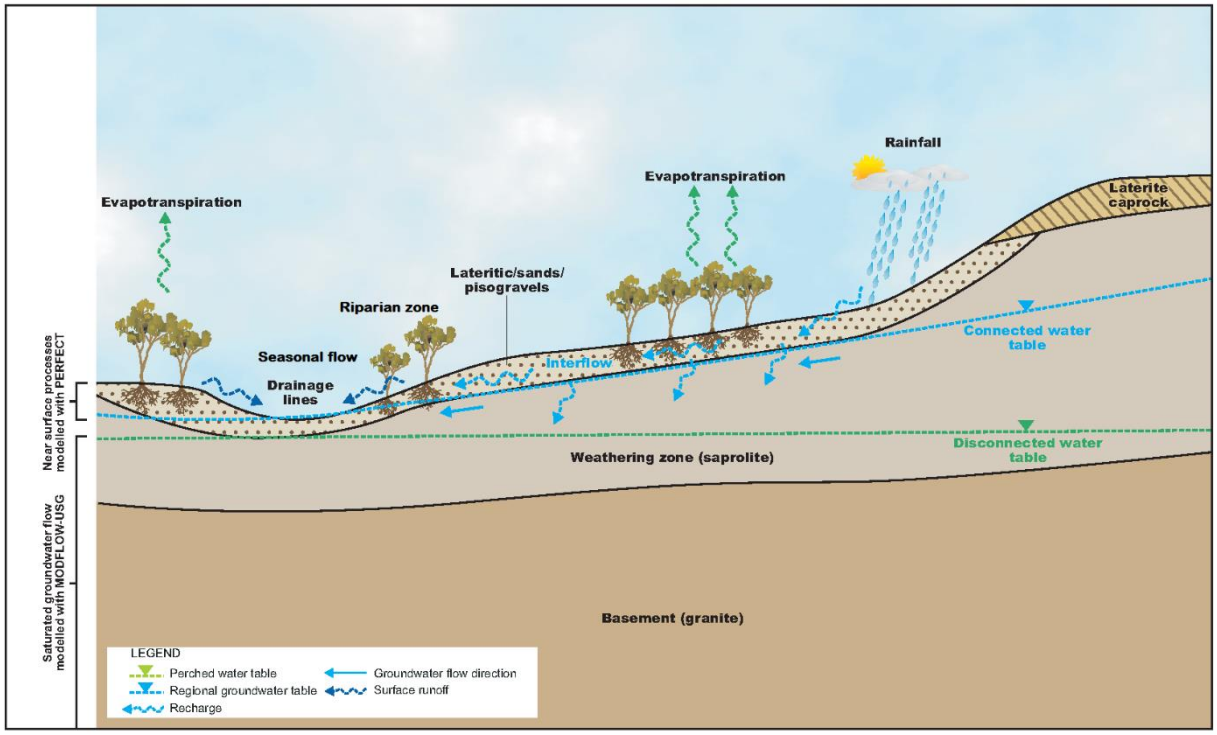


Figure 0.12 Conceptual representation of surface water groundwater interaction

Proportional representation of flow components

Attribution of flow components to streamflows has been examined on Jack Rocks gauge data which has a reasonable density of flow and EC data during 1981 and 1999 observation period. Grigg *et al.* (2020) provided a case that principal contribution to the Darling Range streams comes from groundwater (i.e., baseflow), which is also supported by baseflow estimates in section 0 (45% to 67% interpreted as baseflow).

In the following, we present a simple case calculation, based on Jack Rocks data, using TDS and streamflow data to estimate flow components.

The calculation is based on an example of several similar approaches, in this case on Gonçalvès et. al. (2020) who presented a methodology that uses hydrochemical data to constrain various flow components (they refer to baseflow and surface/hypodermic flow) with a monthly time step. Their methodology uses major ions to characterise hydrochemical end-members and also assumes fast responding reservoir to runoff and the near-surface flows; and slower responding reservoir to baseflow.

In absence of detailed hydrochemical data for Jack Rocks gauge, only TDS is applied as the hydrochemical constraint. Assuming the average TDS values for the two end-members, runoff/near-surface flow and baseflow, at 100 and 350 mg/L, respectively, it is possible to estimate attribution of these two flow components during 1981 and 1999 winters. The results of several possible realisations obtained using the approach by Gonçalvès et. al. (2020) are presented in Figure 0.13.

In this case we present the following possible realisations which yield similar streamflow timeseries results:

– “Low baseflow”, and low recharge rate realisation (in this case using 46 mm/yr recharge rate)
– “High baseflow” – and higher recharge realisation (in this case using 113 mm/yr recharge rate)
– Baseflow aligned with the chloride mass balance (CMB) recharge estimate (in this case using 56 mm recharge rate)
– Baseflow aligned with the CMB recharge estimate and peak flows

A reasonable match (Figure 0.13) between measured and calculated data (both flows and TDS) using a simple parsimonius analytical model indicates a clear interaction between flow components and the ability of this simple model to reasonably represent streamflows. All presented realisations have similar correlation between observed and simulated results, with correlation coefficient (R^2) varying between 0.71 and 0.77.

The results also indicate that using a range of recharge rate values it is possible to obtain similar streamflow results, even when constrained by TDS. The recharge rate in this case varied between 46 and 113 mm/yr, with the balance of streamflow supplied from quickflow (mainly interflow) components. In these evaluated realisations baseflow contributes between 18% to 50% of streamflow.

This range could be potentially even larger given that the analytical solution can accommodate it and produce plausible streamflow estimates. Baseflow proportion is likely to vary more during shorter timesteps, e.g., quickflow would be dominant during the initial phases of the streamflow event, while baseflow will be dominant in the receding part of the event. This is also reflected in the simulated realisations in which the streamflow peak precedes the baseflow peak. More detail on these realisations is provided in GHD (2021b) (Appendix D).

Streamflow salinity data can also provide indications of the prevailing flow regimes. The relationship (Figure 0.14) between the recorded streamflows and TDS for the same period indicates a relatively stable range of TDS at low flows and then log-linear decrease in TDS with rising flow rates.

Below flow rates of 0.05 m^3/s the recorded TDS ranges between 280 and 345 mg/L. It is reasonable to assume that at these flow rates practically all contribution is coming from groundwater as baseflow. In this particular case the surface flow becomes active when the flow rate exceeds 0.05 m^3/s.

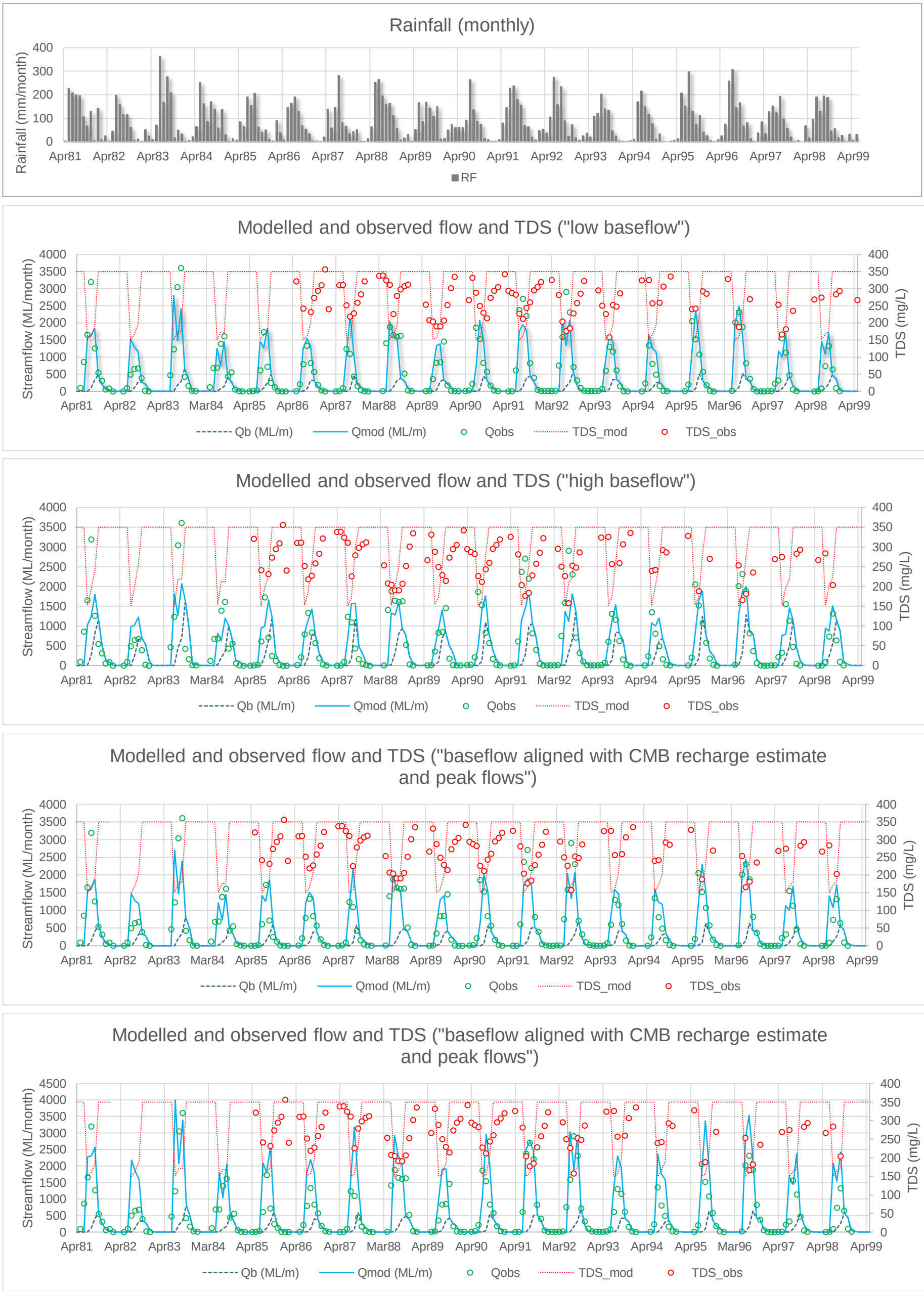


Figure 0.13 ***Application of simple analytical TDS-constrained baseflow-quickflow models to represent measured streamflows at Jack Rocks gauge (Qb – baseflow; Qmod – modelled streamflow; Qobs – observed streamflow; TDS_mod – modelled TDS; TDS_obs observed TDS)***

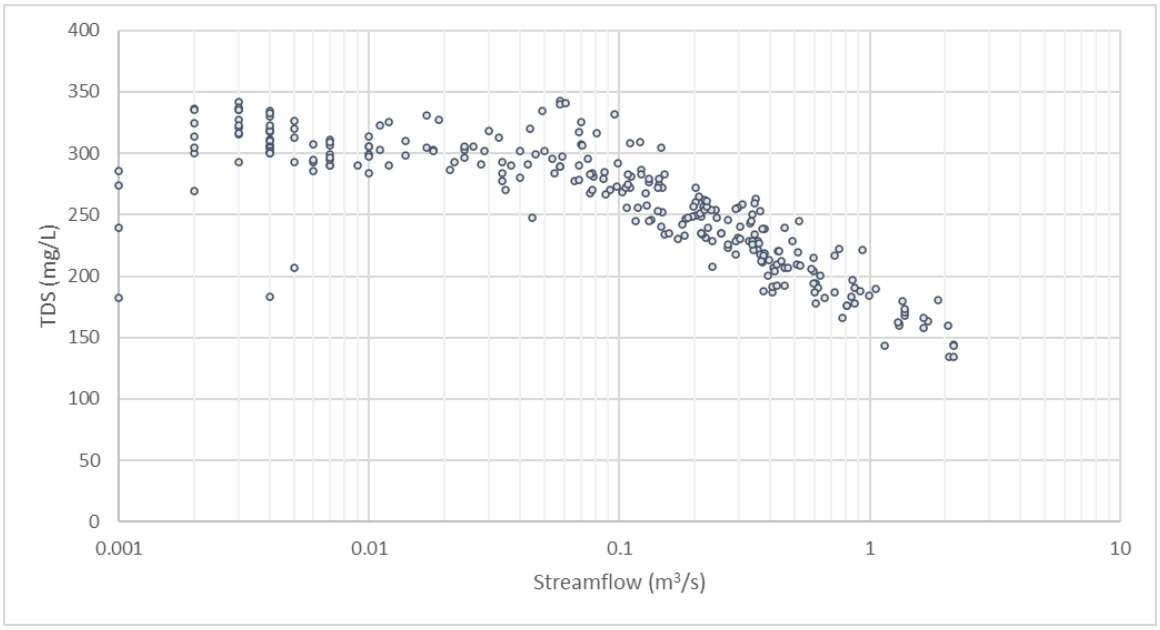


Figure 0.14 Relationship between average daily flow rates and TDS (Jack Rocks gauge (614031)

Holyoake hydrological setting

This section summarises the results of the baseline groundwater, surface water and environmental technical investigations that were completed across the Holyoake mine region. The aim of investigations was to establish baseline hydrological conditions, including water quality (surface water and groundwater).

Hydrogeological characterisation

Alcoa and DWER have historically collected limited groundwater level and groundwater quality data within the Holyoake mine region, while neighbouring mine regions have been investigated in more detail.

As part of the baseline monitoring program GHD installed 17 new groundwater monitoring bores in 2020, to supplement nine existing Alcoa groundwater bores (Figure A-11, Appendix A). The location of the monitoring bores was selected to provide site wide coverage of groundwater conditions. One of the monitoring sites included installation of paired bores (shallow and deep).

The subsequent baseline monitoring program comprised monthly water level dips and physico-chemical parameter measurements between October 2020 and February 2023 (up to four monitoring rounds) with groundwater samples collected for laboratory analysis of a broader suite of parameters across each event. The timing of the monitoring events was aligned to represent the seasonal periods of later winter annual groundwater level maximum, and the late summer groundwater level minimum. No groundwater level data loggers were installed at Holyoake mine region.

Aquifer units

Hydrogeological information on the aquifer system units was confirmed from installation and hydraulic testing of groundwater monitoring bores by GHD within the Holyoake mine region. Data on bore depths and screen interval were reviewed to interpret the lithology profile and infer depth to basement rock. A summary of the geological logs is provided below, and monitoring bore locations are presented in Figure A-11, Appendix A. Detailed geological logs of GHD bores are provided in GHD (2020b) (Appendix B).

A review of the GHD geological logs indicates a thicker lateritic profile than that of the Myara North mine region and depth to fractured bedrock was deeper, with a generalised profile as described below:

– **Lateritic/ duricrust caprock**: 1 to 7.5 m deep with an average of 1 to 2 m. The caprock comprises minor soils with pea-gravel and cemented duricrust or laterites and is less developed than in Myara North. One bore returned a well sorted sand from surface with an absence of caprock.
– **Saprolite**: Highly variable depths from 1 to 32 m, comprising completely weathered clay. Generally, clay is mottled or pallid towards the top becoming greener with depth indicating transition to weathered bedrock. Several bores also returned a uniform silty clay lens up to 20 m thick within this succession.
– **Weathered zone**: Weathered basement zone (which includes saprock) is characterised by a gravelly texture and decreasing clay content but with a higher clay content that in Myara north. Groundwater flow was minor with measured flows during drilling of only 4 L/minute, significantly less than in Myara North.
– **Fractured basement**: Depth to fractured granite varies from 6 to 36 m BGL. Two notably shallower bores intercepted a quartzite and dolerite intrusions whereas one deep bore recorded a schist at 33.5 m.

Slug tests (GHD 2023a) were conducted on GHD monitoring bores, and the results are summarised and presented in Figure 0.1. The monitoring bore slotted intervals reflect the horizons with water strikes, which were generally identified within the transition zone from weathered bedrock to fractured granite.

Highest hydraulic conductivity values were returned from bores screened in the basement saprock to highly weathered granite and likely related to discrete high permeable zones within this unit. Hydraulic conductivity ranges from <0.1 to just over 1.0 m/day with an average of 0.3 m/day as shown in Figure 0.1. The average hydraulic conductivity for Holyoake mine region is lower in comparison to Myara North mine region. This is consistent with the described lithology and drilling, where higher groundwater flows, associated with the basement/saprock profile, were more common.

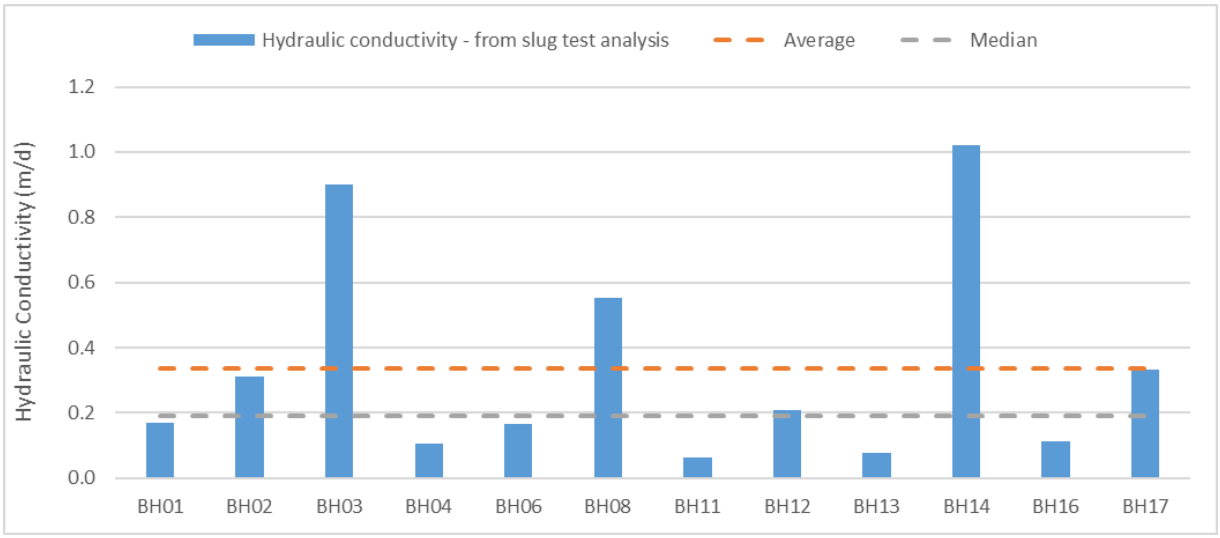


Figure 0.1 Holyoake slug testing results (hydraulic conductivity)

Groundwater levels and flow

Groundwater levels, flow and discharge

The newly instated monitoring bores, which are located close to, or within the valley floors and creek lines, indicate that the depth to groundwater is generally greater than 10 meters BGL (valley floor level), with one of the 17 locations exhibiting depth to groundwater less than 5 m (BH12). The average depth to groundwater is 14.5 meters below ground level.

At a regional scale, an inferred relationship between topography and depth to groundwater indicate that groundwater flows towards the north-west, where it would discharge in or along the major drainage lines, including the lower lying areas of the South Dandalup Dam and associated lower lying tributaries (e.g., South Dandalup River).

Groundwater level trends and observations

As noted earlier, there is lack of historical monitoring data within the Holyoake mine region to assess long-term groundwater level changes. A total of six bores were identified that have longer-term monitoring data, with four having sufficient frequency of historical monitoring data to assess seasonal variation. These bores show a seasonal variation of around 1 to 2 m.

The Holyoake mine region historic bores generally have a greater depth to groundwater than Myara North mine region bores. A summary of historical groundwater level trends and salinity is presented in Table 0.1. The groundwater levels of the six monitoring bores show declining groundwater levels since 1990s, with an average decline of close to 9 meters over 30 years (or 0.3 m/year) which broadly aligns with the reduction in rainfall seen over this period. This is considered to reflect the reducing rainfall patterns, which also appears to be declining since 1990s.

Table 0.1 Holyoake mine region- summary of historical groundwater level trends and salinity

Monitoring well ID	Groundwater levels			Groundwater salinity		
	1990 SWL (mBGL)[1]	2020 SWL (mBGL) [1]	Change SWL (m)	1990 TDS (mg/l) [1]	2020 TDS (mg/L) [1]	Change TDS (mg/L)
MJ46071A	10	17	-7	250	300	50
MJ46071B	10	17	-7	NA	NA	NA
MK46051A	17	22	-5	NA	NA	NA
MK46101A	10	25	-15	150	200	50
MK49162A	9	20	-11	2000	2000	0

Monitoring well ID	Groundwater levels			Groundwater salinity		
	1990 SWL (mBGL)[1]	2020 SWL (mBGL) [1]	Change SWL (m)	1990 TDS (mg/l) [1]	2020 TDS (mg/L) [1]	Change TDS (mg/L)
ML49131A	10	20	-10	1000	1400	400
Notes	SWL - Standing Water Level					
	TDS – Total Dissolved Solids					
	1 - average values estimated from graphs observations (semi-quantitative)					
	NA - Not applicable, no data or unreliable data					

The installation of 17 new groundwater monitoring bores within and in proximity to the Holyoake DE facilitated a better understanding of groundwater levels across the mine region, with the data providing a more spatially representative dataset for groundwater within the whole of Mine DE. Key observations from the new monitoring bores include:

– Data from the new bores, which are predominately located close to, or within the valley floors/ creek lines, highlighted that groundwater levels are more variable and generally deeper than in the Myara North mine region.
– The groundwater is more than 10 meters BGL (valley floor level), with one of the 17 locations exhibiting depth to groundwater levels less than 5 m (BH12). The average depth to water is 14.5 meters BGL.
– Groundwater levels in the B16 nested wells exhibited different responses to seasonal variations. The shallow well fluctuated in response to individual rainfall events, while the deep well also responded to these events but showed a steady increase overall, continuing beyond the wet season. The deep well levelled off from September to mid-December before declining with the onset of summer.
– Groundwater levels reduce over the monitoring period (October 2020 to February 2023) in more than 60% of the monitoring bores, consistent with a seasonal change from late winter groundwater highs to summer groundwater lows. The reduction in groundwater levels results in the drying out of one bore (BH15) with groundwater level reducing beyond the base of bore at 8 m, indicating the absence of a saturated profile at this location during summer.
– The average seasonal groundwater level decline for all new bores is 0.7 m, significantly less than Myara North mine region (1.9 m for Myara North mine region bores), which may reflect, based on the observations across the Myara North and Holyoake mine regions, that the bores with shallower depth to water, tend to have a greater seasonal range in groundwater levels.

Groundwater quality

Groundwater salinity trends and observations

Groundwater quality within the Holyoake mine region is typically fresh, consistent with the current site setting within the state forest. The limited historical data (Table 0.1) suggests a slight rise in TDS, consistent with the noted general decline in groundwater levels, though it may also fall within seasonal variations (lack of seasonal data). There is a relatively large range in salinities measured in the 1990s with TDS data in the range of 150 mg/L to 2000 mg/L (average of 850 mg/L). The spatial extent of the bores is limited, but the two bores with high salinities (MK49162A and ML49131A) are located 400 m apart just outside of the south-east boundary of Holyoake DE.

The following observations are made from the groundwater monitoring program (October 2020 to February 2023):

– Groundwater is consistently fresh for the majority of bores and for the majority of sampling rounds. The average TDS of the new monitoring bores is around 580 mg/L.
– Three bores (BH03, BH05 and BH12) have a relatively high TDS ranging between 1,000 - 1,770 mg/L. Two of these sites (BH03 and BH05) are located relatively close together (1.8 km) along the same drainage line in the far north-east of the project area and may reflect local hydrological and hydrogeochemical conditions.
– Groundwater pH in Holyoake is generally uniform, with an average field pH of 6.5. Historical bores show minimal variation (less than 0.5 pH units), while new bores exhibit a wider range (1.2 pH units), likely due to

the influence of bore construction materials (alkaline grouts and cements) and the stabilisation of groundwater conditions.

Other groundwater quality parameters

The groundwater quality sampling for this assessment included the analysis for a wide range of water quality parameters. The data from the four monitoring rounds indicated no discernible seasonal change in groundwater quality, although some effects of sampling following the drilling of the new groundwater monitoring bores was noted.

The results showed low nutrient levels and consistent with the land-use type (i.e. lack of applied nutrients or sources), albeit marginally higher than in Myara North mine region. Metal concentrations were also marginally higher than Myara North mine region but still typical of 'natural' conditions and representative of the geological setting.

Low concentrations of PFAS were detected in five of the sampled bores, however all detections were below the drinking water assessment criteria. Low-level detection of PAH (pyrene) was noted in most bores during the first monitoring round. PAH concentrations reduced in the second sampling round, possibly indicating that the drilling was the original source, or that the PAH source was related to short-term impacts from bushfires (GHD 2023a, Appendix B).

Surface water characterisation

Surface water flow

Holyoake gauging stations

There are several flow-gauging sites relevant to the broad region of the Holyoake mine region (Appendix A, Figure A-11), details of which are summarised in Table 6-2. It is noted that all gauged sites are situated outside of the Holyoake DE, and there are large areas of the proposed mining catchment for which no flow-gauging data is available.

Table 0.2 Gauging stations relevant to Holyoake

Site ID	Site name	Flow record	GS catchment area (km^2)	Average annual rainfall (mm)	Annual average streamflow (ML) [3]	Runoff (mm)
South Dandalup tributary						
614043	Pindalup	1984 to 1998	7 km^2	1,130.5	59	8.4
614059 [1]	Skeleton Road	1988 to 1998	19 km^2	1,112.2	2,519	133
614060 [1]	Gordon Catchment	1988 to 2018	2 km^2	948.8	17	8.5
Murray River and tributaries						
614045	Chadoora (Swamp Oak Tributary)	1984 to 1997	5 km^2	1,130.5	20	4.0
614047	Davis Brook – Murray Valley Plantation (Murray River Tributary)	1954 to 2002	66 km^2	1,130.5	6,407	97.1

Note:

1 Annual average rainfall for 614059 and 614060 derived from SILO 5 km daily grid data (1970-2020), remaining sites derived from SILO extraction for Karnet station (1970-2019)

Long-term trends in annual flow

Long-term annual flow data for the area neighbouring the Holyoake mine region is restricted to the Gordon catchment for the South Dandalup River (Figure 0.2). The Baden Powell gauging station is the only other site in proximity to the Holyoake area, with data from other stations predating 2000 (GHD 2021a, Appendix C).

As with Myara North there is an observed step change in streamflow in the Gordon catchment after 2000 (Figure 0.2), with similar step changes observed in Baden Powell annual flow data (data not shown).

Long-term trends in flow seasonality

Similar to the long trends in flow seasonality in Myara North the box plots of monthly flow data (grouped by pre 2000 and post 2000) for Gordon (South Dandalup River) show a delay in flow commencement and typically earlier cease to flow for periods after 2000 (Figure 0.3) (GHD 2021a, Appendix C).

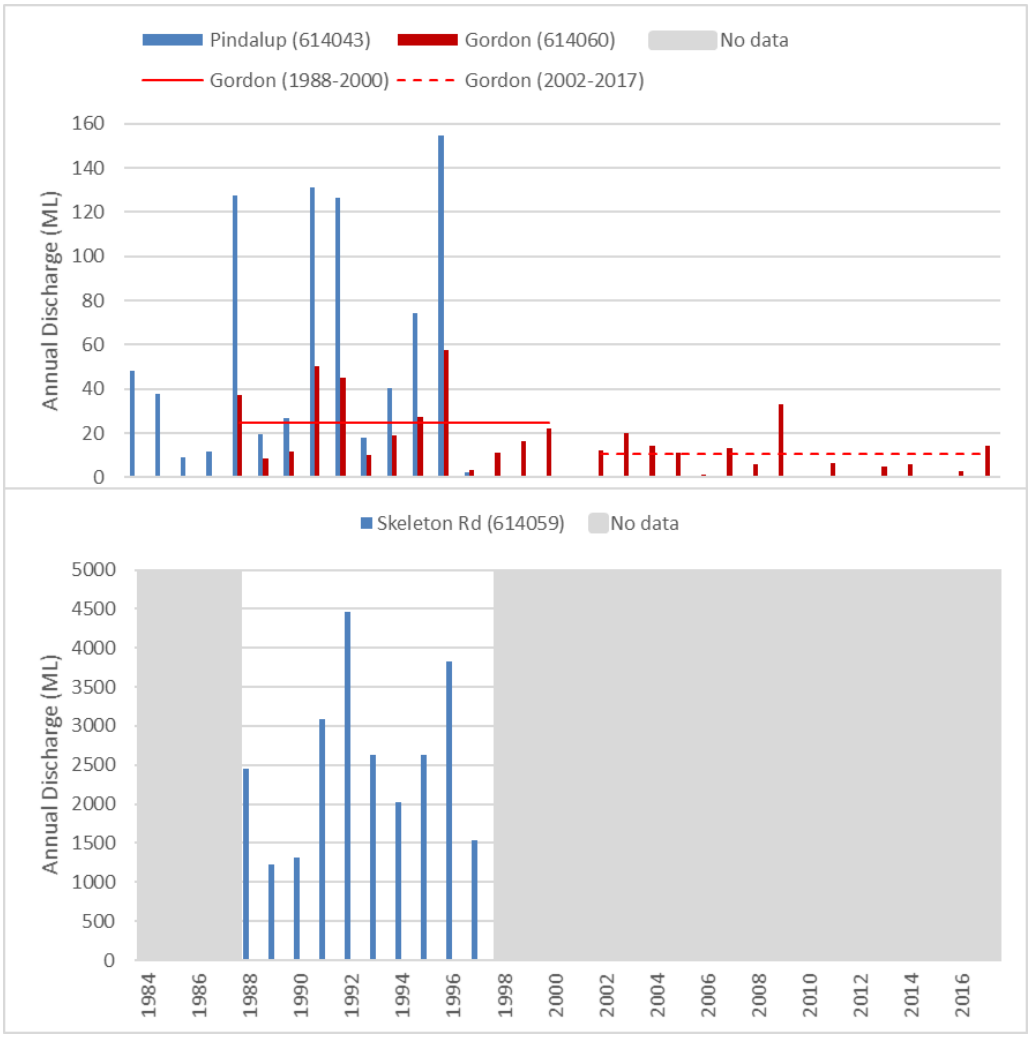


Figure 0.2 ***Annual flows at relevant South Dandalup catchment gauging stations***

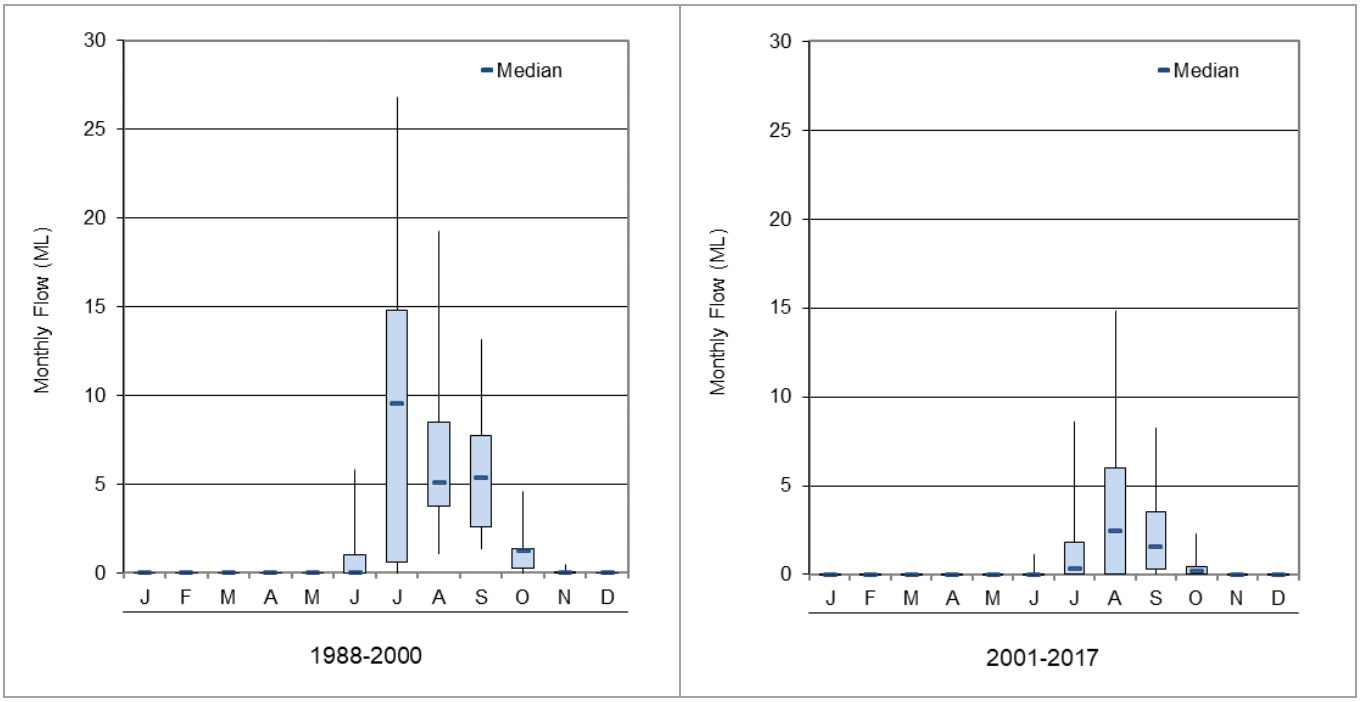


Figure 0.3 Flow seasonality, Gordon (South Dandalup) for periods 1988-2000 and 2001-2017

Short-term trends in surface water level and flow conditions

During the 2020 baseline monitoring period flow conditions at surface water sampling locations were recorded during monthly surface water sampling events (GHD 2023a, Appendix C). Surface water level loggers were installed late September 2020 at two Holyoake surface water monitoring locations.

Table 0.3 Holyoake surface water logger data summary

Site ID	Subcatchment	Installation date	Cease to flow (2020 season)	Cease to flow (2021 season)	Cease to flow (2022 season)
6141005	South Dandalup River	September 2020	October 2020	November 2021	November 2022
HSW05	Unnamed northern tributary of South Dandalup River		October 2020	November 2021	November 2022

Key observations from the surface water flow observations (August 2020 – November 2022) include dry conditions observed across multiple sites for all sampling events, including the central South Dandalup tributary through the Holyoake DE, with its upstream location observed to flow during one sampling event. No water level data was recorded at the Swamp Oak Brook monitoring location, while water levels at the other logger locations observed variable response to seasonal rainfall events in the limited logger record, with an increase in surface water level in response to rainfall occurring within 1 to 3 days.

The observed surface water flow conditions from 2020 to 2022 across the Holyoake mine region and a summary of the two surface water logger data results (September 2020 – February 2023) are provided in GHD 2023a, Appendix B.

Baseflow and interflow

Data analysis by GHD for the gauging stations located in the study area indicates that baseflow and interflow represents between 37% and 80% of streamflow, depending on location and baseflow separation methodology. The analysis was undertaken for the full streamflow record, varying between sites, between 1980 and 2018. These gauging stations are for much smaller catchments than those used for Serpentine Catchment (section 0) and represent a wider range or results.

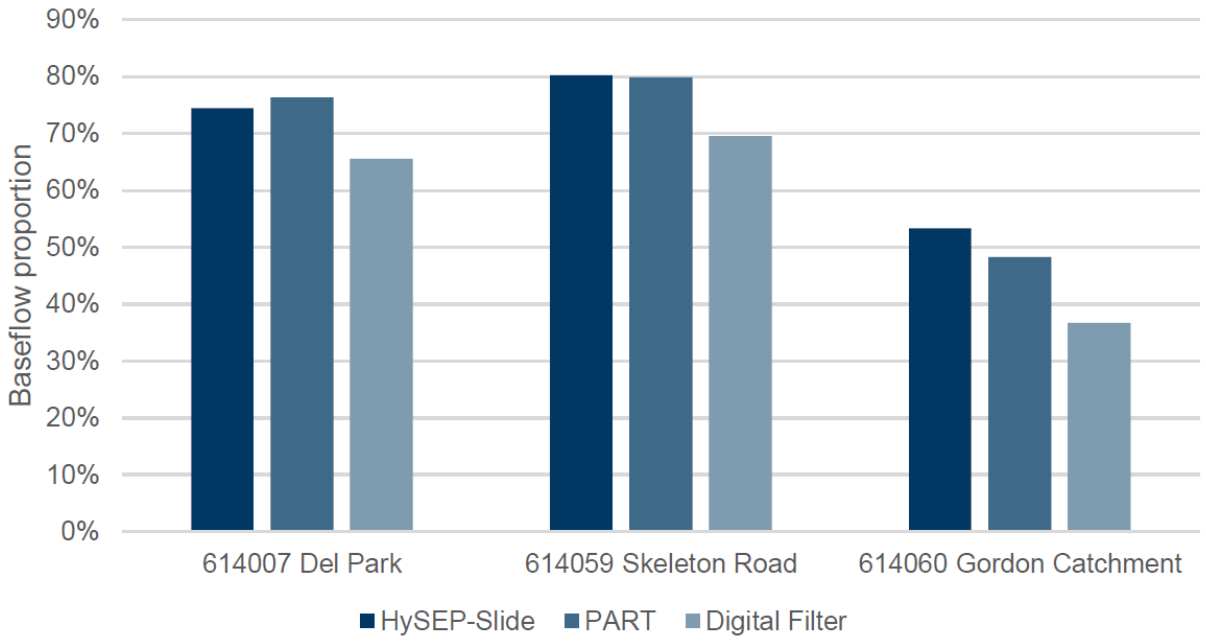


Figure 0.4 ***Baseflow contribution to runoff***

Surface water quality

Historical water quality data

Historical surface water quality monitoring within the proposed Holyoake mine region has primarily been undertaken by DWER, with Alcoa monitoring limited to one site on Davis Brook (DV04) with sufficient data for review. Data is limited to salinity, pH and some turbidity data. As with Myara North mine region, data for many sampling locations is not continuous, and records range from short periods in the 1970s, to periods from the mid-1970s through mid-1980s, or mid-1980s to mid-1990s.

The historical data identifies that surface water is typically fresh, with median EC typically below 350 µS/cm. Limited pH data is available for gauging locations which indicates that median pH of tributaries is neutral.

Baseline turbidity for monitoring locations in the South Dandalup catchment (Holyoake mine region) are marginally higher than Myara North mine region, with median values ranging between 0.9 and 7.3 NTU.

Short-term trends in surface water quality data (EC and turbidity logger data)

EC loggers were installed at three sites: the lower reaches of South Dandalup River (site 6141005), an unnamed northern tributary (HSW05), and the outflow from the Holyoake mine region to the Swamp Oak Tributary of the Murray River (HSW03). No data was collected from HSW03 due to dry conditions. For the end-of-season flow period, median EC values were similar at sites 6141005 (197.7 µS/cm) and HSW05 (186.7 µS/cm), with site 6141005 showing a marginally higher maximum EC (244.6 µS/cm). In July 2021, data from sites HSW05 and 6141005 showed EC ranges of 33.9 to 193.9 µS/cm (average 149.9 µS/cm) and 74.0 to 225.9 µS/cm (average 156.3 µS/cm), respectively. Gradual increases in EC indicated rising groundwater contribution, while sudden decreases suggest surface water runoff events (GHD 2023a, Appendix B).

Turbidity loggers were installed at the same locations as the EC loggers in the Holyoake mine region, but no data was collected from site HSW03 due to dry conditions. In September 2020, turbidity data was available for a week, showing median turbidity of 4 NTU at site 6141005 and 6 NTU at site HSW05. The average turbidity at 6141005 was 25.9 NTU, with a maximum of 130 NTU. Unlike the fleeting pulses measured at Myara North mine region, these longer pulses are representative of an actual turbidity event. The pulses correspond to storm events, with higher peaks earlier in the season and lower peaks later in the season. The source of turbidity is unknown but may relate to prescribed burns covering a significant proportion of the catchment conducted in late 2018.

In the period from August 2022 to February 2023, turbidity data showed that at HSW05, turbidity ranged from 0.3 to 73.3 NTU, with an average of 6.17 NTU, and at 6141005, turbidity ranged from 0.6 to 223.4 NTU, averaging

12.69 NTU from August to October 2022. In November 2022, turbidity increased significantly, with values ranging from 86.9 to 313.4 NTU and an average of 199.07 NTU. Pulses of elevated turbidity were observed, often corresponding with rainfall events, and some spikes were attributed to sampling disturbances, while others remain unexplained. Site HSW05 had shorter-duration turbidity spikes, with a maximum of 129.2 NTU (GHD 2023a, Appendix B).

Baseline surface water laboratory results

Surface water grab samples were collected from selected surface water monitoring locations when flowing water was present during the monthly surface water monitoring events between August 2020 to September 2022. The field and laboratory program included an extended field and laboratory parameter suite during the wetter months of August, September and October 2020, with a shorter field and laboratory parameter suite collected in subsequent years (2021 and 2022) and during the drier months (GHD 2023a, Appendix B).

The results of the baseline monitoring program identify that surface water quality is generally similar across the Holyoake mine region, reflecting the similar hydrological and hydrogeological conditions. As with groundwater quality the surface water quality is typically fresh and consistent with the site setting within state forest.

The surface water physico-chemical samples collected and tested in-situ as well as those tested in the laboratory are similar to historical observations across the Holyoake mine region. Surface water is non-saline with neutral pH. Surface water samples typically had low to moderate turbidity and low total suspended solids.

The nutrient concentrations in the samples are generally low and align with the expected conditions of national park land use, where no nutrients are applied. However, some samples showed slight increases in total nitrogen and total Kjeldahl nitrogen, with two samples from sites HSW05 (Sept 2020) and 6141349 (Sept 2021) exceeding the guidelines at 1.2 and 1.4 mg/L, respectively. Additionally, three samples had total phosphorus concentrations above the recommended limits, including two notably high readings at HSW01 (0.68 mg/L) and DV04 (3.4 mg/L) in September 2020.

Metals concentrations were representative of the similar geological setting, with ANZECC guideline exceedances reported for zinc and copper in limited samples in August 2021. Microbiological parameters were detected at all sampling sites, with comparatively higher maximum detections reported at Holyoake mine region than in Myara North mine region.

Low concentrations of PFAS were detected at five sites across different monitoring months, however all detections were below the drinking water assessment criteria.

For other contaminants of potential concern, including MBAS surfactants, BTEX compounds, TRH, PAH, OC pesticides and explosives, all samples analysed returned results less than the laboratory limit of reporting.

Conceptual understanding of surface water and groundwater connectivity

Long-term observations of streamflows and groundwater level observations from the downgradient part of the Holyoake DE are not available. In their absence, section 0 presents data from outside of the Holyoake DE for illustration of likely streamflows expected within the Holyoake DE.

Despite the lack of observational data within the Holyoake DE, the nature of and the processes involved in surface water and groundwater connectivity are considered identical to Myara North DE (described in section 0). The notable potential differences are related to:

– Groundwater in Holyoake mine region is deeper than in Myara North DE. This means that access to watertable for phreatophytic communities is potentially more limited which would also limit their lateral extent. This is also illustrated by the proportion of potential GDEs of the Holyoake DE which constitutes 19%, compared to 33% in Myara North DE.
– Due to the deeper groundwater levels, surface flows are also likely to be smaller and flow events shorter than in Myara North DE, since less baseflow would be available to support streamflows. This is supported by the baseline surface water monitoring program. It is however possible that during the historical period before the last two decades the groundwater levels in Holyoake DE were shallower and surface flows greater than those observed in 2020.

O’Neil hydrological setting

This section summarises the results of the baseline groundwater, surface water and environmental technical investigations that were completed across the O’Neil mine region. The aim of investigations was to establish baseline hydrological conditions, including water quality (surface water and groundwater).

Hydrogeological characterisation

As part of a recent investigation to understand the project wide hydrogeological conditions and develop a robust baseline groundwater level and groundwater quality dataset in the O’Neil mine region, GHD installed 15 new groundwater monitoring bores in August 2023 over 14 locations. One monitoring site included installation of paired bores (shallow and deep), providing data on groundwater for the potential upper ‘perched’ unit and the underlying more regional groundwater. No historical groundwater monitoring (water level and quality) was undertaken within the O’Neil mine region in the past.

To date, one year of groundwater monitoring has been completed to capture the seasonal highs and seasonal lows across Winter 2023 and Summer 2024 including:

– Biannual sampling events (October 2023 and April 2024) including groundwater sample collection across the network for laboratory analysis of a broad suite of parameters, and manual water level dips (January 2024, April 2024, June 2024, August 2024 and October 2024)
– Continuous groundwater levels with EC and water level loggers installed in seven bores.

Aquifer units

Hydrogeological information on the aquifer system units was confirmed from installation and hydraulic testing of groundwater monitoring bores by GHD at O’Neil. Data on bore depths and screen interval were reviewed to interpret the lithology profile and infer depth to basement rock. A summary of the geological logs is provided below, and monitoring bore locations are presented in Figure A-10, Appendix A. Detailed geological logs of GHD bores are provided in GHD (2024a) (Appendix B).

A review of the GHD geological logs indicates a generalised profile as described below:

– **Lateritic/ duricrust caprock**: 0.5 to 4 m deep. The caprock comprises loose pisolitic soils underlain by superficial cemented duricrust or laterites (0.5 – 2 m thick). Some bores contained transported sandy stiff clay (0.5 – 2 m thick) below the laterite.
– **Saprolite**: Highly variable depths from 4 to 30 m, comprising highly weathered clay. Generally, clay is mottled or pallid towards the top becoming greener with depth indicating transition to weathered bedrock noting saprolite transitions to saprock through development of chips of weathered basement (0.1 – 12 m thick).
– **Weathered zone**: Weathered basement zone (which includes granitic saprock ranging 0.5-4m thick) noting saprock grading to weathered bedrock was not observed in eight bores.
– **Fractured basement**: Depth to fractured granite varies from 16 to 35 m BGL.

Quartz veins, ranging in thickness between 0.5 – 2.5 m, were intercepted in seven bores.

Slug tests (GHD 2024a) were conducted on nine of the GHD monitoring bores, and the results are summarised and presented in Figure 0.1. The estimated hydraulic conductivity at the monitoring bores is within an expected range of the geology and ranged from between 0.0041m/day (OEMB04) to 0.42 m/day (OEMB09), with an average hydraulic conductivity of 0.12 m/day. The average hydraulic conductivity for the O’Neil bores is lower compared to those in the Myara North (0.6 m/day) and Holyoake (0.3 m/day) mine regions. The bore with the highest hydraulic conductivity is screened in basement/highly weathered granite.

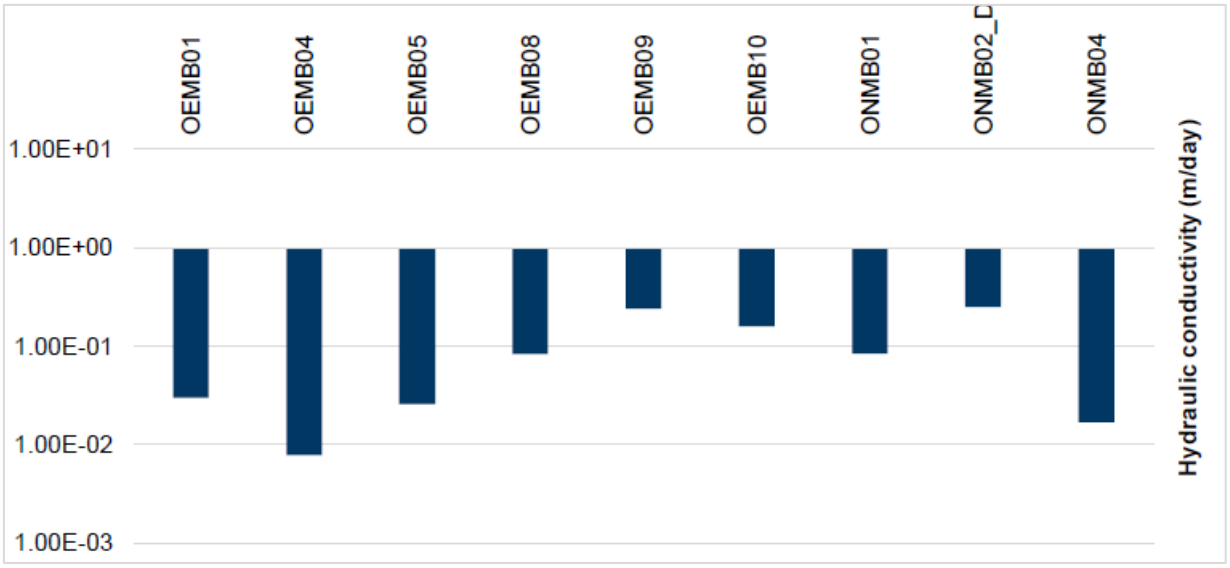


Figure 0.1 O'Neil slug testing results (hydraulic conductivity)

Groundwater levels and flow

Groundwater levels, flow, trends and observations

Key observations from the 2023 – 2024 monitoring period (GHD 2024b) include:

- Groundwater is generally deep (>15 m BGL), with average depth to groundwater (DTW) ranging between 1.1 m BGL (OEMB02) and 24 m BGL (OEMB01).
- Seasonal variations in field dips from January 2024 to June 2024 were observed in all bores with a varying degree of change with the majority of water levels decreased during the monitoring period:
  - OEMB01, OEMB05, and ONMB04 had consistent groundwater levels throughout the monitoring period, recording a seasonal change of less than 0.27 m.
  - OEMB08, and OEMB09 observed moderate variation of 0.35 m to 0.37 m.
  - OEMB02, OEMB04 OEMB10, ONMB01, ONMB02_D showed similar patterns yet the highest seasonal variation of 0.85 m to 2.98 m.

Manual dips broadly indicate regional groundwater flows from the northeast to the southwest, which are generally consistent with topography.

Key observations from the groundwater level data loggers installed in late April 2024 indicate:

- Groundwater depth aligning with manual field water level dips.
- Groundwater levels show seasonal variation, but additional data over a longer period is needed to confirm this trend. Response times vary across monitoring locations, suggesting local factors may influence how quickly groundwater levels respond to rainfall events.
- ONMB01 showed the most immediate response to rainfall, with up to 1 m rise recorded.
- Bores OEMB05, OEMB08, OEMB09, and ONMB02_D showed a decline in groundwater levels, with little response to rainfall, except during events exceeding 30 mm.
- OEMB04 showed a steady increase of ~0.2 m from May to July.
- OEMB10 remained steady, with minimal response to rainfall.
- The shallow aquifer forms a temporary perched system after rainfall, recharging the deeper aquifer before draining when no further rainfall occurs.

Groundwater quality

Groundwater salinity

Groundwater physical parameters were collected for the GHD monitoring wells in April 2024 and June 2024 monitoring rounds. Groundwater ranges from fresh to brackish with an average EC of 1,910 µS/cm, ranging from 248 µS/cm in ONMB01 (average DTW; 4.56 m BGL) to 5,450 µS/cm in OEMB01 (average DTW; 24 m BGL). Both bores are located on the western boundary of the O'Neil DE approximately 6km apart.

Other groundwater quality parameters

The groundwater quality sampling for this assessment included the analysis for a wide range of water quality parameters over the two monitoring rounds.

The results showed low nutrient levels and consistent with the land-use type (i.e. lack of applied nutrients or sources). Metal concentrations were typical of 'natural' conditions and representative of the geological setting, with ANZG guideline exceedances reported for zinc and cadmium in limited samples. No concentrations of BTEX or PFAS were detected. TRH and PAH concentrations were noted across the same four bores (GHD 2024b, Appendix F). No microbiological testing was undertaken as part of the monitoring program.

Surface water characterisation

Surface water flow

Flow conditions at surface water sampling locations were recorded across six monitoring rounds from July to November 2023. Sampling was completed when sufficient water was available to collect a sample without sediments being disturbed and when where a minimum of 0.1m of flowing water was present. Key observations of surface water flow conditions include that all sites recorded flows during the wet season, which gradually declined and ceased by October and November 2023. By the November monitoring round, all locations were dry.

Surface water level and turbidity loggers were installed at five tributary sites (SE03, SE21, SE34, MCRA_SW02, MCRA_SW06, and MCRA_SW07) to provide representative upstream and downstream monitoring data. All turbidity loggers except for SE21 malfunctioned during the monitoring period.

Datalogger measurements from one site (SE21) was available from February 2023 to March 2024, with logged surface water levels presented in Figure 0.2. Field data and logger data showed comparable trends. Logger data also indicated a direct response to rainfall events and surface water levels.

Turbidity data for July 2023 to July 2024 from all installed loggers is unavailable due to malfunctioning loggers.

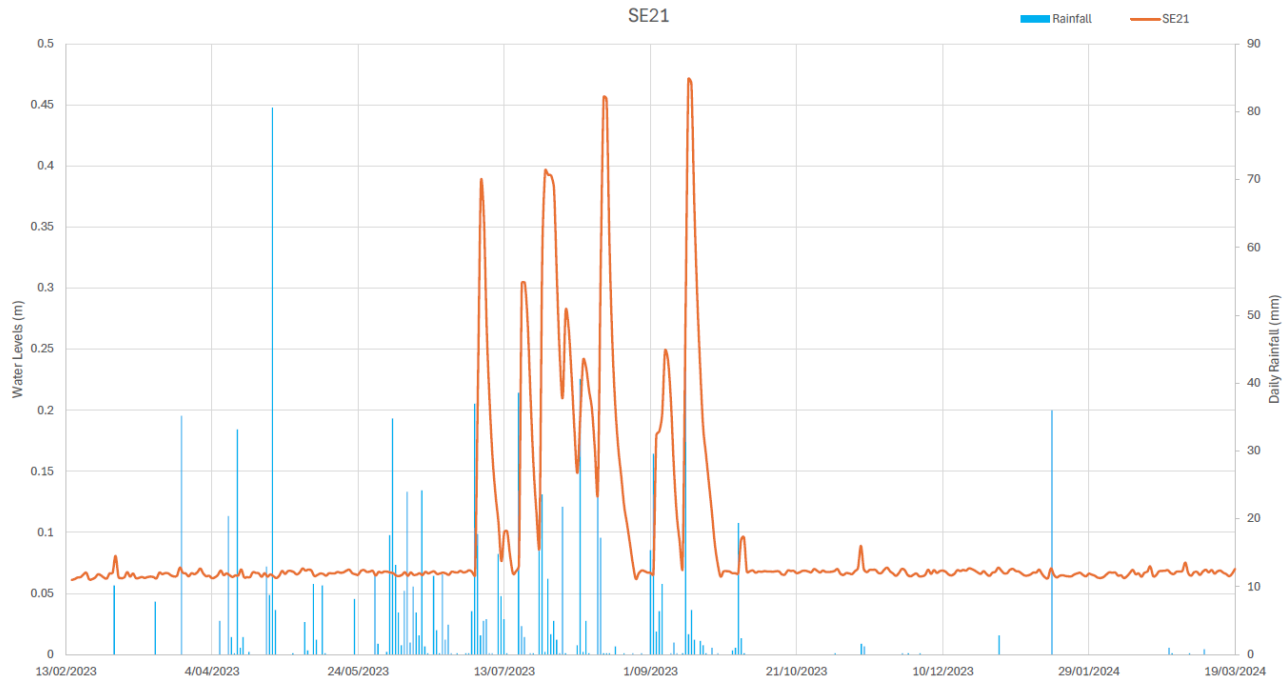


Figure 0.2 Surface water level recorded from SE21 (2023 – 2024)

Surface water quality

The results of the baseline monitoring program identified that surface water quality is typically fresh with EC ranging between 111 µS/cm and 861 µS/cm with an average of 269 µS/cm. Surface water samples typically had low to moderate turbidity and low total suspended solids.

The nutrient concentrations in the samples are generally low and align with the expected conditions of national park land use, where no nutrients are applied.

Metals concentrations were representative of the similar geological setting, with ANZECC guideline exceedances reported for zinc and copper in limited samples. Microbiological parameters were detected at all sampling sites on at least one of the sampling rounds

Low concentrations of PFAS were detected across five sites.

For other contaminants of potential concern, including surfactants, BTEX compounds, TRH, PAH, OC pesticides and explosives, all samples analysed returned results less than the laboratory limit of reporting with the exception of TRH recorded at one site in October.

Conceptual understanding of surface water and groundwater connectivity

Long-term observations of streamflows and groundwater level observations from the O'Neil mine region are not available. Despite the lack of historic observational data within the O'Neil mine region, the nature of and the processes involved in surface water and groundwater connectivity are assumed identical to those described for Myara North and Holyoake mine regions (described in section 0). This is considered a precautionary approach in the absence of comprehensive baseline information for the O'Neil mine region.

Assessment of hydrological effects of mining

Groundwater level changes

Numerical modelling was completed to assess groundwater level changes due to the Proposal on groundwater flow processes and interaction of those processes with intermittent streamflows in the Myara North DE (GHD 2021b) and Holyoake DE (GHD 2021c). The numerical modelling used a combination of numerical groundwater with streamflow routing and soil water balance models (MODFLOW-USG and PERFECT).

Within both Myara North and Holyoake DEs, the modelling indicates that changes in recharge and surface flow dynamics due to bauxite mining have the potential to raise the groundwater levels in mined areas by several metres. Predicted change in groundwater levels is noted to follow seasonal variation.

Within the Myara North DE, groundwater level mounding during the clearing and mining period has the potential to increase groundwater levels by several metres, with more than 10 m rises immediately below cleared and mined areas in some instances compared to unmined conditions. Areas of greatest rise lie directly beneath the most densely mined areas. This agrees well with historical observations of groundwater level change around other mined areas, for example at MK42132A location, near cleared area south of the Myara North DE, a rise of 12 m was observed, with MK43041A, MK43071A, and MK43072A also showing similar increases. If bores situated some distance away from the cleared areas show water level increases of this magnitude, the groundwater rise directly underneath the cleared areas would be even more pronounced.

Within the Holyoake DE, groundwater level mounding during the clearing and mining period has the potential to temporarily raise groundwater levels by several metres, again with more than 10 m rises below cleared and mined areas compared to unmined conditions. Groundwater levels in and around mined and cleared areas rise over the first 15 years. The climate change model, that considers a step decrease in recharge and runoff by 30% shows groundwater levels to be projected deeper but with similar mounding effects. In locations close to mining, mining essentially offsets and delays climate related groundwater level declines.

Within both the Myara North and Holyoake DEs the extent of mounding is predicted to be generally localised to cleared and mined areas.

The magnitude of mounding decreases towards low-lying areas and groundwater receptors (potential GDEs). Mounding within most of the potential GDEs is predicted to be less than 1 m, however in some localised areas, groundwater rise during mining is predicted also in 1 m to 2 m and 2 m to 5 m bands. The predicted mounding bands in potential GDE areas for dry, typical, and wet climate during mining and post mining are presented in Figure 0.1 and Figure 0.2.

The groundwater level mounding effects in the Myara North and Holyoake DEs recede over the post-mining rehabilitation period with the following key observations made:

– In the Myara North DE, residual groundwater level mounding of between 1 to 5 m is predicted by the end of the simulation in 2060 for drier periods, and up to 10 m during wetter periods.
– In the Holyoake DE, residual groundwater level mounding is predicted to be typically 1 to 10 m, but up to 20 m beneath the most densely mined areas.
– The magnitude of mounding diminishes to approximately 1 m in valley floor areas away from mining.

The predicted change in groundwater levels are within the historical groundwater level range of potential GDEs located in the valley floor systems, and therefore the temporary change in groundwater levels is not anticipated to have an adverse impact on potential GDEs.

The predicted change in groundwater levels are a snapshot in time relative to the baseline scenario. Due to the trend decline in groundwater levels, the rise is simulated to be less when compared to current or historic groundwater levels.

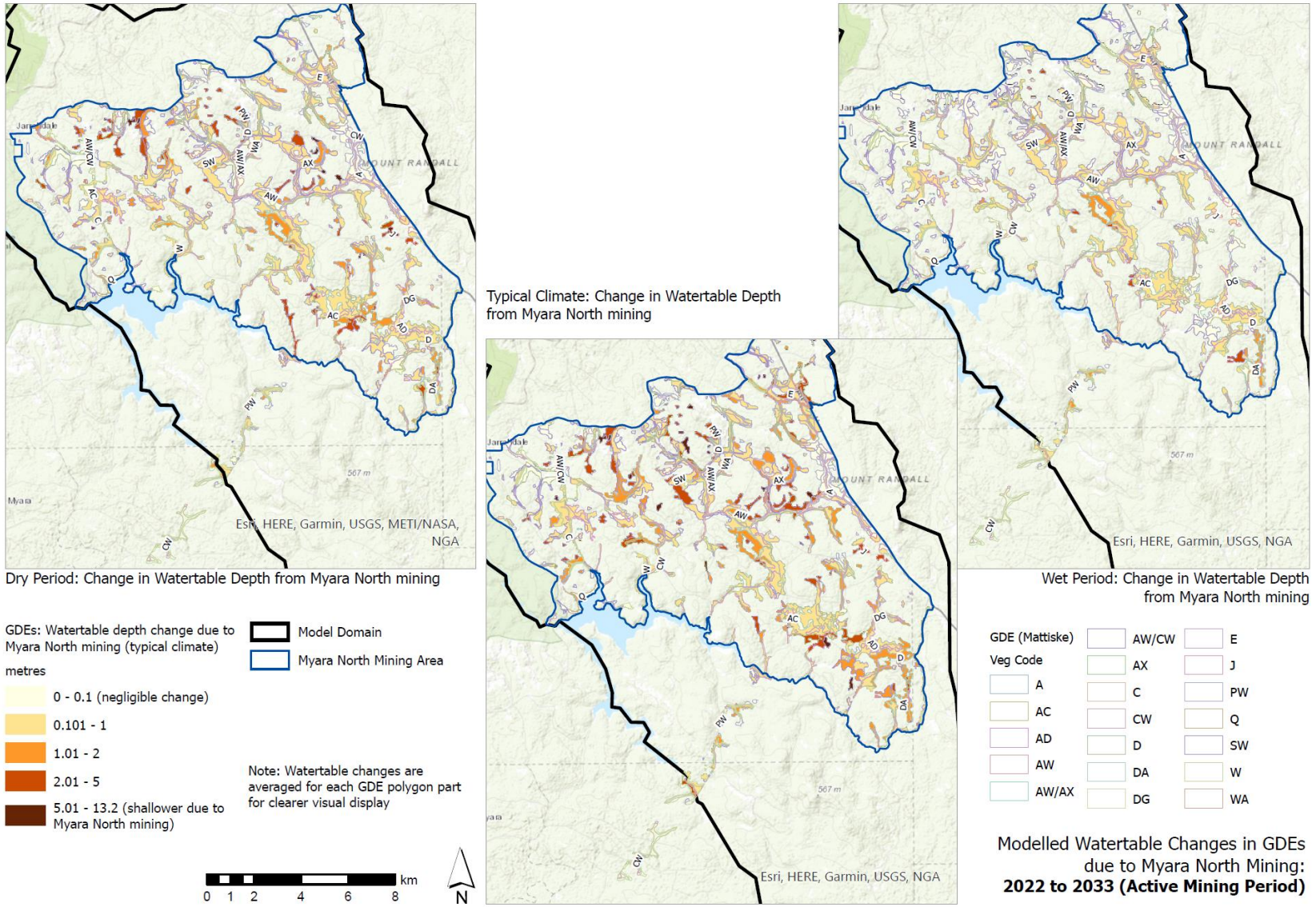


Figure 0.1 Modelled change in depth to groundwater within mapped GDEs, Myara North, 2022 to 2033 (during mining)

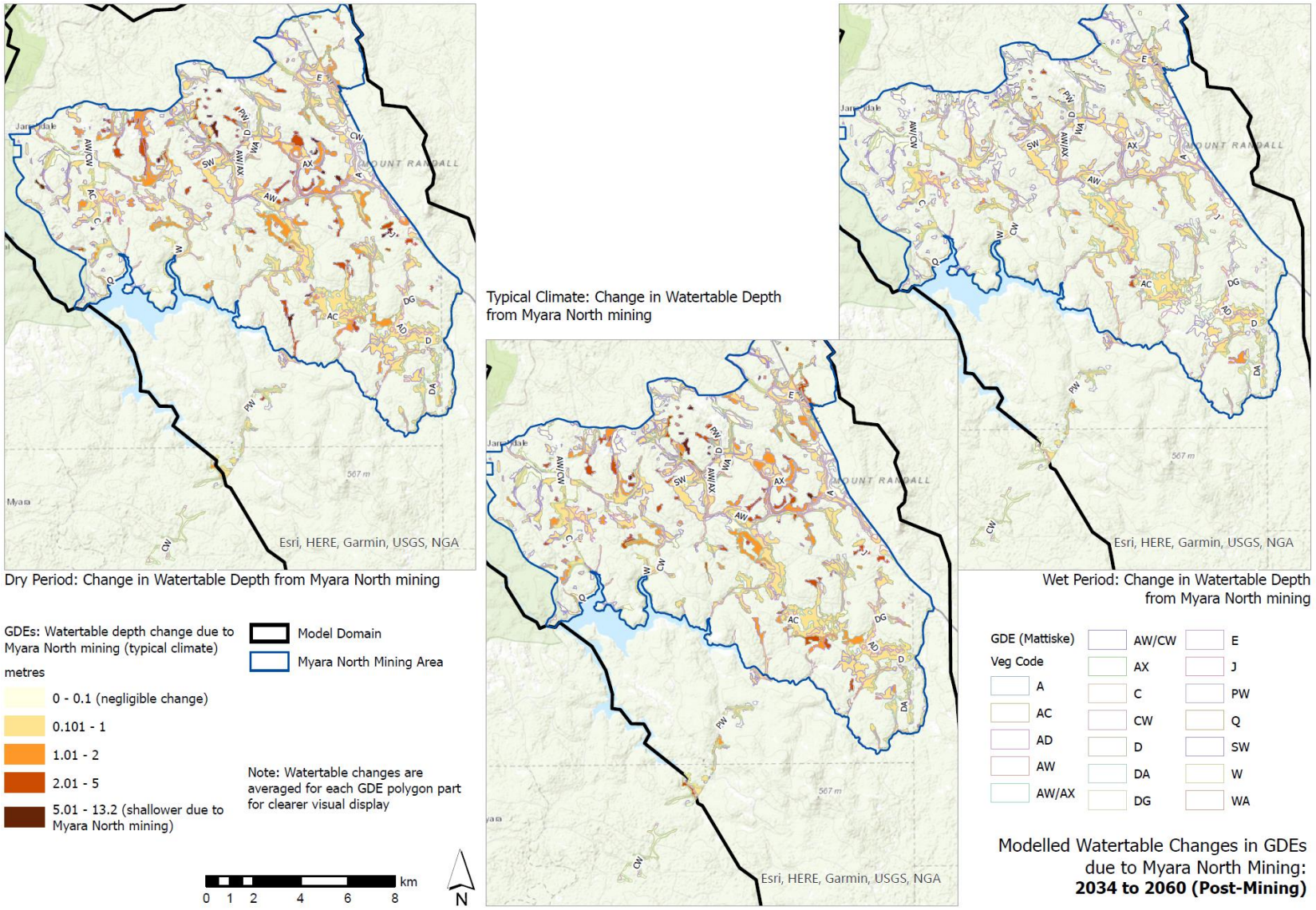


Figure 0.2 ***Modelled change in depth to groundwater within mapped GDEs, Myara North, up to 2060 (post mining)***

Streamflow changes

Historical effects

Historical mining effects on streamflow provide an indication of future mining impacts. Historical mining in the McCoy and O'Neil mine regions represented approximately 15% of the Big Brook stream gauge catchment area. The clearing associated with this mining commenced in 2002 and ceased in 2014.

Rehabilitation commenced in 2006 and is ongoing. Referring to Figure 0.3 and Figure 0.4, there is a slight change in gradient of the double-mass runoff curve since the commencement of mining, indicating an increase in runoff from the mined area relative to nearby unmined catchments. Mining in the Serpentine River catchment commenced in 2010 but represents less than 2% of the stream gauge catchment area and is therefore considered "largely unmined" for comparison purposes.

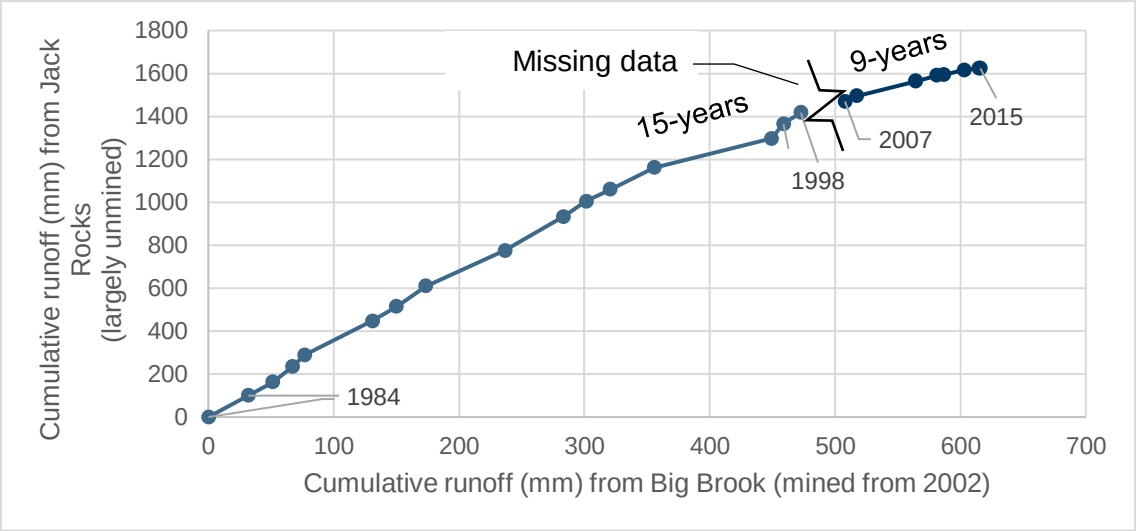


Figure 0.3 Mining impacts to Big Brook runoff compared to Jack Rocks

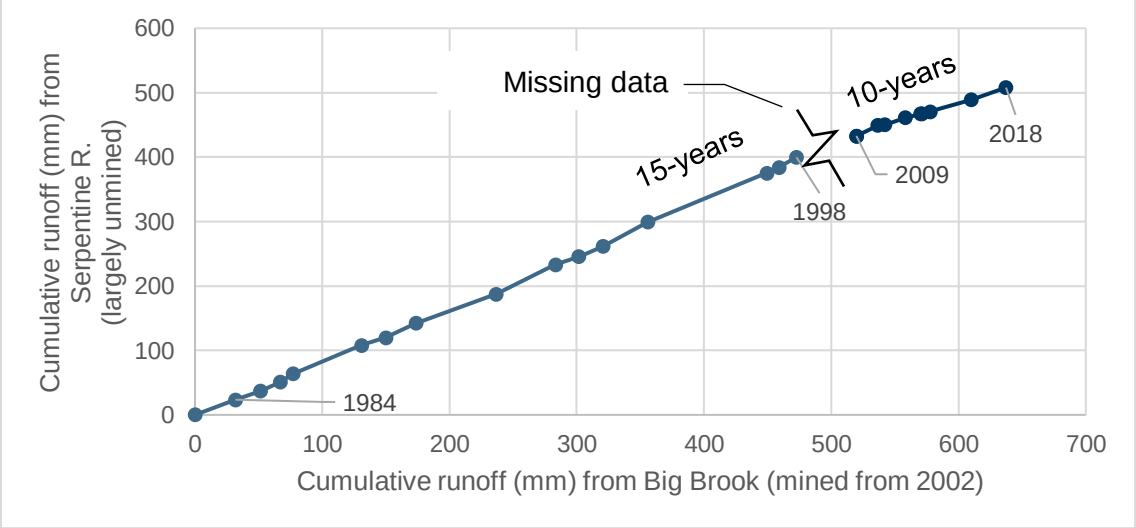


Figure 0.4 Mining impacts to Big Brook runoff compared to Serpentine River

Future effects

The changes in recharge and flow dynamics due to bauxite mining and the increase in groundwater levels predicted from the numerical modelling, has the potential to increase streamflows during clearing, mining and rehabilitation periods.

Serpentine Reservoir (Myara North)

Within the Myara North DE, mining will result in an estimated average increase in streamflows of the Serpentine Reservoir from the modelled catchments of 1.3 GL/year over the active clearing and mining period. The following patterns of streamflow change are predicted as a comparison for mined and unmined cases (Figure 0.5):

– Higher annual flows are predicted to occur in the first decade of mining, typically 1 GL/yr but ranging as high as 2 to 3 GL/yr in some years (Figure 0.5).

– From 2030 onwards, during the post-rehabilitation period, annual flow decreases occur, ranging from nil in dry years, to 1 GL/yr in wetter years

– In some dry years marginally higher annual flows to the reservoir are simulated to occur due to higher residual groundwater level from the mining and clearing period.

– The modelled climate change (not shown in Figure 0.5), simulated as 30% decrease in recharge and surface flows, indicates reduced inflows into the reservoir but also reduced impact from mining (Figure 0.6).

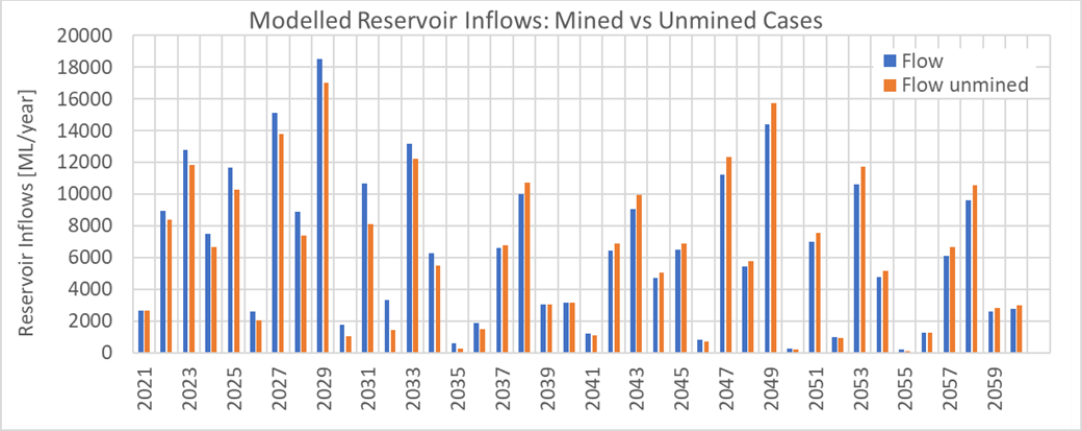


Figure 0.5 Modelled streamflow to Serpentine Reservoir (mined vs unmined)

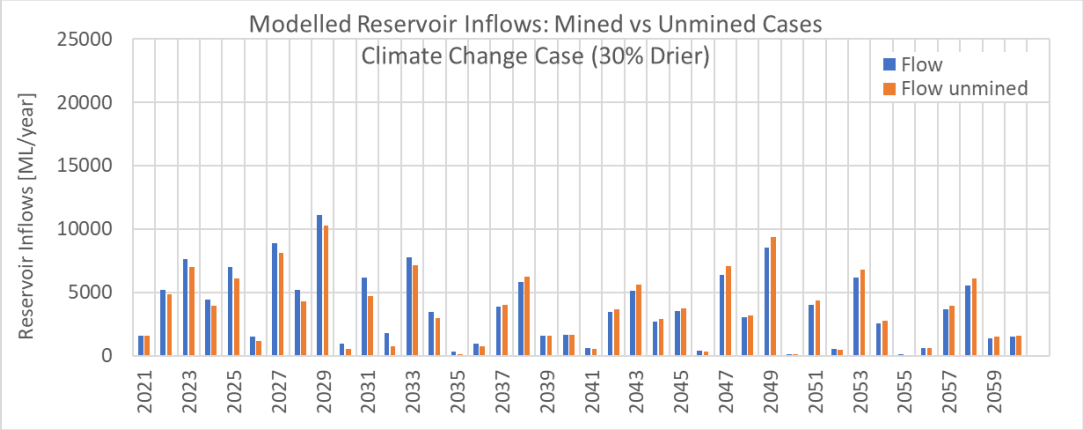


Figure 0.6 Modelled streamflow to Serpentine Reservoir (mined vs unmined), climate change case

Wungong Brook (Myara North)

Within the Wungong Brook Catchment the streamflows are predicted to slightly increase during mining (on average between 0.05 to 0.1 GL/yr, followed by minor flow reduction (on average 0.02 GL/yr) during post-mining period (Figure 0.7), similar to catchments feeding the Serpentine Reservoir.

During mining the predicted flows are on average 0.6 GL/yr, while post-mining they will be approximately 0.35 GL/yr. These represent only minor change when compared to non-mining scenario (0.09 and -0.005 GL, respectively).

Climate change, modelled as 30% decrease in recharge and surface flows will result in reduced flows in the Wungong Brook, typically by over 50% (Figure 0.8).

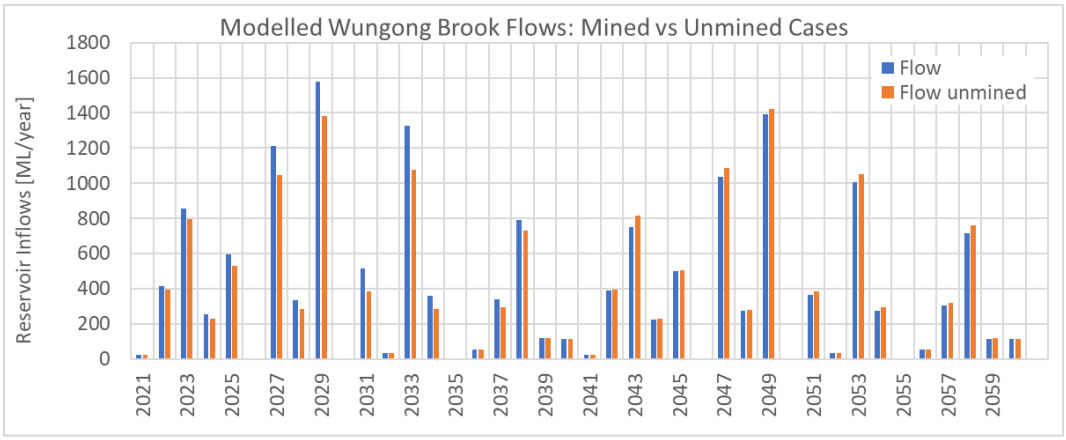


Figure 0.7 ***Modelled streamflow to Wungong Reservoir (mine vs unmined)***

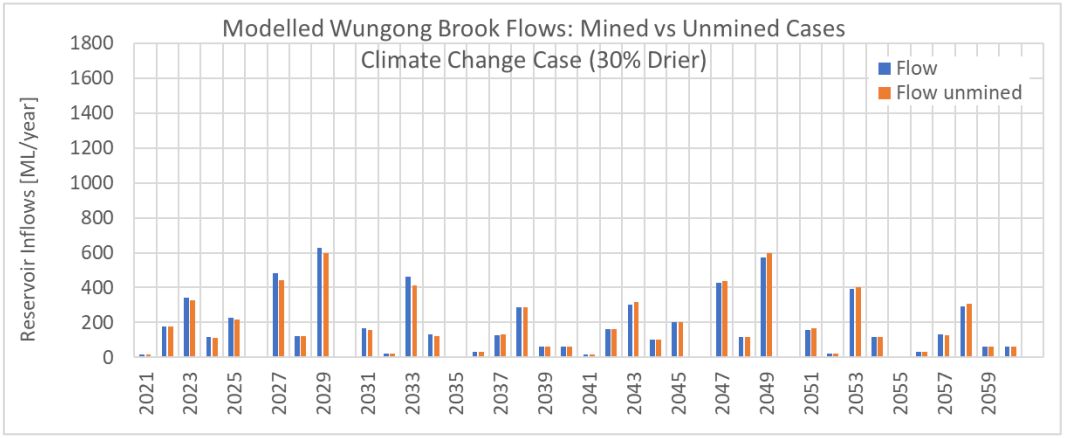


Figure 0.8 ***Modelled streamflow to Wungong Reservoir (mined vs unmined), climate change case***

Gooralong Brook (Myara North)

The streamflow change in Gooralong Brook is predicted to follow the same pattern as Wungong Brook and streamflows to the Serpentine Reservoir. Slight increase in streamflows is predicted during mining and clearing, followed minor reductions in the rehabilitation and post-mining (Figure 0.9).

During mining the predicted flows are on average 2.3 GL/yr, while post-mining they will be approximately 1.7 GL/yr. These would constitute only a minor change when compared to non-mining scenario (2.25 and 1.74 GL, respectively).

The climate change effect, represented as 30% reduction in groundwater recharge and surface flow, however this is attributable to climate change rather than the effect of mining. The climate change scenario suggests average flows of 1.42 and 1.0 GL/yr for mining and post-mining periods, respectively. The differences between mining and non-mining scenarios are minor, flows under non-mining scenario would be 1.40 and 1.06 GL/yr.

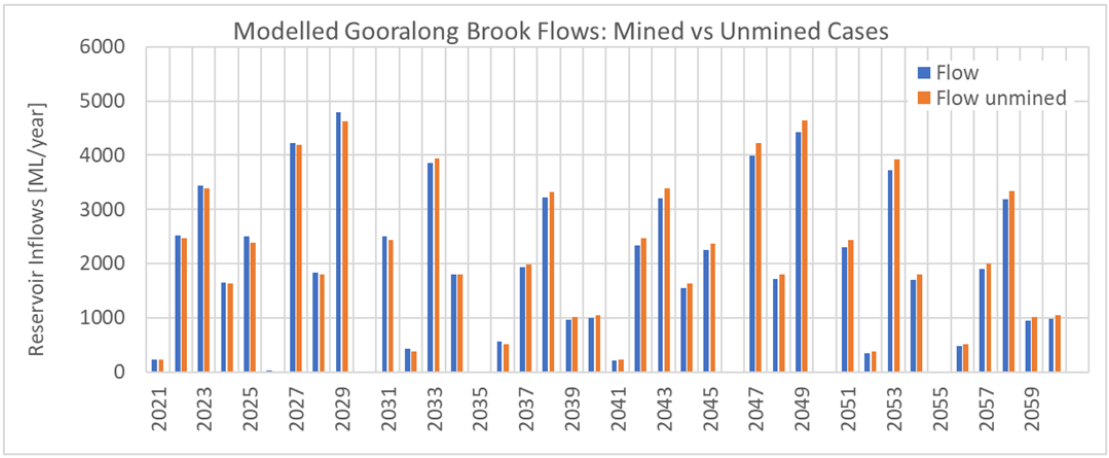


Figure 0.9 Modelled streamflow, Gooralong Brook (mined vs unmined)

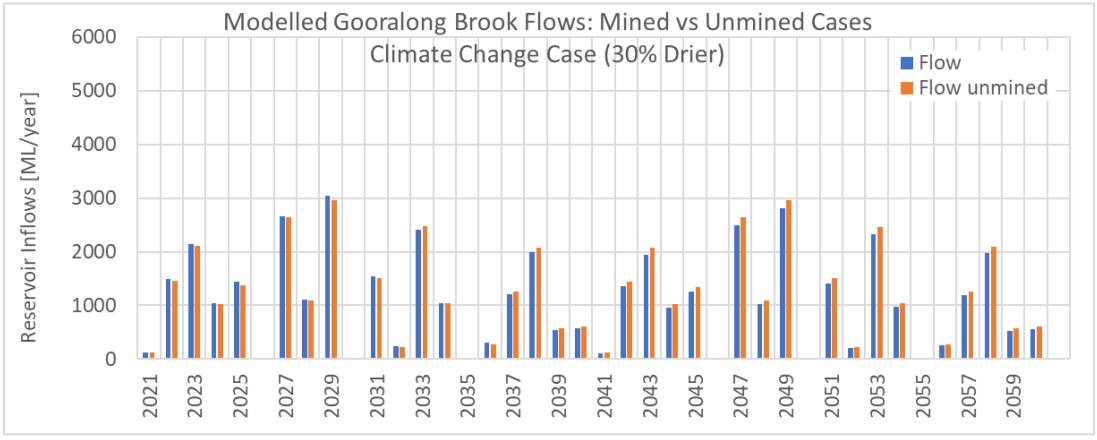


Figure 0.10 Modelled streamflow, Gooralong Brook (mined vs unmined), climate change case

South Dandalup Reservoir (Holyoake)

Within the Holyoake DE, numerical groundwater modelling identified average increases in streamflows to the South Dandalup Reservoir from the modelled catchments of 0.1 GL/year during the active clearing and mining period from 2029 to 2033, and 0.2 to 0.3 GL/year in the post-mining period (GHD 2021b). The annual variability is shown in Figure 0.11.

Streamflows in the Holyoake DE are predicted to be marginally higher during and after mining compared to the base case without mining.

The potential impact of the climate change – drying conditions – will result in further reduction of streamflows, which are predicted to reduce by approximately 30% (Figure 0.12), i.e., equivalent to reduction of recharge. Mining will still provide minor increase of streamflows.

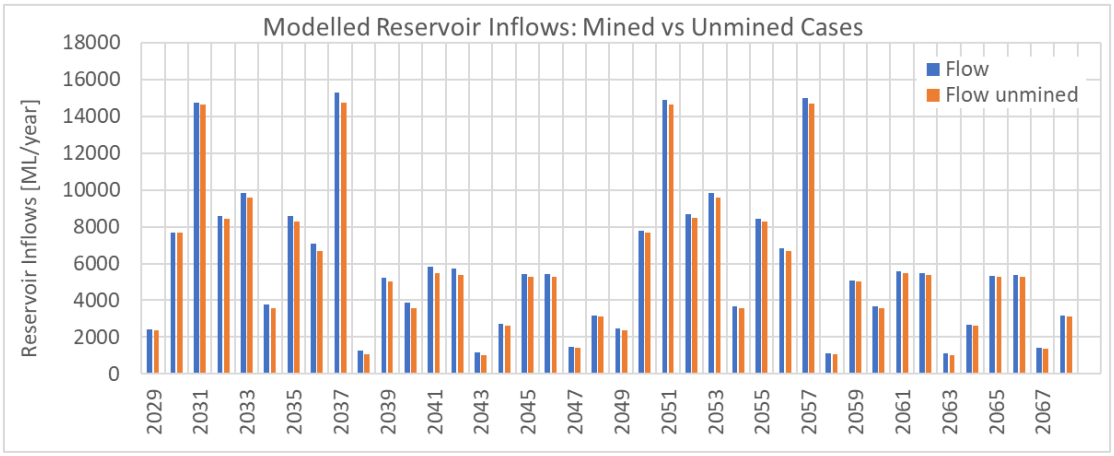


Figure 0.11 Modelled streamflow to South Dandalup Reservoir (mined vs unmined)

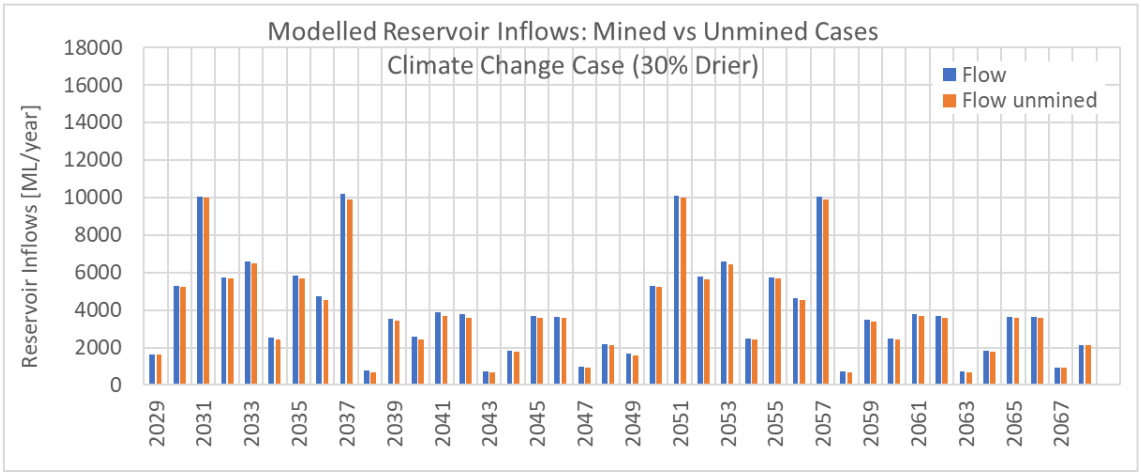


Figure 0.12 Modelled streamflow to South Dandalup Reservoir (mined vs unmined), climate change case

Davis Brook (Holyoake)

Mining in the Holyoake DE is predicted to increase flows in the Swamp Oak Brook during mining and partly post mining. In absolute values the increases will be small, on average 0.06 GL/yr and 0.17 GL/yr during and post mining (Figure 0.13). During some years of mining the increases will be more notable, for example between 2034 and 2042 the increases may represent a multiple of flows that would have occurred for the unmined case. During dry years of the post-mining period the flows are predicted to be very similar to unmined cases, but in wetter years flows may increase 25% to 50%.

The potential climate change effect on Davis Brook flows is reduction of overall flows when compared to the current case. Mining effects will remain the same (i.e., higher flows in wetter years, similar flows in dry years (Figure 0.14). The flow increases for the climate change case would still occur, but will be reduced, i.e., 0.01 GL/yr and 0.06 GL/yr during and post-mining.

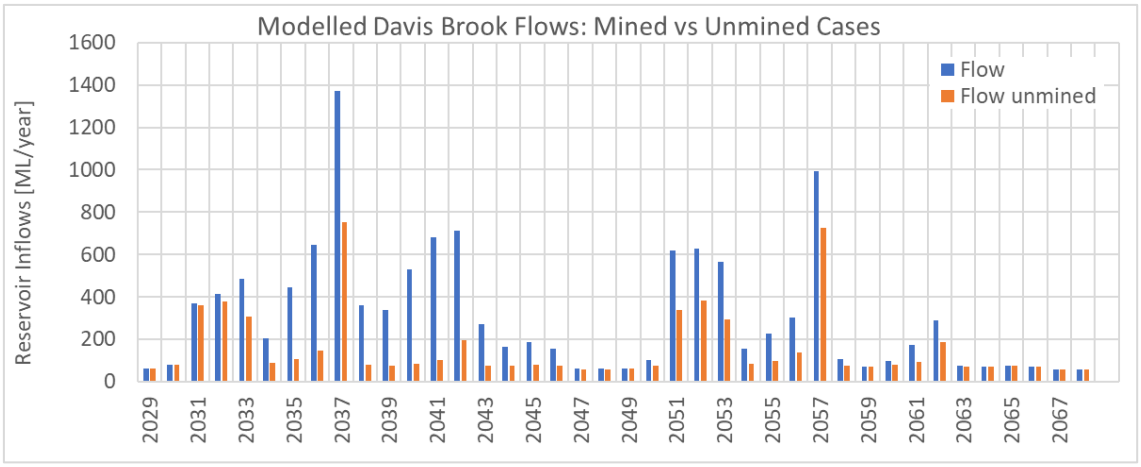


Figure 0.13 ***Modelled flows, Davis Brook (mined vs unmined)***

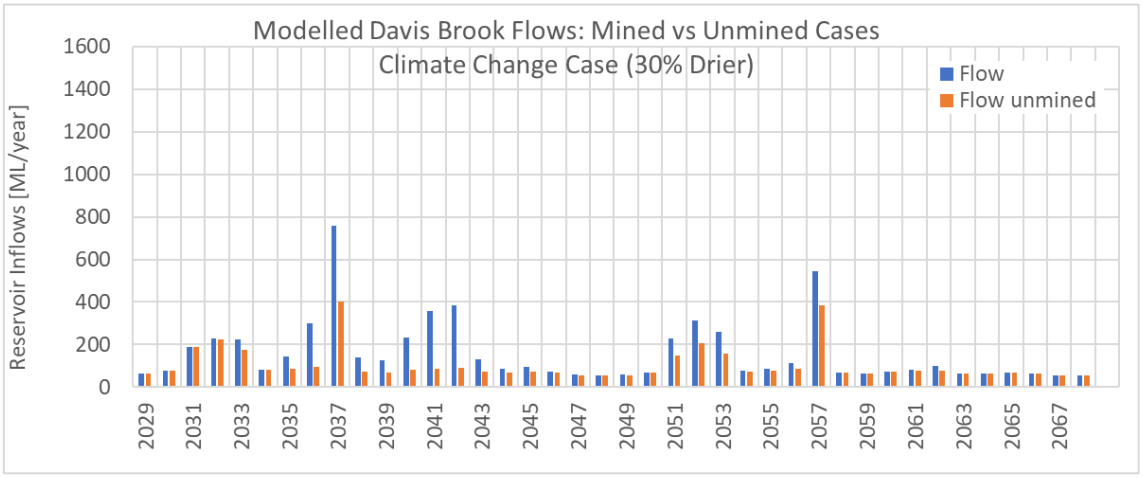


Figure 0.14 ***Modelled flows, Davis Brook (mined vs unmined), climate change case***

Swamp Brook (Holyoake)

Mining in the Holyoke DE is predicted to introduce minor flow increases in Swamp Brook, 0.01 GL/yr and 0.02 GL, during mining and during the post-mining period (Figure 0.15). Slightly increased flows will occur during both, the wet and dry years.

The drying climate is predicted to reduce the flows by almost 50% (Figure 0.16), while preserving the overall effect of mining on streamflows (slight increase of flows during and post-mining).

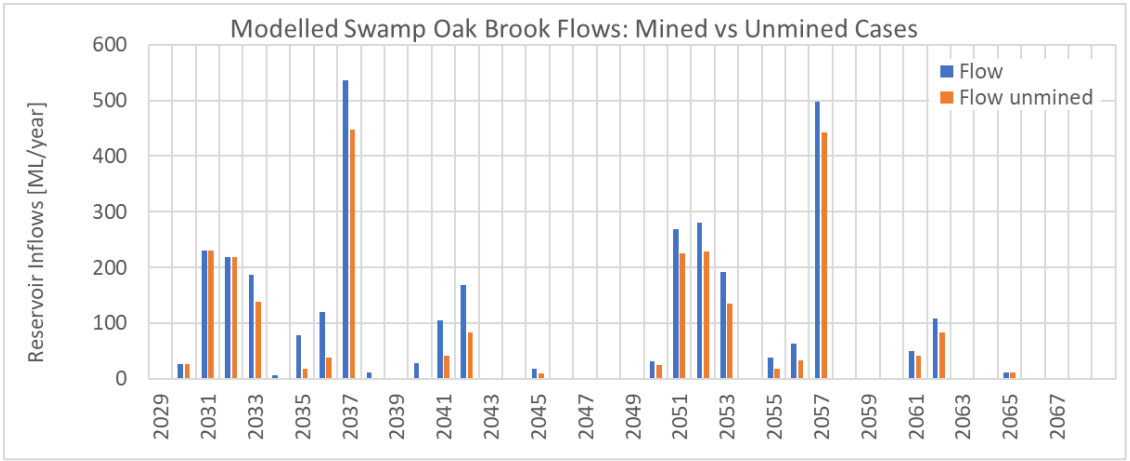


Figure 0.15 ***Modelled flows, Swamp Oak Brook (mined vs unmined)***

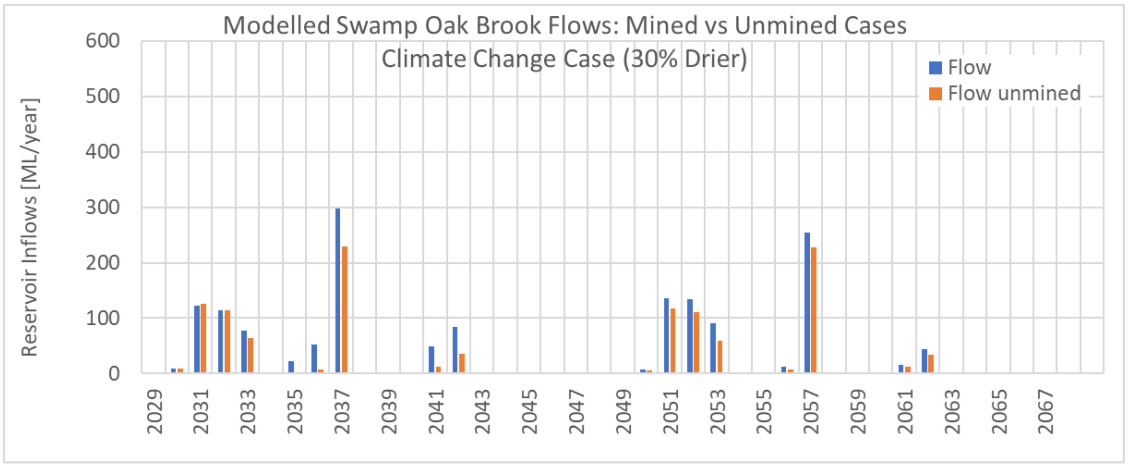


Figure 0.16 Modelled flows, Swamp Oak Brook (mined vs unmined), climate change case

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Appendices

Appendix A

Figures

Figure A-1 *Context – Myara North*

Figure A-2 *Context – Holyoake*

Figure A-3 *Topography – Myara North*

Figure A-4 *Topography - Holyoake*

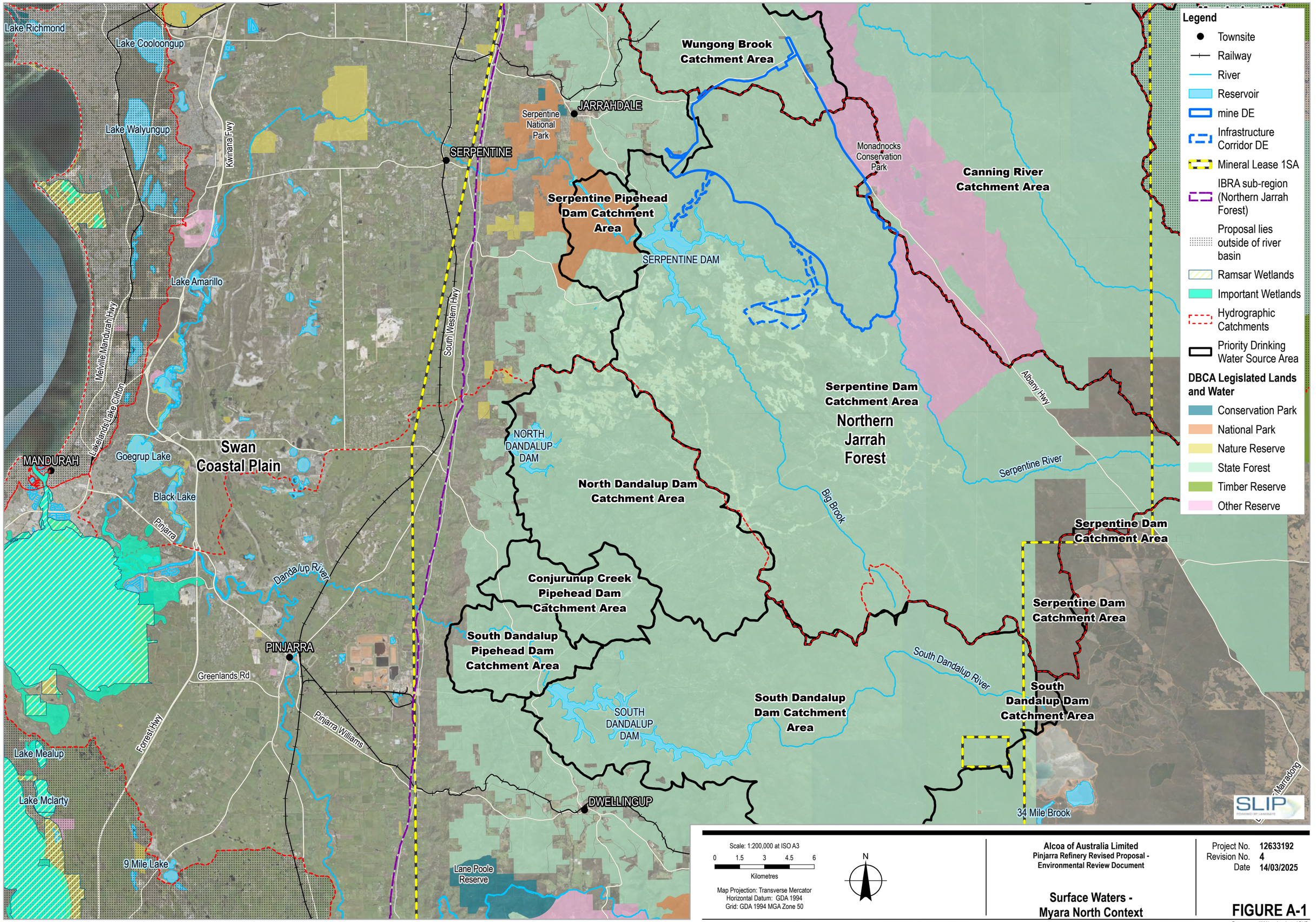
Figure A-5 *Surficial Geology – Huntly*

Figure A-6 *Receptors – Myara North*

Figure A-7 *Receptors - Holyoake*

Figure A-8 *Monitoring locations – Myara North*

Figure A-9 *Monitoring locations – Holyoake*



Scale: 1:200,000 at ISO A3

0 1.5 3 4.5 6

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

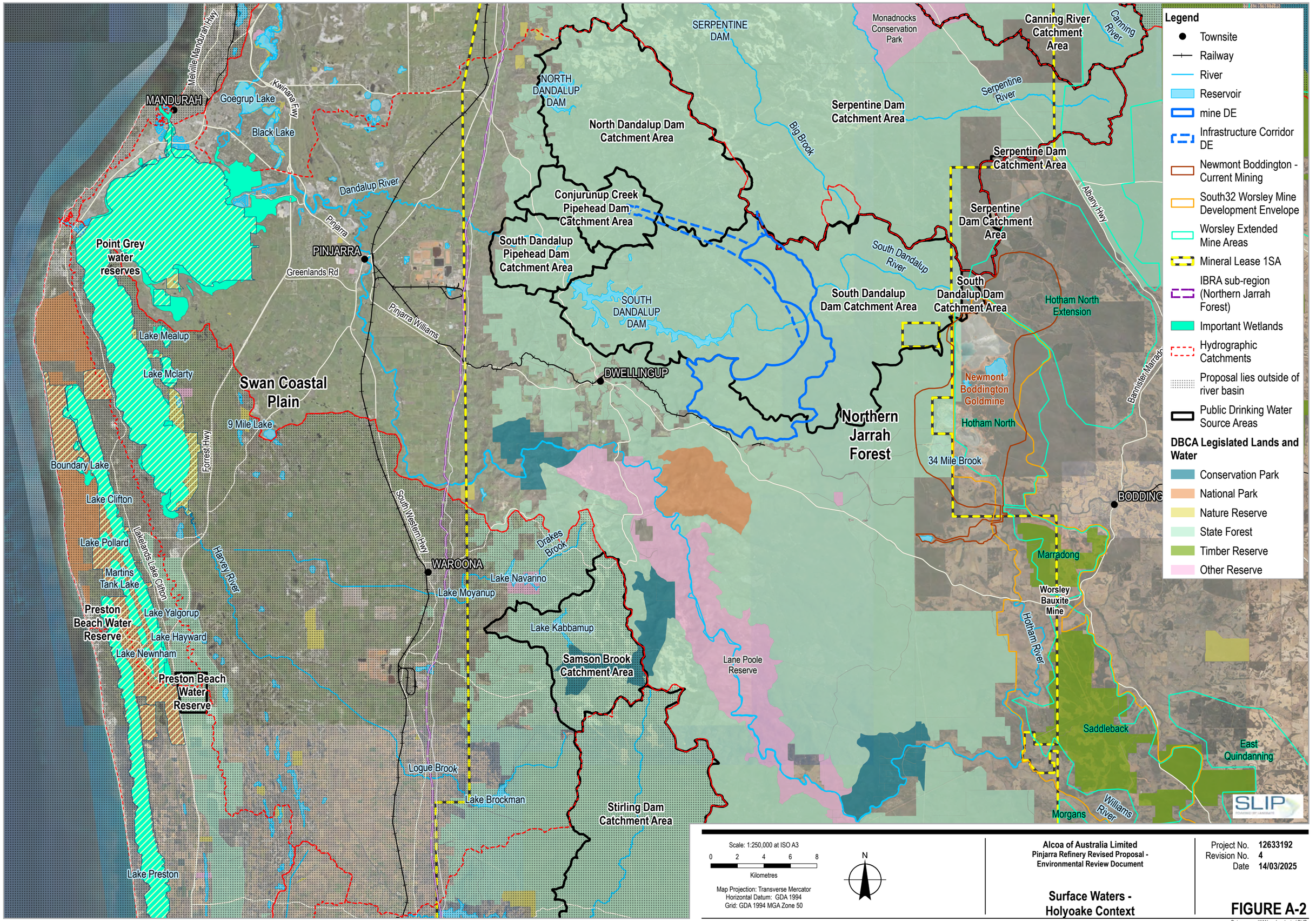
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Pinjarra Refinery Revised Proposal - Environmental Review Document

Surface Waters - Myara North Context

Project No. **12633192**
Revision No. **4**
Date **14/03/2025**

FIGURE A-1

Data source: WANow: Landgate / SLIP.



Scale: 1:250,000 at ISO A3

0 2 4 6 8

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

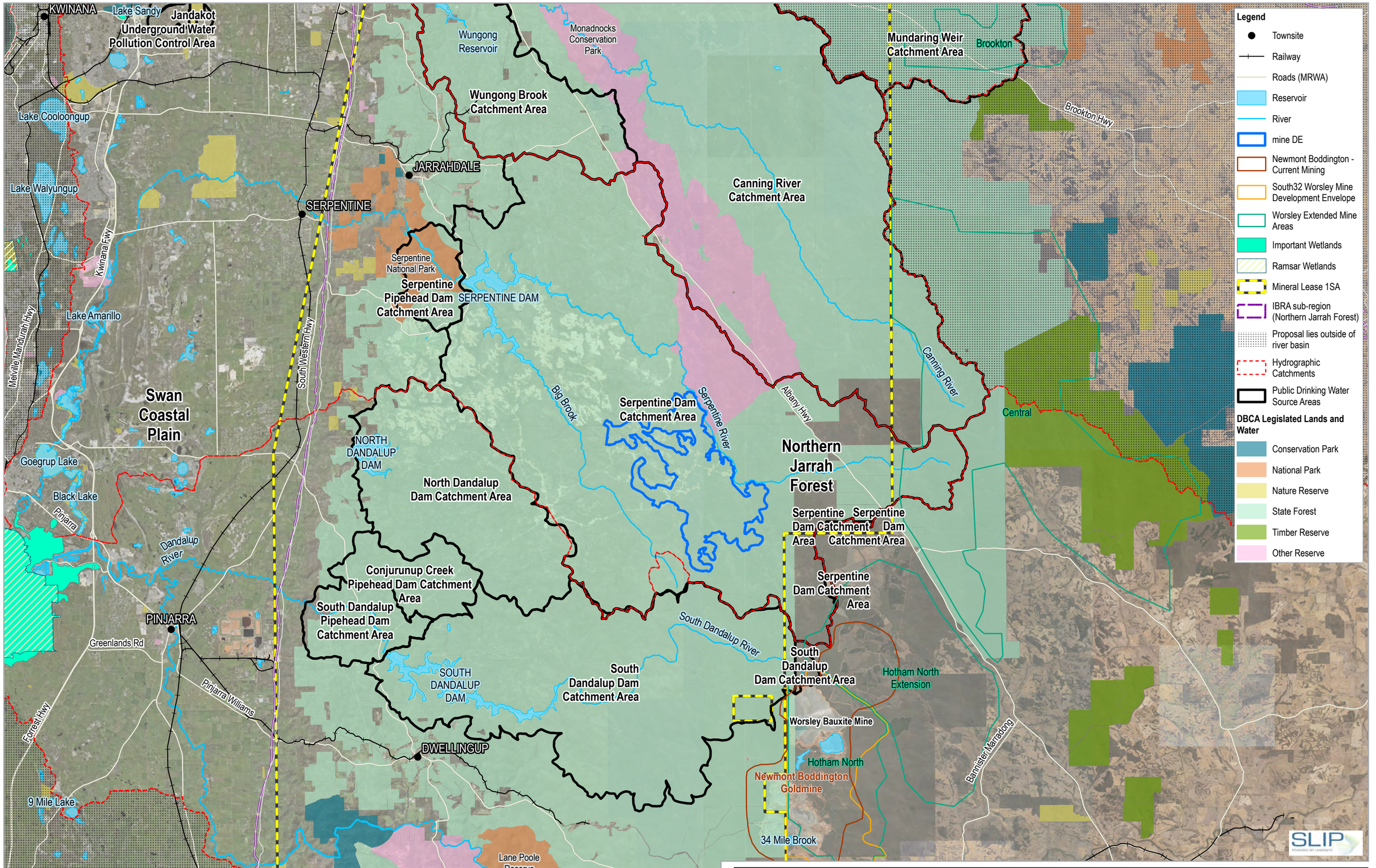
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Surface Waters - Holyoake Context

Project No. **12633192**
Revision No. **4**
Date **14/03/2025**

FIGURE A-2

Data source: WANow: Landgate / SLIP.



Scale: 1:250,000 at ISO A3

0 1.5 3 4.5 6

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

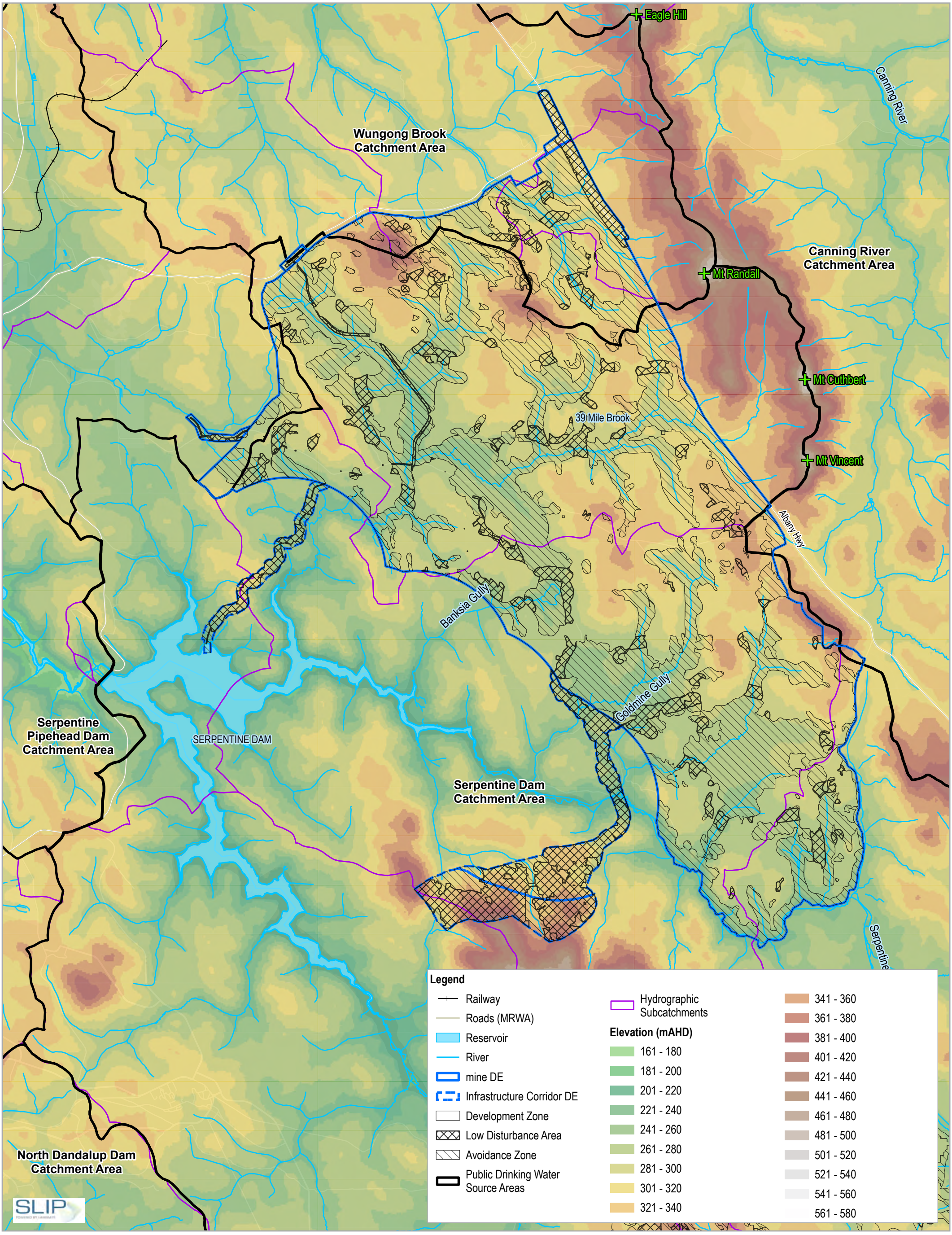
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Surface Waters - O'Neil Context

Project No. **12633192**
Revision No. **4**
Date **14/03/2025**

FIGURE A-3

Data source: WANow: Landgate / SLIP.



Scale: 1:70,000 at ISO A3

0 0.5 1 1.5 2

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

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Surface Waters - Myara North Development Envelope - Topographic Elevation

Project No. **12633192**
Revision No. **4**
Date **14/03/2025**

FIGURE A-4

Data source: Light Gray Base: Esri, TomTom, Garmin, Foursquare, METI/NASA, USGS.

NORTH DANDALUP DAM
North Dandalup Pipehead Dam
Swamp
North Dandalup Dam Catchment Area
Big Brook
Serpentine Dam Catchment Area
Serpentine Dam
Conjurunup Creek Pipehead Dam Catchment Area
Conjurunup Creek
South Dandalup Pipehead Dam Catchment Area
South Dandalup Pipehead Dam
South Dandalup Dam Catchment Area
South Dandalup
SOUTH DANDALUP DAM
Kennedy's Pool
South Dandalup River
DWELLINGUP
Dwellingup
Pinjarra Williams
Davis
Swamp
Oak
SLIP

Legend

- Townsite
- Railway
- Roads (MRWA)
- Streams
- Reservoir
- mine DE
- Infrastructure Corridor DE
- Development Zone
- Low Disturbance Area
- Avoidance Zone
- Public Drinking Water Source Areas
- Hydrographic Subcatchments

Elevation (mAHD)

- 101 - 120
- 121 - 140
- 141 - 160
- 161 - 180
- 181 - 200
- 201 - 220
- 221 - 240
- 241 - 260
- 261 - 280
- 281 - 300
- 301 - 320
- 321 - 340
- 341 - 360
- 361 - 380
- 381 - 400

Scale: 1:80,000 at ISO A3

0 0.5 1 1.5 2

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

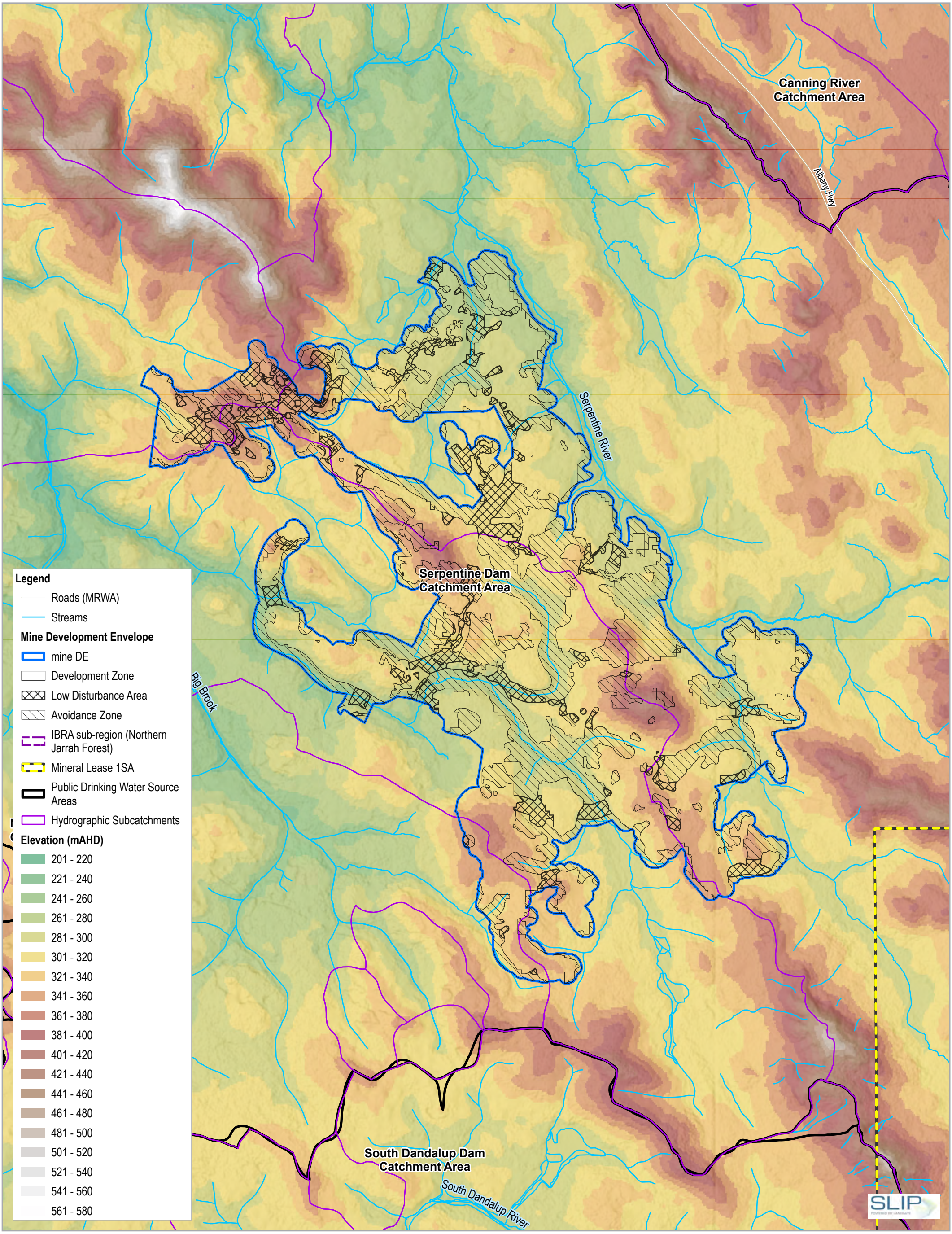
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Surface Waters - Holyoake Development Envelope - Topographic Elevation

Project No. **12633192**
Revision No. **4**
Date **14/03/2025**

FIGURE A-5

Data source: Light Gray Base: Esri, TomTom, Garmin, Foursquare, METI/NASA, USGS.



Scale: 1:60,000 at ISO A3

0 0.5 1 1.5 2

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

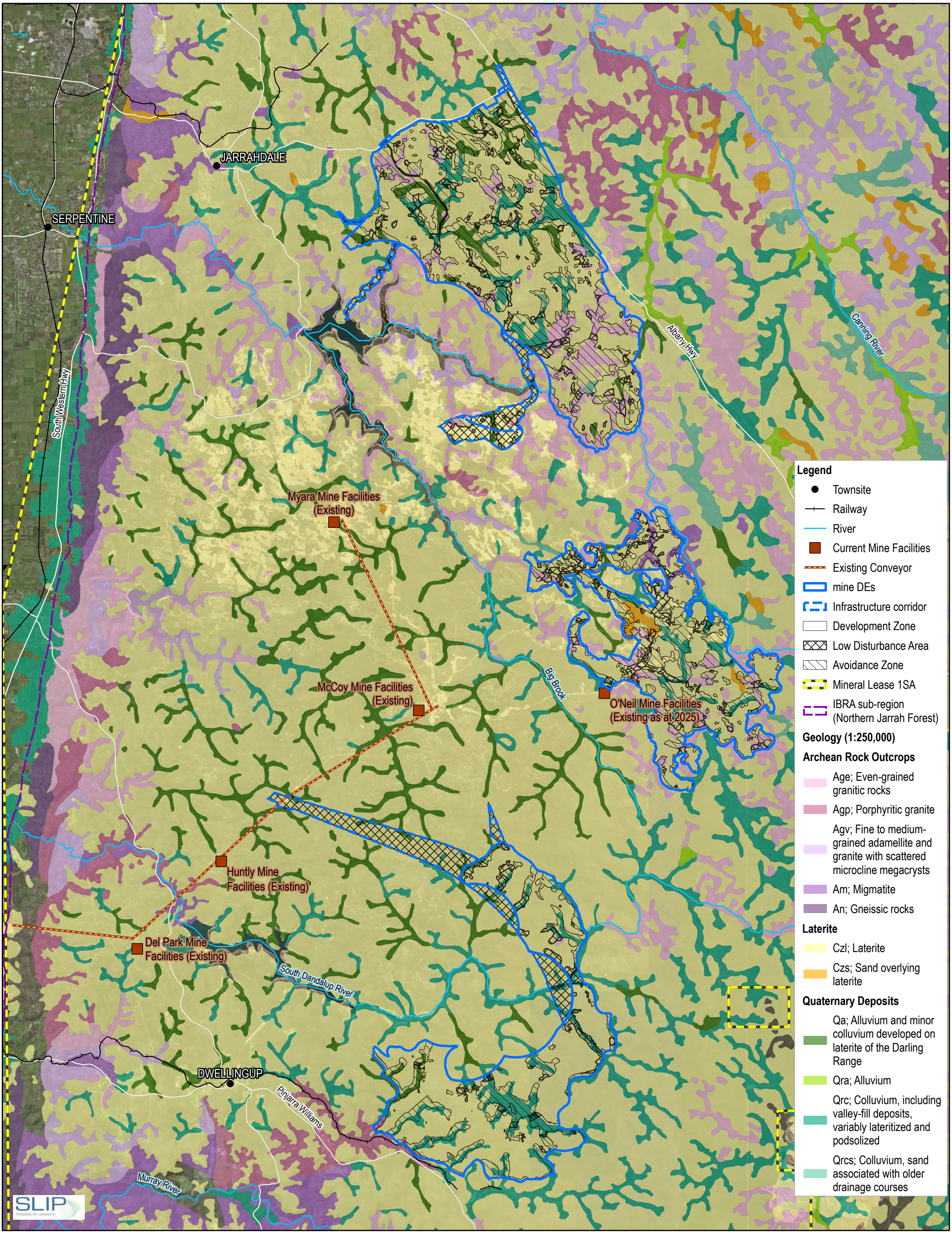
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Surface Waters - O'Neil Development Envelope - Topographic Elevation

Project No. **12633192**
Revision No. **4**
Date **14/03/2025**

FIGURE A-6

Data source: World Hillshade: Esri, Geoscience Australia, NASA, NGA, USGS.



Scale: 1:155,000 at ISO A3

0 1 2 3 4

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

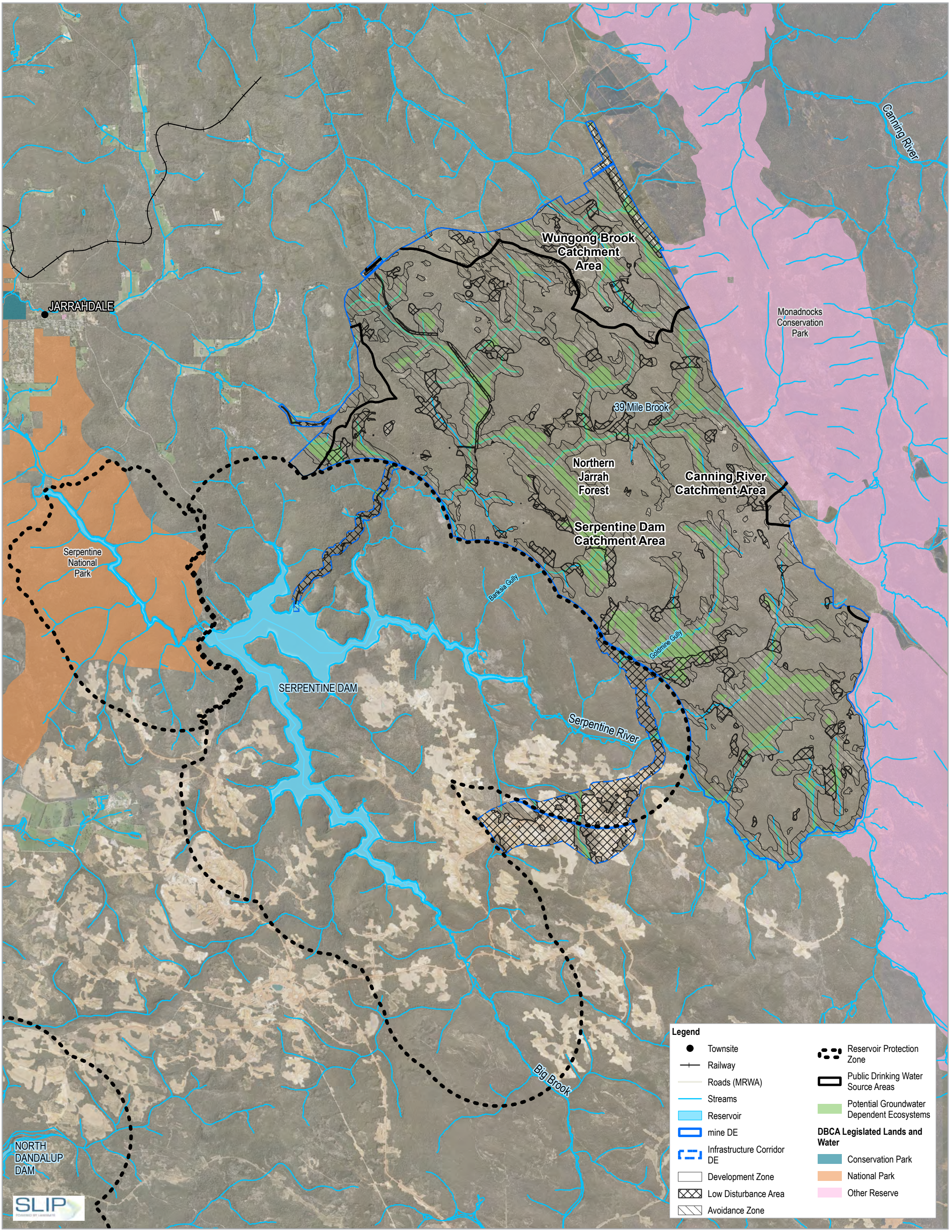
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Surficial Geology - Mine DE

Project No. **12633192**
Revision No. **3**
Date **14/03/2025**

FIGURE A-7

Data source: WANow: Landgate / SLIP.



Scale: 1:80,000 at ISO A3

0 0.5 1 1.5 2

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

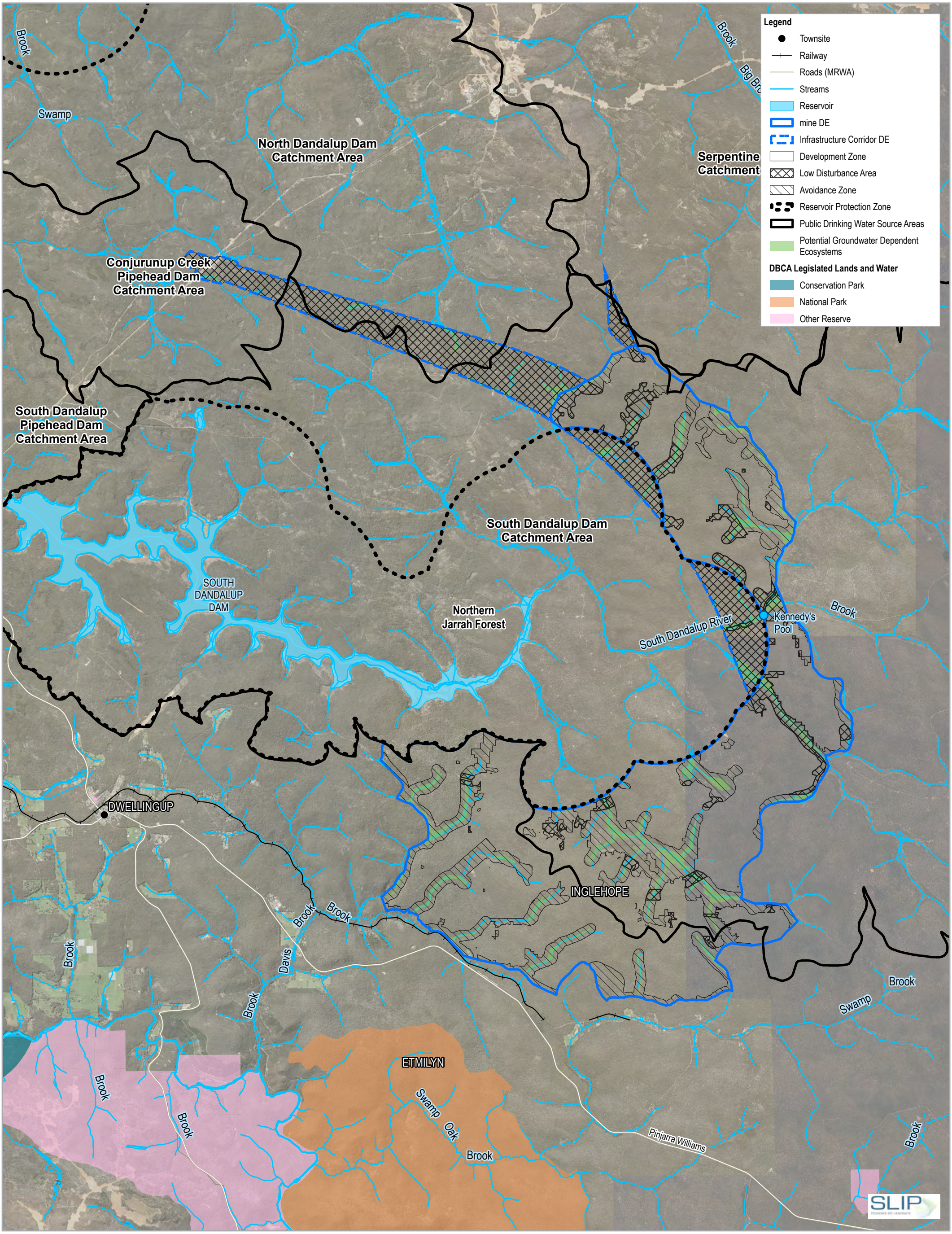
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Pinjarra Refinery Revised Proposal - Environmental Review Document

Inland Waters Receptors- Myara North Development Envelope

Project No. **12633192**
Revision No. **4**
Date **14/03/2025**

FIGURE A-8

Data source: WANow: Landgate / SLIP.



Scale: 1:80,000 at ISO A3

0 0.5 1 1.5 2

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

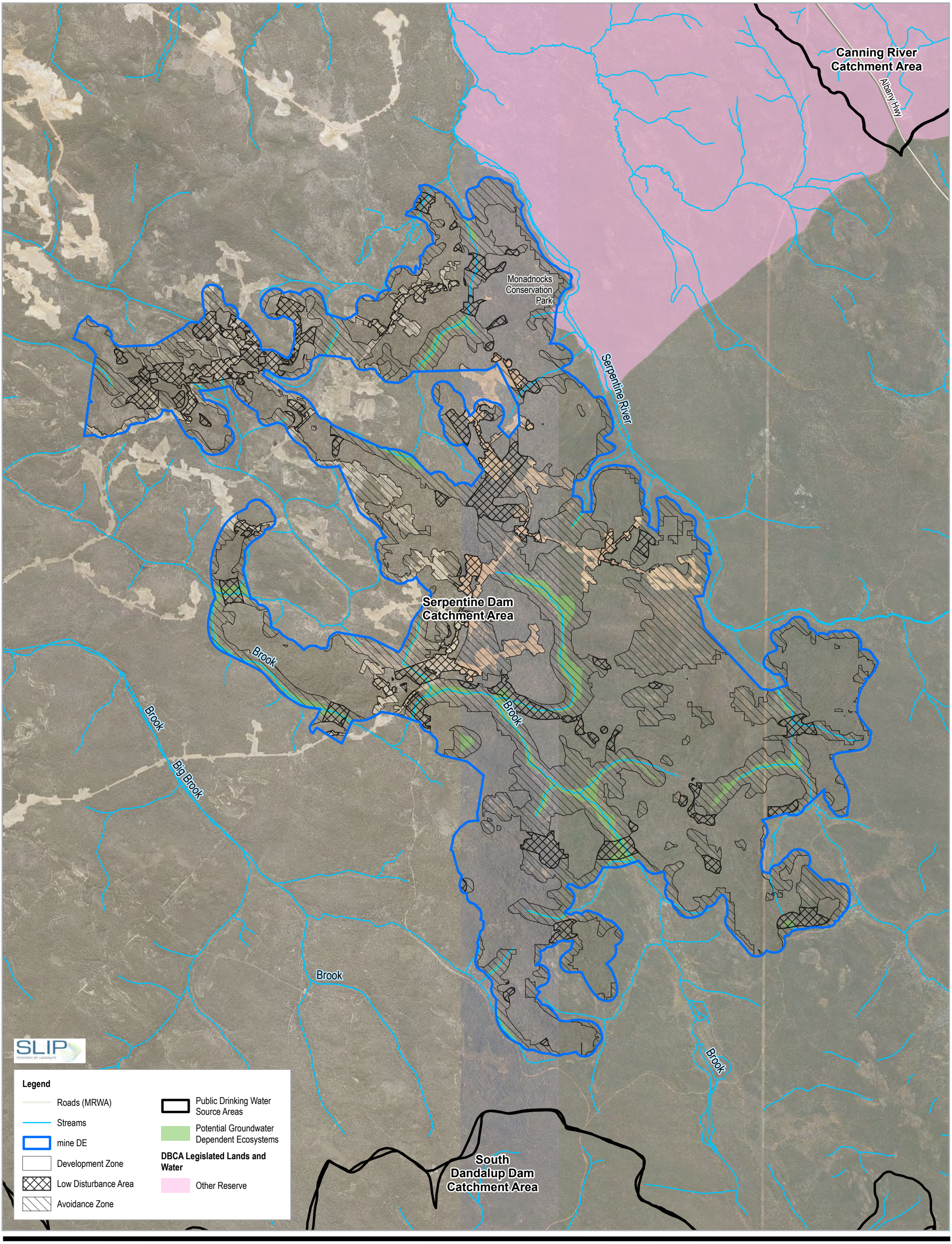
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Pinjarra Refinery Revised Proposal - Environmental Review Document

Inland Waters Receptors - Holyoake Development Envelope

Project No. **12633192**
Revision No. **4**
Date **14/03/2025**

FIGURE A-9

Data source: WANow: Landgate / SLIP.



Scale: 1:50,000 at ISO A3

0 0.5 1 1.5 2

Kilometres

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

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Pinjarra Refinery Revised Proposal - Environmental Review Document

Inland Waters Receptors- O'Neil Development Envelope

Project No. **12633192**
Revision No. **4**
Date **14/03/2025**

Figure A-10

Data source: WANow: Landgate / SLIP
World Hillshade: Esri, Geoscience Australia, NASA, NGA, USGS.

Wungong Brook Catchment Area
Canning River Catchment Area
Serpentine Pipehead Dam Catchment Area
Serpentine Dam Catchment Area
North Dandalup Dam Catchment Area
Conjurunup Creek Pipehead Dam Catchment Area
South Dandalup Pipehead Dam Catchment Area
South Dandalup Dam Catchment Area
Serpentine Dam Catchment Area
Serpentine Dam Catchment Area
Serpentine Dam Catchment Area
Serpentine River
Wungong Brook
Canning River
Big Brook
O'Neill Brook
South Dandalup River
Holyoake Brook
Davis Brook
Murray River
Swamp Oak Brook
34 Mile Brook
616124
WG42
WG54
J3808-1A
B18
616058
B17
B16_D
B16_S
B13
GG03
SW06
B07
B12_D
B12_S
TN01
B10
TN34
K3917-1A
B24
B09_B
B09
TN14
614031
B08
B11
SW05
SW04
SW03
SN01
K4011-1A
L4009-3A
J4012-1A
6141121
SN02
K4104-1A
B04
B03
6141125
K4106-1A
SW08
SW02
B02
B01
SN04
SW01
SW07
BF04
614035
MCRA_SW06
ONMB02_S
ONMB02_D
OEMB17
ONMB04
OEMB14
OEMB16
SE01
OEMB13
OEMB15
SE21
ONMB05
OEMB12
OEMB11
ONMB01
OE_SW02
OEMB10
OEMB09
SE34
SE03
OEMB02
SE16
OEMB08
OEMB07
MCRA_SW02
SE02
OEMB01
OEMB03
OEMB06
OEMB05
OEMB04
MCRA_SW07
BH01
614060
6141333
BH02
614059
HSW05
BH04
BH03
HSW01
BH05
BF20
6141352
614001
BH06
6141349
6141005
BH07
6141004
6141325
6141340
BH08
BH10
BH09
HSW04
BH11
BH12
J4904-4.25
SD31
DV04
BH14
BH13
K4916-2A
614043
BH15
BH16
614047
614045
HSW02
614186
1100
1000
900
Jarrahdale
Monadnocks Reserve
Monadnock Conservation Reserve
Park Lane
Myara North
Historic bore data (Alcoa, 1974 - 2021)
Holyoake
Historic bore data (Alcoa, 1974 - 2021)

Legend

- GHD bores
- Alcoa bores
- Surface water sampling location
- Surface water level and EC logger
- Proposed water level and turbidity logger
- DWER flow gauging site
- Watercourse
- Bibbulmun Track

ISOHYET

- 900
- 1000
- 1100
- mine DEs
- Infrastructure Corridor DEs
- PDWSA
- Reservoir Protection Zone
- Waterbody

GDE Category

- Slopes with higher seasonal soil moisture
- Swamps and broad valleys
- Valley floors and lower slopes
- Tahom

Scale: 1:200,000 at ISO A3
Inset not to scale
0 1.5 3 4.5 6
Kilometres
Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

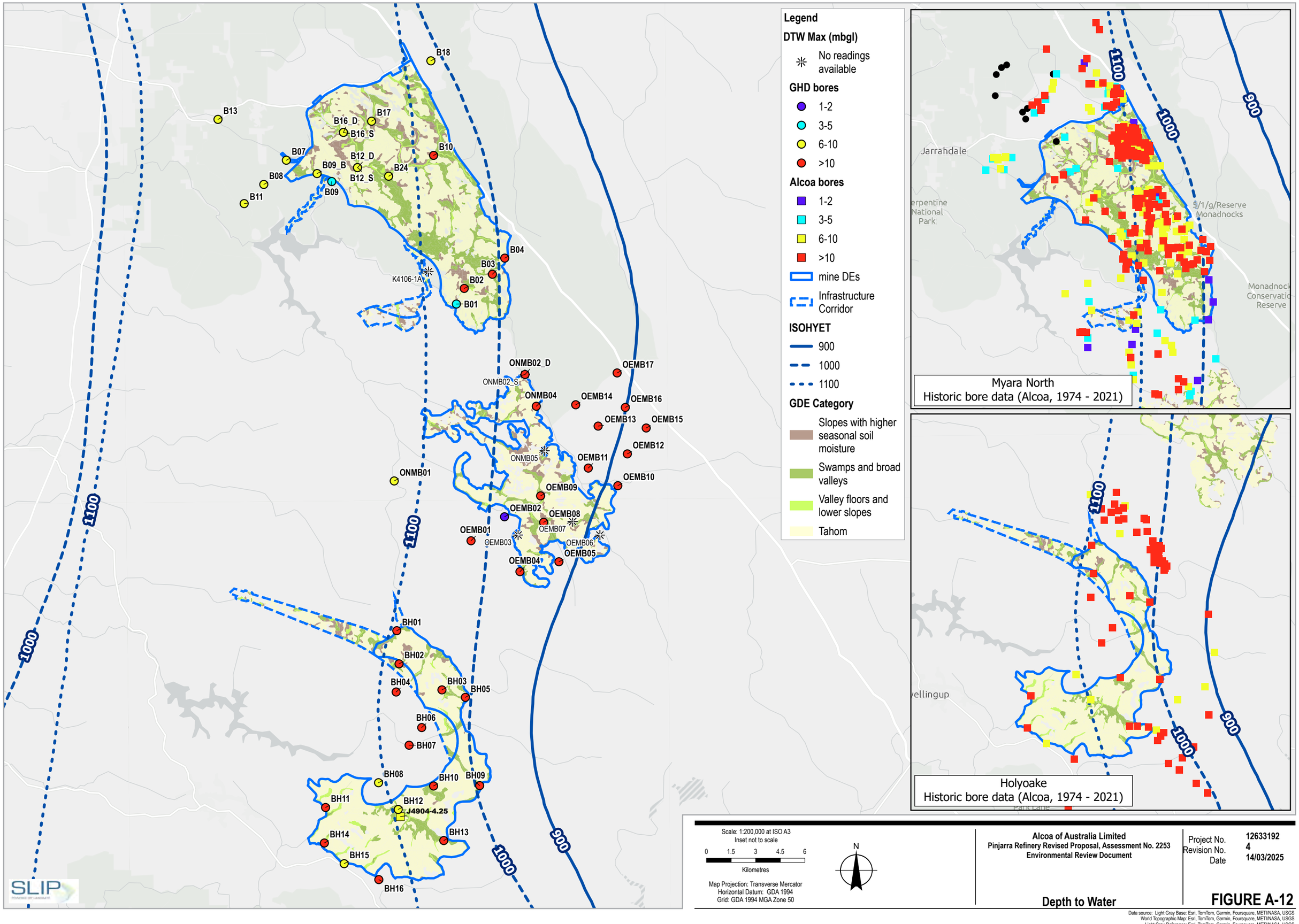
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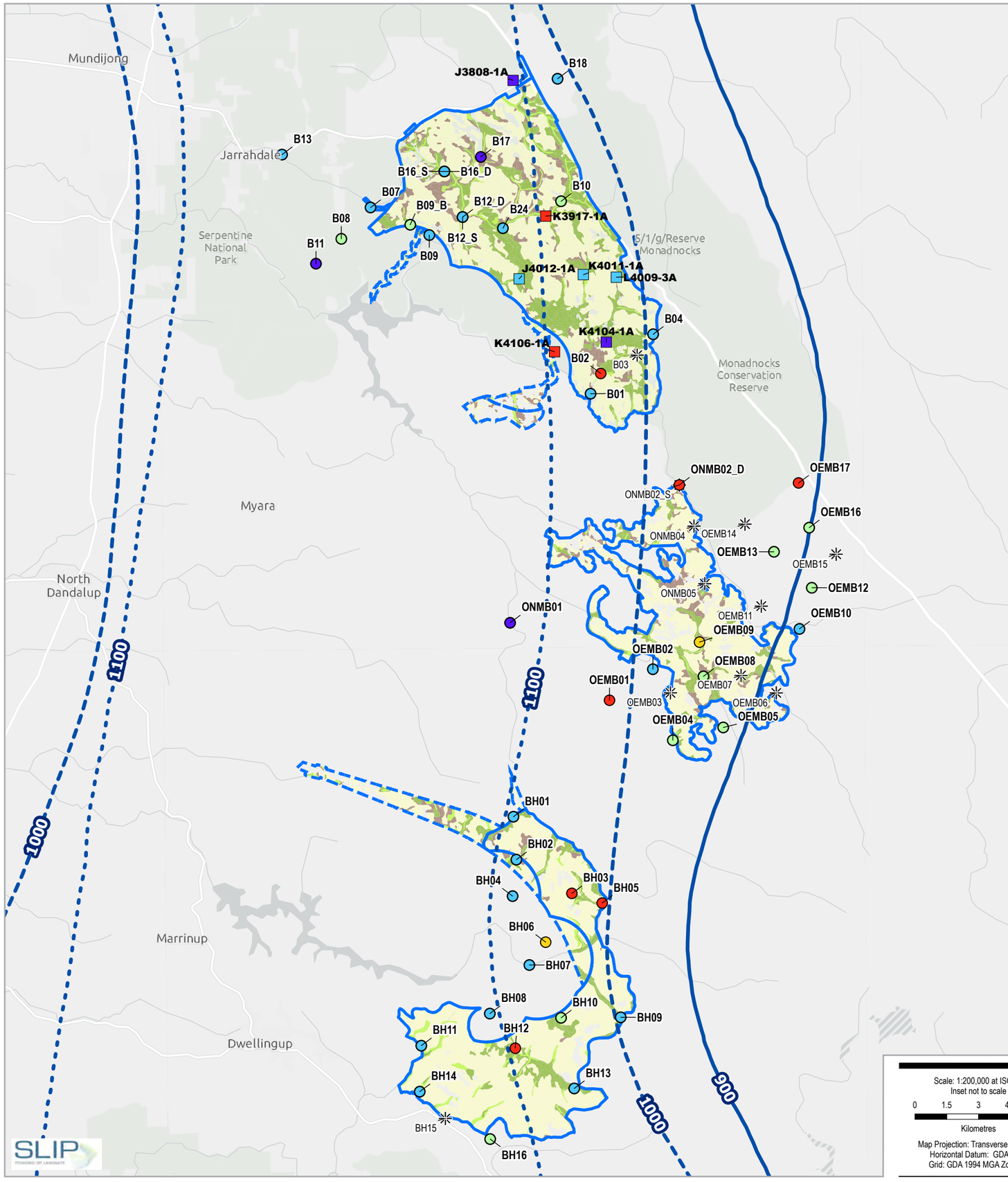
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Water Monitoring Locations

FIGURE A-11

Data source: Light Gray Base: Esri, TomTom, Garmin, Foursquare, METI/NASA, USGS
Light Gray Reference: Esri, TomTom, Garmin, Foursquare, METI/NASA, USGS.


B18
B13
B16_D
B17
B16_S
B07
B12_D
B10
B09_B
B24
B08
B12_S
B11
B09
B04
B03
K4106-1A
B02
B01
ONMB02_D
OEMB17
ONMB02_S
ONMB04
OEMB14
OEMB16
OEMB13
OEMB15
OEMB12
ONMB05
OEMB11
ONMB01
OEMB10
OEMB09
OEMB02
OEMB08
OEMB07
OEMB01
OEMB03
OEMB06
OEMB05
OEMB04
BH01
BH02
BH04
BH03
BH05
BH06
BH07
BH08
BH10
BH09
BH11
BH12
J4904-4.25
BH13
BH14
BH15
BH16
1100
1000
900
SLIP
Legend
DTW Max (mbgl)
No readings available
GHD bores
1-2
3-5
6-10
>10
Alcoa bores
1-2
3-5
6-10
>10
mine DEs
Infrastructure Corridor
ISOHYET
900
1000
1100
GDE Category
Slopes with higher seasonal soil moisture
Swamps and broad valleys
Valley floors and lower slopes
Tahom
Jarrahdale
erpentine National Park
5/1/g/Reserve
Monadnocks
Monadnock Conservatio Reserve
Myara North
Historic bore data (Alcoa, 1974 - 2021)
vellingup
Holyoake
Historic bore data (Alcoa, 1974 - 2021)
Scale: 1:200,000 at ISO A3
Inset not to scale
0 1.5 3 4.5 6
Kilometres
Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50
N
Alcoa of Australia Limited
Pinjarra Refinery Revised Proposal, Assessment No. 2253
Environmental Review Document
Project No. 12633192
Revision No. 4
Date 14/03/2025
Depth to Water
FIGURE A-12
Data source: Light Gray Base: Esri, TomTom, Garmin, Foursquare, METI/NASA, USGS
World Topographic Map: Esri, TomTom, Garmin, Foursquare, METI/NASA, USGS
Light Gray Reference: Esri, TomTom, Garmin, Foursquare, METI/NASA, USGS



Legend

TDS Max

- No readings available

GHD bores

- <250
- 250 - 500
- 500 - 800
- 800 - 1000
- >1000

Alcoa bores

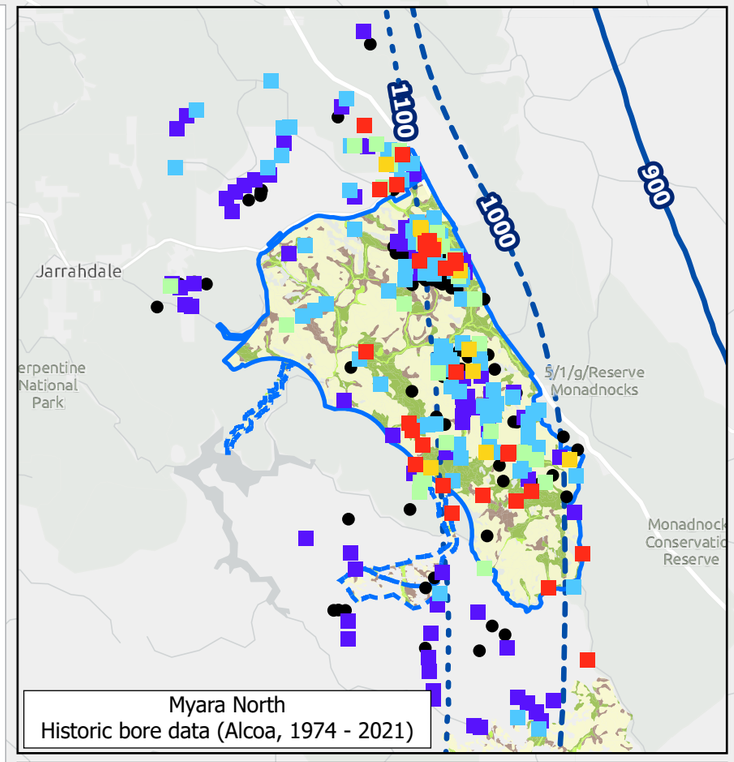
- <250
- 250 - 500
- 500 - 800
- 800 - 1000
- >1000
- mine DEs
- Infrastructure Corridor DEs

ISOHYET

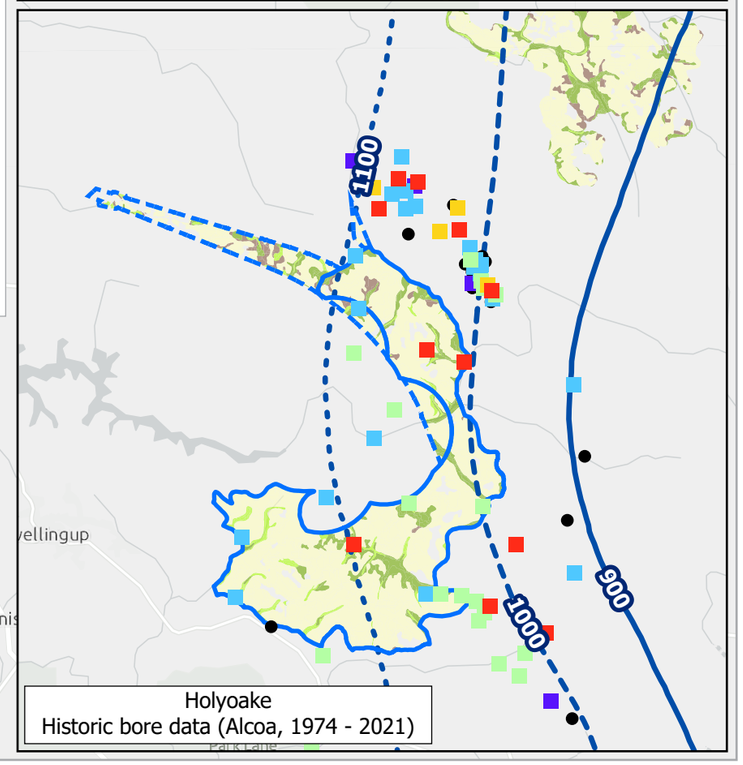
- 900
- 1000
- 1100

GDE Category

- Slopes with higher seasonal soil moisture
- Swamps and broad valleys
- Valley floors and lower slopes
- Tahom



Myara North
Historic bore data (Alcoa, 1974 - 2021)



Holyoake
Historic bore data (Alcoa, 1974 - 2021)

Scale: 1:200,000 at ISO A3
Inset not to scale
0 1.5 3 4.5 6
Kilometres
Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

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Date **14/03/2025**

Groundwater Salinity

FIGURE A-13

Data source: Light Gray Base: Esri, TomTom, Garmin, Foursquare, METI/NASA, USGS
World Topographic Map: Esri, TomTom, Garmin, Foursquare, METI/NASA, USGS
Light Gray Reference: Esri, TomTom, Garmin, Foursquare, METI/NASA, USGS

Appendix B

Baseline Surface and Ground Water Monitoring Report – Myara North and Holyoake 2020-2023

Refer to Environmental Review Document Appendix B8.1

Appendix C

Hydrological Setting and Understanding - Myara North and Holyoake

Refer to Environmental Review Document Appendix B8.3

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Appendix D

Groundwater Modelling Report for Huntly Mine - Myara North

Refer to Environmental Review Document Appendix B8.4

Appendix E

Groundwater Modelling Report for Huntly Mine - Holyoake

Refer to Environmental Review Document Appendix B8.5

Appendix F

Inland Waters Baseline Report Year 1 – O’Neil

Refer to Environmental Review Document Appendix B8.2

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