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Baseline Inland Waters Assessment

Huntly and Willowdale

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November 2024

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Baseline Inland Waters Assessment
Huntly and Willowdale

Alcoa of Australia Limited

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WSP acknowledges that every project we work on takes place on First Peoples lands.
We recognise Aboriginal and Torres Strait Islander Peoples as the first scientists and engineers and pay our respects to Elders past and present.

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1 Introduction

1.1 Background

Alcoa of Australia Limited (Alcoa) began operations in Western Australia (WA) in 1963 with the commissioning of the Kwinana Refinery, in accordance with the Alumina Refinery Agreement Act 1961. This State Agreement, between Alcoa and the WA Government, permitted Alcoa to mine bauxite within Mineral Lease 1SA (ML1SA). The area extends from Mundaring to Collie, and the agreement initially supported development of the Kwinana Refinery. Since then, Alcoa and the WA Government struck two further State Agreements covering the development of the Pinjarra Alumina Refinery and the Wagerup Alumina Refinery:

— Alumina Refinery (Pinjarra) Agreement Act 1969.

— Alumina Refinery (Wagerup) Agreement and Acts Amendment Act 1978.

These three State Agreements support the entirety of Alcoa's operations in Western Australia and the approximately 4,300 associated direct jobs and 1,600 indirect jobs, predominantly in regional areas. Current operations (as shown in Figure 1.1) include:

— Two bauxite mines (Huntly and Willowdale).

— Three alumina refineries (Kwinana, Pinjarra and Wagerup), however Kwinana curtailment commenced in 2024.

— Two dedicated port facilities (Kwinana and Bunbury), however Kwinana curtailment commenced in 2024.

The **Huntly Mine** was established in 1972 and supplies bauxite to the Pinjarra and Kwinana Refineries (prior to Kwinana curtailment).

The **Willowdale Mine** was established in 1984 and supplies bauxite to the Wagerup Refinery.

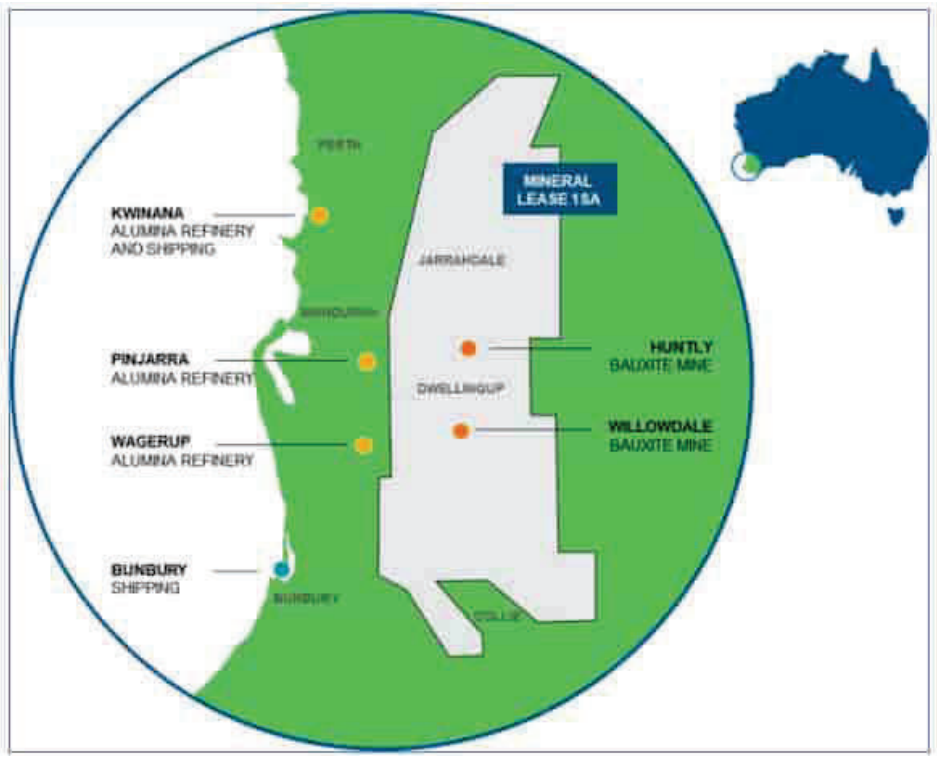


Figure 1.1 Alcoa operational locations, Mineral Lease and Huntly and Willowdale Mine areas (after Alcoa 2023–2027 MMP)

The bauxite ore has formed relatively shallow to surface. As such, mining operations involve a moving footprint, followed by progressive and leading rehabilitation efforts. The mining sequence is illustrated in Figure 1.2 below. At each mine site, operations are designated into separate spatial regions (mine regions) (refer Figure 2.2 and Figure 2.3). Various sequences of the mining cycle may be occurring across several mine regions concurrently.

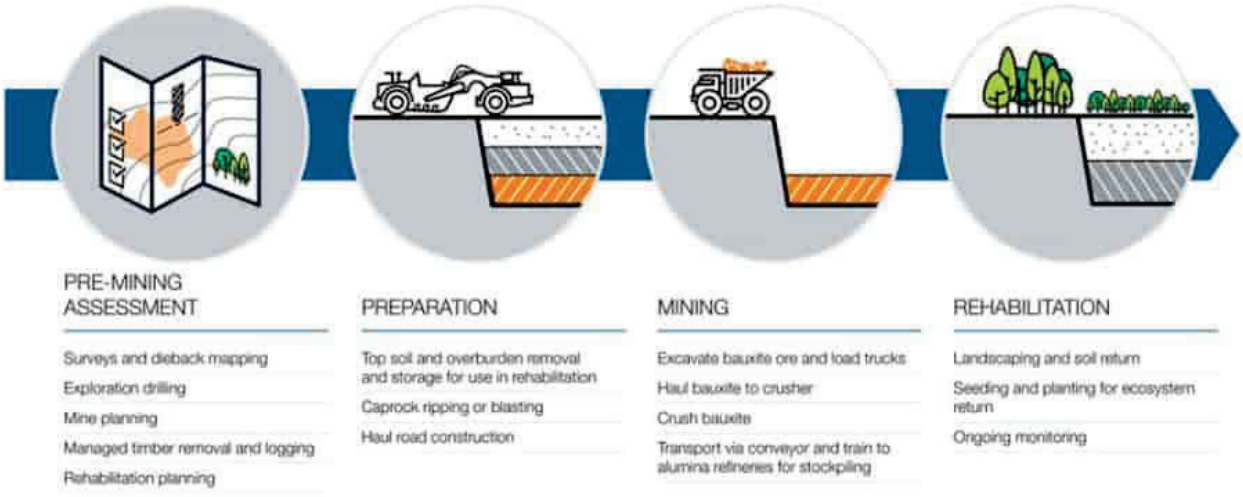


Figure 1.2 Mining cycle sequence (after Alcoa 2023–2027 MMP)

In August 2023, a third party referred the Bauxite mining on the Darling Range in the southwest of WA for the years 2022 to 2026 (Assessment 2384) and the Bauxite mining on the Darling Range in the southwest of WA for the years 2023 to 2027 (Assessment 2385) proposals to the EPA.

Inland Waters are identified as a key environmental factor for consideration, noting that the proposed mining areas lie largely within catchments for public drinking water reservoirs.

Alcoa has engaged WSP Australia Pty Ltd (WSP) to prepare a baseline assessment and ecohydrogeological conceptual model (this report) to support an environmental impact assessment via a Public Environmental Review for continued operations at the Huntly Mine and the Willowdale Mine.

1.2 Objectives

This report intends to describe existing (baseline) hydrological and hydrogeological conditions for the two Mine Development Envelopes (DEs) where mining operations are planned / documented under Assessments 2384 (Huntly) and 2385 (Willowdale) (refer Figure 2.1).

Specifically, these relate to mine operations within the Myara, O'Neil, Huntly, Del Park mine regions of the Huntly Mine and the Wills, Keats and Tasman mine (parts of Larego) regions of the Willowdale mine, for the activities covered under Mining and Management Plans for 2022 to 2026 and 2023 to 2027.

For the purposes of this report, baseline conditions are considered to be those prior to 2022.

1.3 Limitations and assumptions

The level of detail provided within is considered high-level due to the absence of site specific (i.e., within DE) assessments to inform the report. Knowledge gaps and uncertainties are listed in Section 6.

Studies and assessment completed

Limited review and analysis of any climate, water level, water flow or water quality data has been undertaken within the Development Envelopes. Most information presented herein is a reproduction of work completed by others.

Availability of site-specific data

Much of the key information underpinning the description of the existing conditions has been obtained from assessments and studies completed by others (public and private sources). Previous assessments have covered specific sub-regions of the Huntly mine (i.e., Myara North, Del Park, O'Neil, Mccoy, and Holyoake) and catchment areas within and adjacent to the mines (i.e., Yarragil 4X).

As such, the understanding of the existing conditions presented herein is considered contextually high-level and regionally relevant (representing conditions across the wider Darling Range region).

Definition of baseline

For the purpose of the study, baseline refers to those conditions prior to the initiation of Alcoa's activities associated with Assessment 2384 and 2385.

Timber harvesting, clearing, and mining have occurred in some parts of the DE study areas. Therefore, baseline conditions do not necessarily mean pre-anthropogenic activity within the catchment / study area. Baseline land use is further discussed in Section 2.5.

Catchment condition

Previous studies completed and relied upon in this document to understand baseline conditions may study areas where significantly less mining / timber harvesting has already occurred. The level of activity occurring in the catchment may directly influence the existing catchment condition.

1.4 Available information

The report relies on several key studies and documents as follows:

Alcoa Mine Management Programs

- Alcoa 2021: Mining and Management Program 2021–2025 Inclusive, Huntly and Willowdale Mines.
- Alcoa 2023: Final Mining and Management Program (MMP) 2023–2027 Inclusive, Huntly and Willowdale Mine.

Alcoa Public Environmental Review Document 2253

- Alcoa 2023: Pinjarra Alumina Refinery Revised Proposal, Environmental Review Document (ERD), Assessment No. 2253.

ERD 2253 Inland Water Supporting Documents:

- GHD 2021: Hydrological setting and understanding – Myara North and Holyoake, Pinjarra Alumina Refinery Revised Proposal.
- GHD 2022: Drinking Water Risk Assessment – Serpentine, Serpentine Pipehead, South Dandalup, and Wungong Brook Catchments.
- GHD 2022: Baseline Surface and Groundwater Monitoring report – Myara North and Holyoake, Pinjarra Alumina Refinery Revised Proposal.
- GHD 2022: Hydrology and Water Quality Assessment for Huntly Mine, Pinjarra Alumina Refinery Revised Proposal.

2 Site description

This section describes the general site characteristics that are important for consideration when understanding and conceptualising the existing hydrological and hydrogeological environment.

2.1 Geographical location

The Huntly and Willowdale mine areas are located within the Darling Range southeast of Perth, the capital city of Western Australia (Figure 1.1). The Darling Range (or Ranges) are a landform characterised as a series of low hills and escarpments. The Darling Scarp is a low escarpment running north-south along the western margin of the Darling Range. The Darling Scarp marks the separation of the Darling Range from the Swan Coastal Plain. West of the escarpment, the region is termed the Darling Plateau, an undulating lateritic plateau. Both mines are situated within the Darline Plateau.

The Huntly mine region is in the Murray district of Western Australia. Geographically, it lies at approximately 32° 35’ 54” south latitude and 116° 5’ 2” east longitude. The landscape around Huntly mine region includes a mix of agricultural land, native bushland, state forest and small settlements.

The Willowdale mine region is located east of Waroona and Cookernup, situated in the Peel region of Western Australia. Geographically, it lies at approximately 32° 48’ 0” south latitude and 116° 28’ 0” east longitude. The landscape around Willowdale is characterised by a mix of agricultural land, conservation park, native bushland, and forested areas.

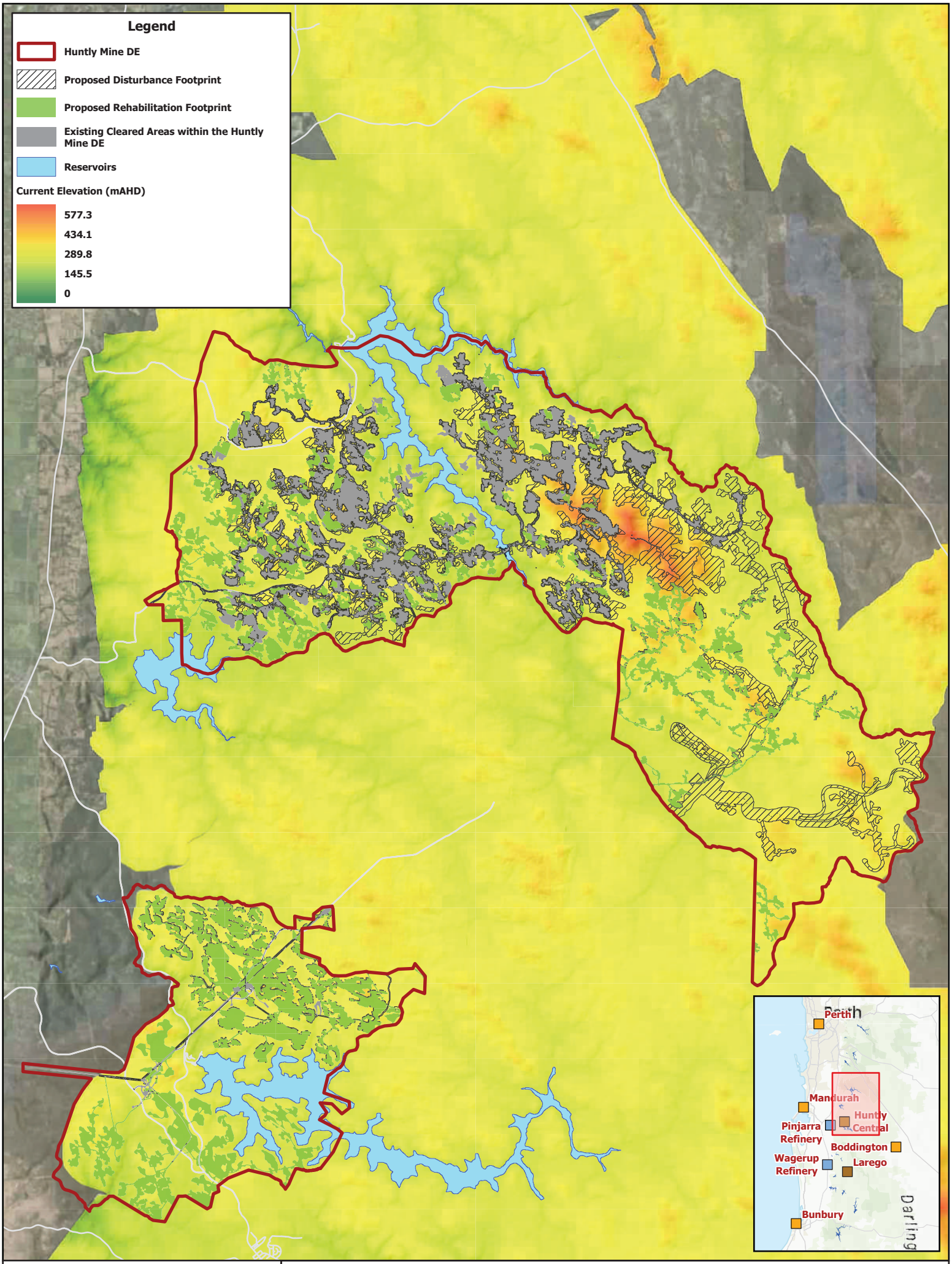
2.2 Topography

The elevation over the Darling Plateau, in the Mine areas typically ranges from about 200 to 400 m above sea level[1]. The terrain is generally undulating, with the Darling Scarp providing a prominent south-north traversing geological feature along the western margin of the range that descends sharply to the coastal plains. Topographic features are presented on Figure 2.1.

The western edge of the Darling Range is characterized by scarps and incised valleys, landforms which are attributed to tectonic activity along the Darling Fault. This feature is observable in regional topographical survey information and satellite imagery to roughly follow the coastline of southwest Western Australia and is approximately demarcated by the extent of Jarrah Forest, a recognized bioregion.

Within Huntley and Willowdale DEs, topography generally comprises wide valleys and undulating hills typically separated by intermediate to high-order tributaries of notable creeks and rivers.

[1] Western Australia topographic map, elevation, terrain. https://en-au.topographic-map.com



Bauxite mining on the Darling Range
2022 to 2026 & 2023 to 2027 (Assessment No. 2384 & 2385)
Inland Waters Baseline Assessment

Figure 2-1a Topography of the Darling Range and surrounds - Huntly

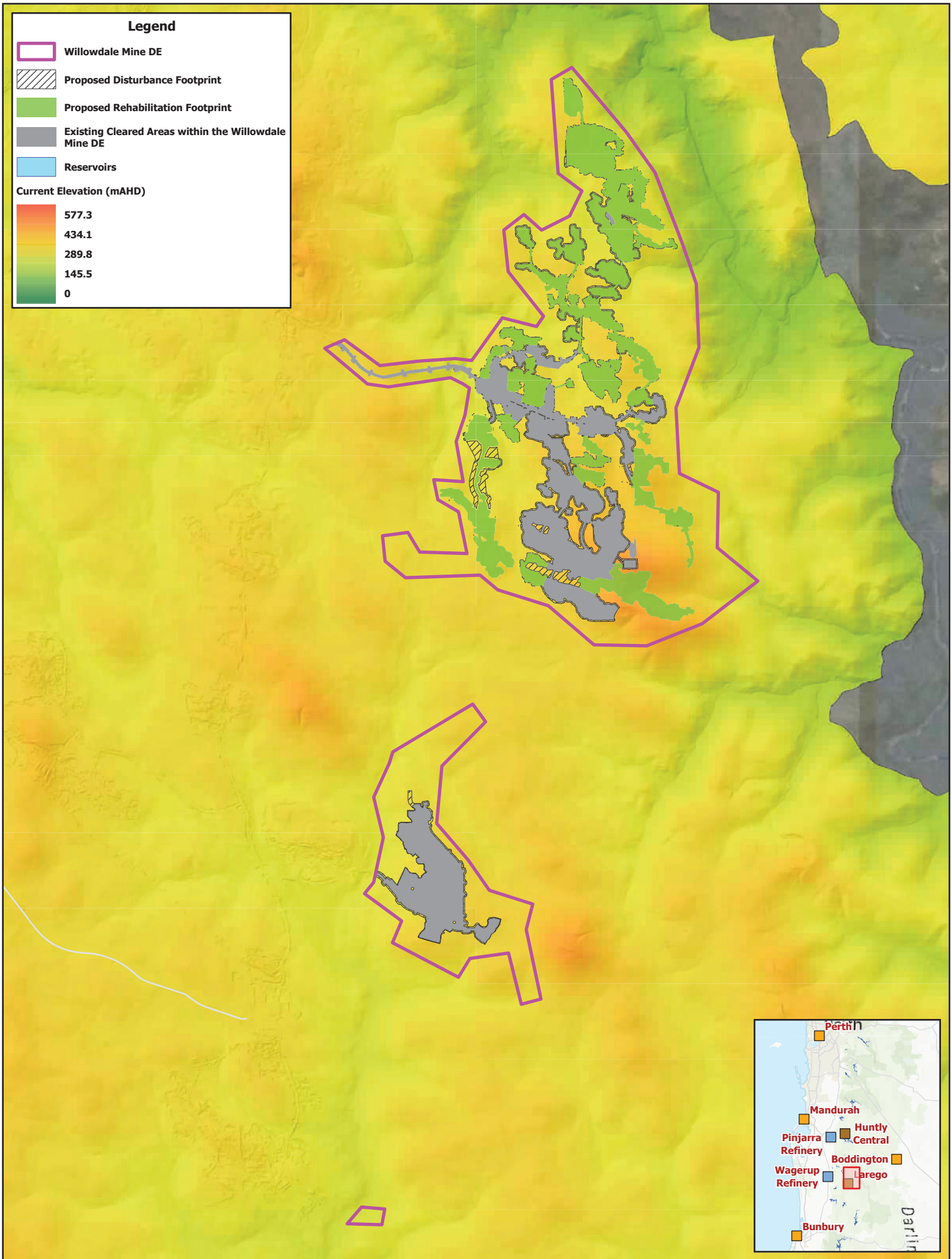
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Bauxite mining on the Darling Range
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Figure 2-1b Topography of the Darling Range and surrounds - Willowdale

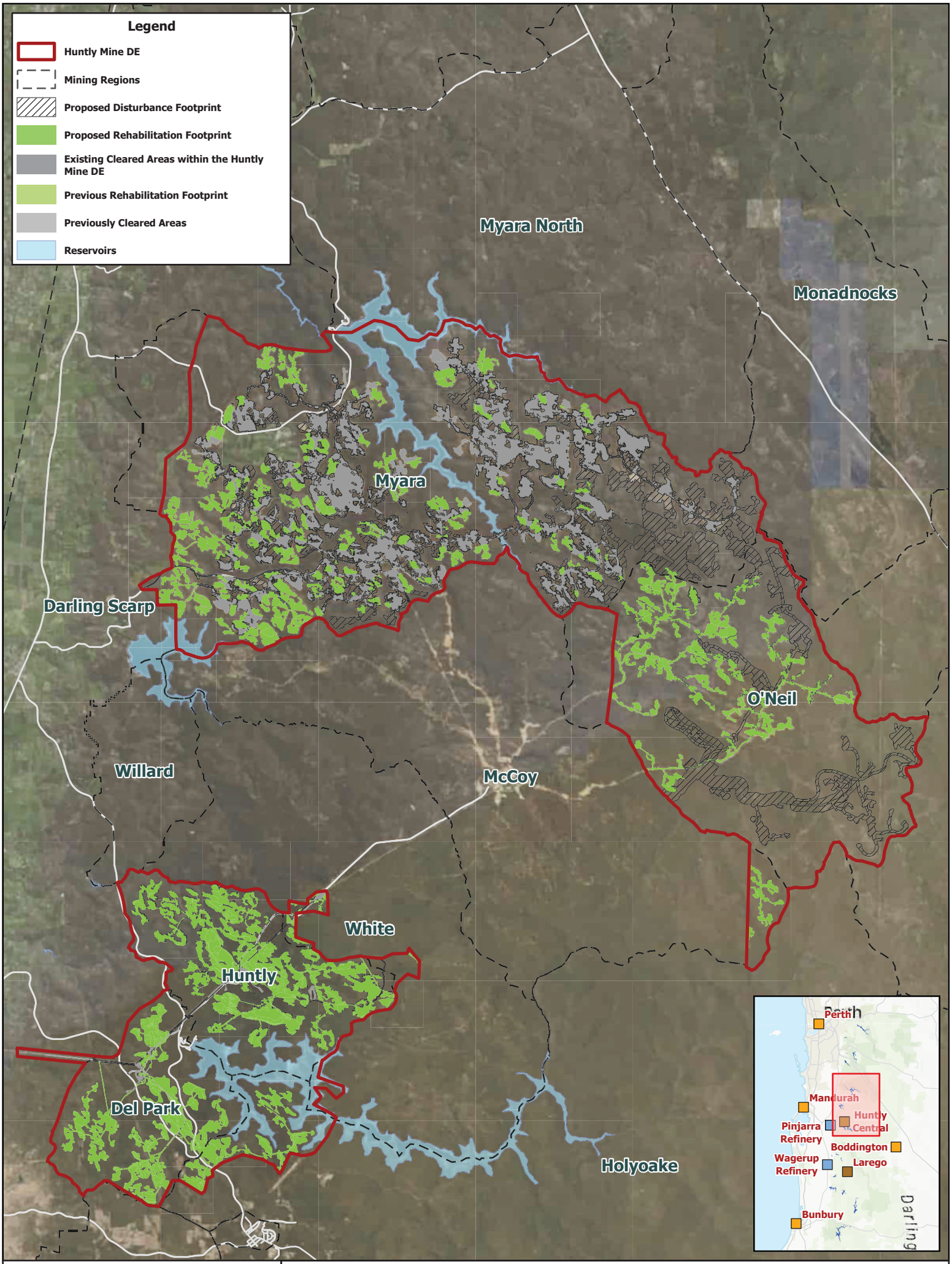
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Bauxite mining on the Darling Range
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Figure 2-2 Huntly Mine region and proposed Development Envelope

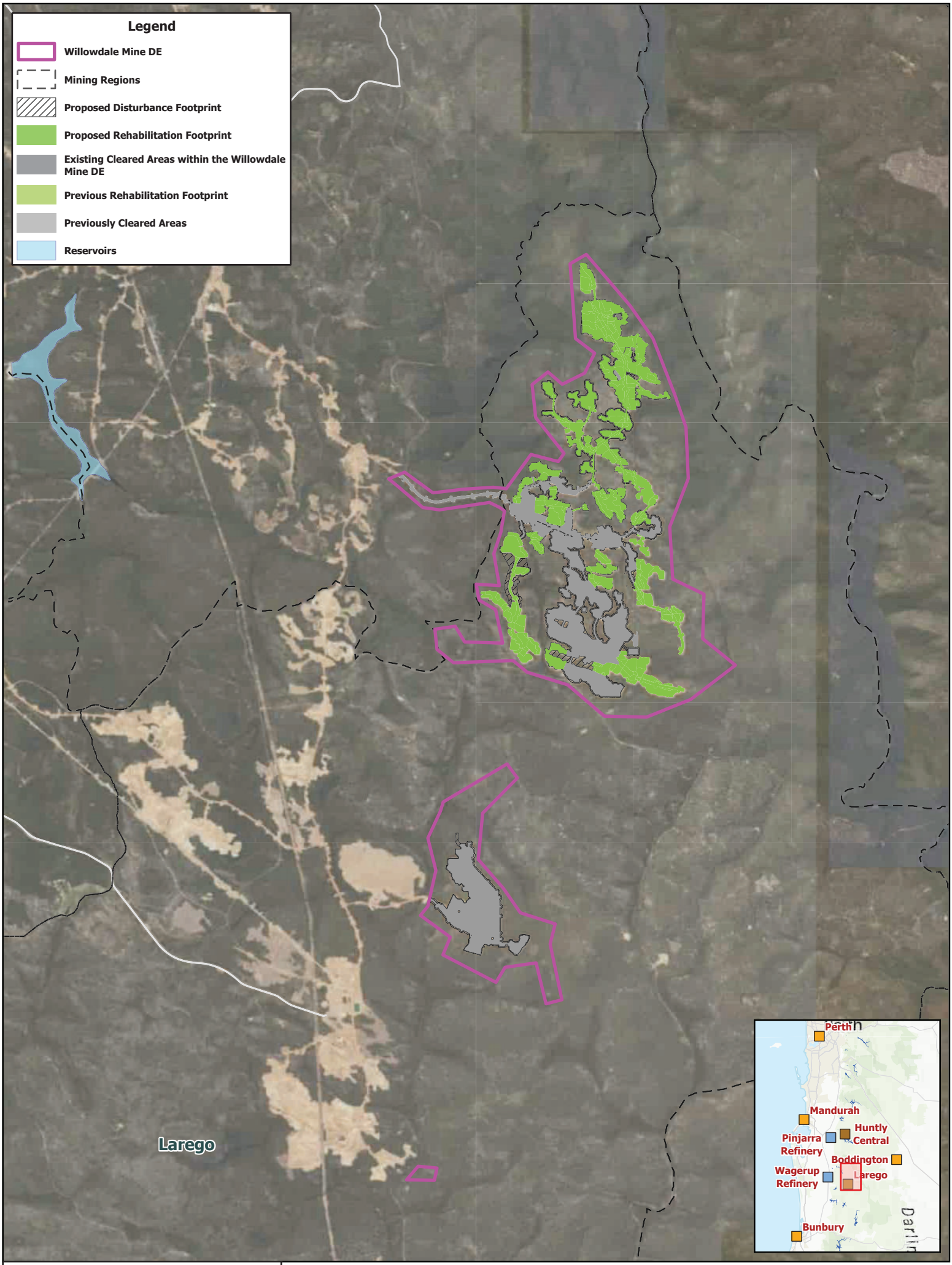
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Bauxite mining on the Darling Range
2022 to 2026 & 2023 to 2027 (Assessment No. 2384 & 2385)
Inland Waters Baseline Assessment

Figure 2-3 Willowdale Mine region and proposed Development Envelope

Kilometres
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Alcoa

2.3 Climate

Alcoa's Huntly and Willowdale mining operations are in the southwest region of WA, which experiences a 'Mediterranean' climate, with hot, dry summers and mild, wet winters. Rainfall is highest on the western extent of the Darling plateau near the Darling Scarp and decreases to the north and east.

Average annual rainfall isohyets indicate around 500 mm in the north-east to 1,300 mm along the western margin of the Darling Plateau (Figure 2.6). Most rainfall occurs between the months of May and October. The nearest Bureau of Meteorology (BoM) stations to the Huntly and Willowdale DEs (refer Figure 2.1) are summarised and presented in Table 2.1 and Table 2.2. Long term average rainfall and maximum temperatures at Karnet and Dwellingup stations are presented in Figure 2.4 and Figure 2.5.

Table 2.1 Nearest BoM weather stations to the Huntly DE

BoM station	Coordinates	Data type	Data temporal range
009111 Karnet	Latitude: -32.4389° south Longitude: 116.0789° east	Rainfall	December 1963 – July 2024
		Evaporation	February 1973 – October 2023
		Solar exposure	January 1990 – present
		Temperature	January 1965 – present
009115 Serpentine Main Dam	Latitude: -32.4022° south Longitude: 116.1039° east	Rainfall	January 1963 – May 2016
		Solar exposure	January 1990 – present
009260 Mount Solus	Latitude: -32.4697° south Longitude: 116.2143° east	Rainfall	February 2004 – July 2024
		Solar exposure	January 1990 – present
009936 Huntly	Latitude: -32.6239° south Longitude: 116.0603° east	Rainfall	January 1990 – July 2024
		Solar exposure	January 1990 – present
009538 Dwellingup	Latitude: -32.7103° south Longitude: 116.0594° east	Rainfall	January 1934 – July 2024
		Evaporation	January 1967 – May 2021
		Solar exposure	January 1990 – present
		Temperature	January 1957 – present

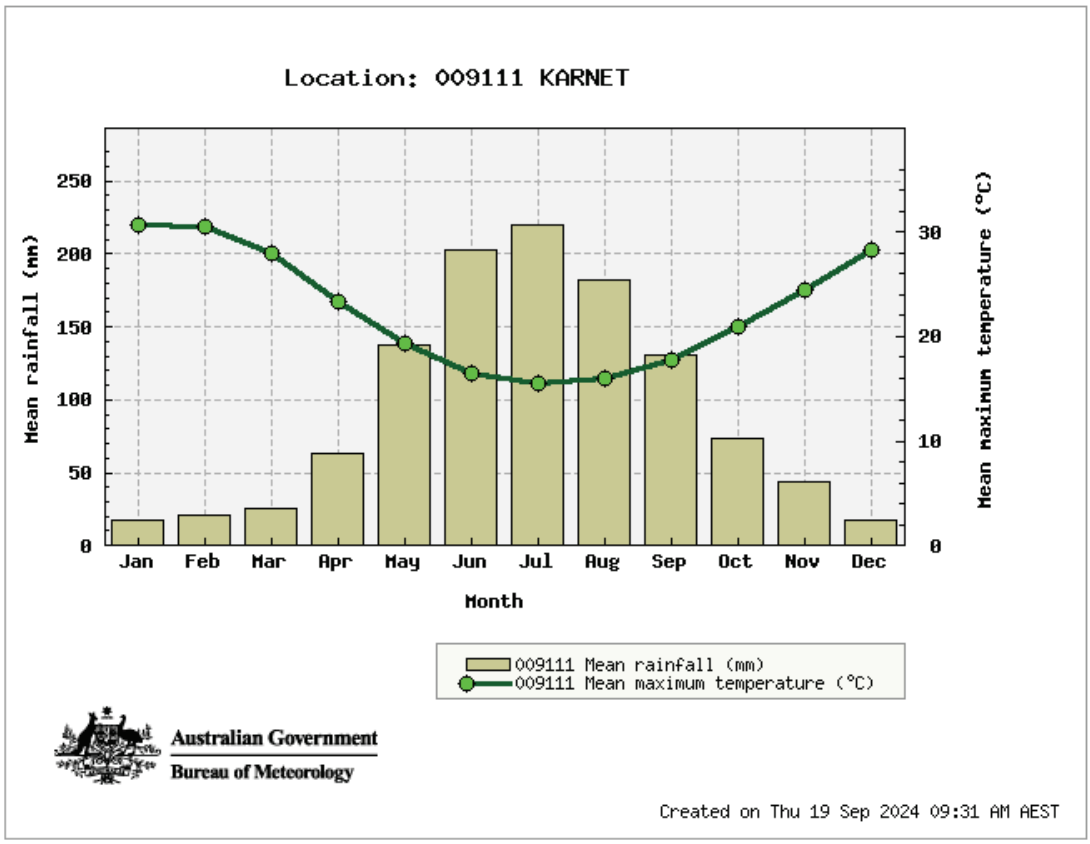


Figure 2.4 Long term average rainfall and maximum temperature at Karnet (1965–2024)

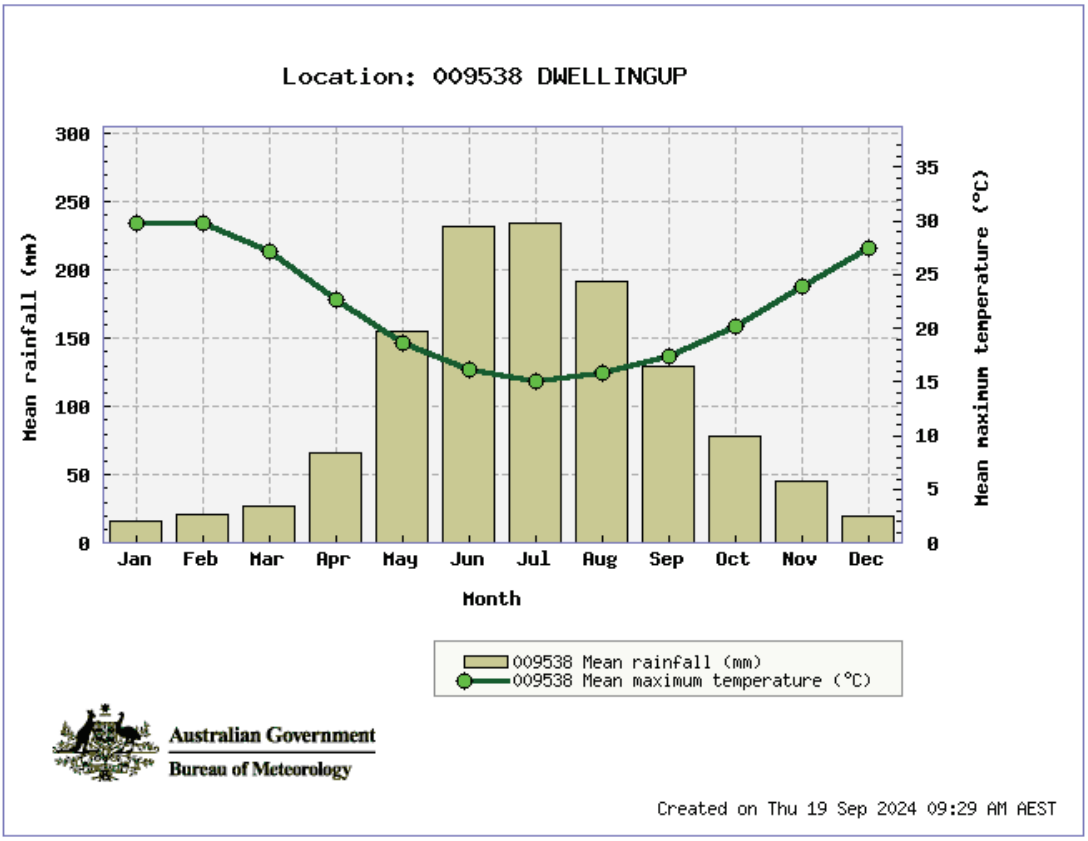


Figure 2.5 Long term average rainfall and maximum temperature at Dwellingup (1935–2024)

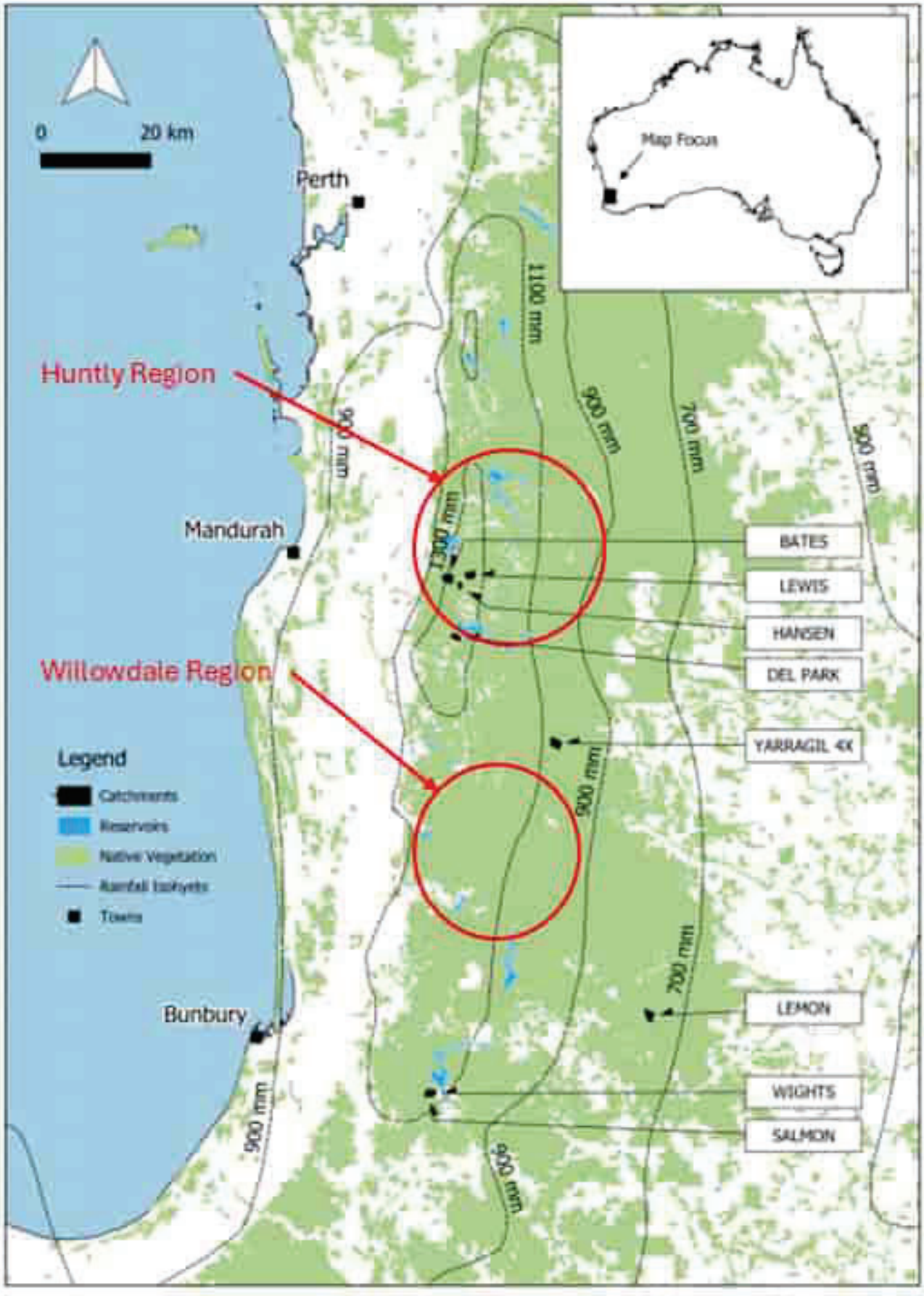


Figure 2.6 Rainfall isohyets (1975–2003) across the Darling Range (after (Grigg & Kinal, 2020))

BoM station ID 109501 is located about 8 km southwest of the Willowdale DE, the data ranges are summarised and presented in Table 2.2. Average monthly rainfall for 2023 at Mount William compared to long-term average is presented in Figure 2.7.

Table 2.2 Nearest BoM weather station to the Willowdale DE

BOM station	Location	Data type	Data temporal range
109501 Mount William	Latitude: -32.938° south Longitude: 116.024° east	Rainfall	February 2004 – July 2024
		Solar exposure	January 1990 – present

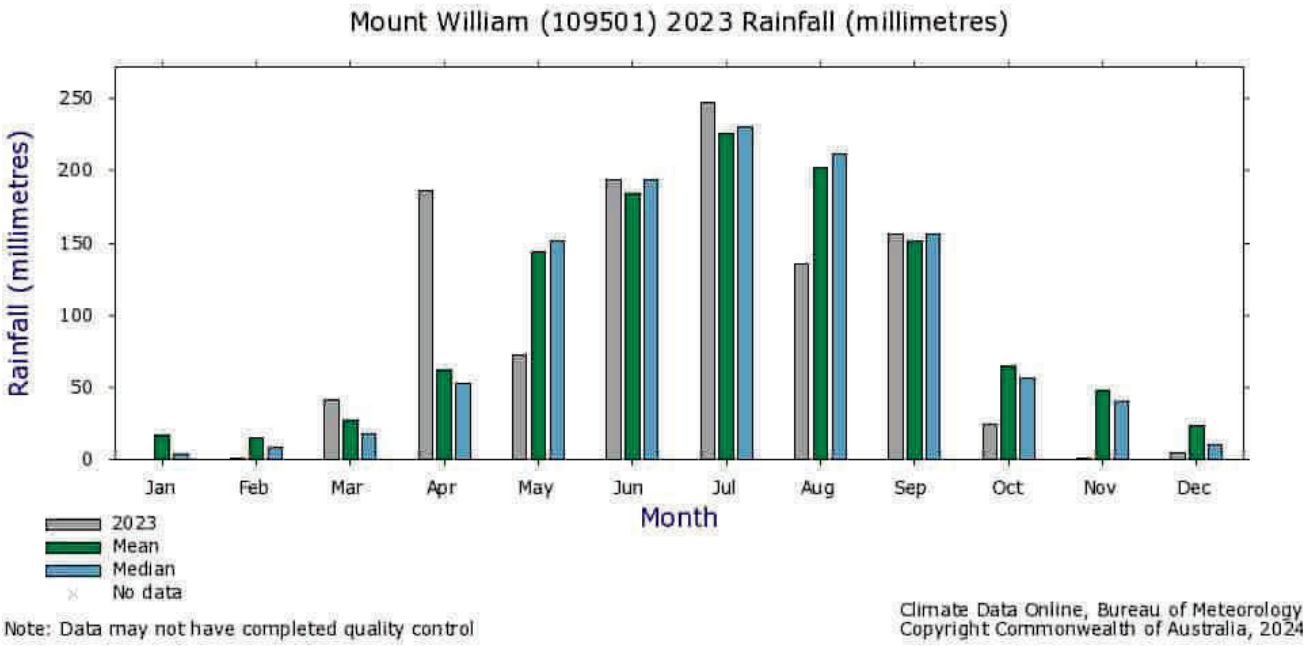


Figure 2.7 Monthly rainfall in 2023 compared to long-term average rainfall at Mount William (2004–2024)

2.3.1 *Climatic trends*

The south-west region of WA has experienced a marked drying trend since 1970, particularly apparent in autumn and early winter seasons (DWER, 2021). Mean temperatures have increased by about 1.1 degrees Celsius (°C) since 1910, with the rate of warming higher since 1960.

By 2030, the mean annual warming across all emissions scenarios is projected to be about 0.5 to 1.1°C above that measured between 1986 and 2005 (DWER, 2021). Although total annual rainfall is expected to decline, the intensity of heavy rainfall events is projected to increase. Furthermore, increased climate variability and longer dry spells or droughts are anticipated. Higher temperatures and evapotranspiration, combined with the possibility of reduced wet season rainfall, are expected to decrease dry-season soil moisture. Consequently, runoff and groundwater recharge are projected to decline (DWER, 2024).

2.4 Geology

2.4.1 Regional setting

Regional geology is presented on Figure 2.10. The area is situated on the western extent of the Yilgarn Craton granite basement area known as the South West Terrane. The bedrock underlying the region comprises Archaean granites with areas of granitic gneiss and dolerite intrusion. Dominant geological structures (faults) run in an approximate south-east to north-west direction. Younger age tholeiitic quartz dolerite dykes are common, intruding through the granite and range from 1 to 200 m thick (average 10 m) (Hickman, 1992). The presence of granite, gneiss or dolerite is a major determinant on the characteristics of the regolith which overlies most of the bedrock. The bedrock outcrops in pockets throughout the Darling Plateau, including on hills or 'monadnocks' as well as within incised valleys where rivers have eroded through the regolith material. The bedrock has an irregular topography, with pinnacles and isolated boulders occurring at shallow depths in the regolith, at places reducing the thickness of laterite (Hickman et al 1992).

Alcoa's operations cover a significant portion of the Darling Plateau, which occupies the south-western fringe of the Yilgarn Craton and is bordered by the Darling Fault and Perth Basin to the west. The Darling Plateau is covered by an extensive laterite, the result of bedrock weathering which typically consists of sand and gravelly topsoils which transition into a saprolite zone of weathering.

Lateritic bauxite developed from the Late Cretaceous (65 million years ago, Ma) to the Eocene (40 Ma), with several periods of erosion and intense weathering of the basement granites and dolerites. Subsequent reactivation of the of the Darling Fault combined with periods of erosion led to the establishment of plateaus and incised valleys, trending to wider valleys and low hills to the east which now characterize the physiography of the region.

A discontinuous, cemented layer (or duricrust) is mostly observed on mid-to upper- slopes transitions to underlying mottled and pallid saprolite clays. Coarse gravels found on the upper slopes, trend to finer gravels downslope and sands near the valley floor, dominated by loams and clay loams.

The transition zone between the fresh basement and saprolite is referred to as saprock. Groundwater has been an active part of lateralisation process, particularly in development of cemented ferruginous hardcap (duricrust). 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 transported by groundwater flow and its precipitation due to evapotranspiration or exposure to the surface (reduction of partial carbon dioxide pressure) (GHD, 2021a).

A generalised stratigraphic profile developed from regional and adjacent catchment studies is summarised in Table 2.3 and shown on Figure 2.9.

Table 2.3 Generalised regolith stratigraphy

Unit	Sub-unit	Description	Thickness
Regolith	Overburden	Comprising sandy gravels.	About 0.2 to 4 m thick (average 0.5 m).
	Lateritic bauxite	Two distinct layers:	About 4 to 6 m in total, comprising:
		— Duricrust or caprock, comprising iron or aluminium cemented rock. Caprock is typically hard to very hard and often strongly cemented with pisolitic nodules.	1 to 2 m.
		— Friable fragmental layer.	>2 m.
	Saprolite	Derived from weathered basement. Mottled and pallid clays generally becoming darker with depth and reflecting the weathered bedrock lithology.	Variable – 1 to 32 m.
	Saprock	Weathered basement comprising (parent) rock fragments and decreasing clay content. Grades sharply into basement.	About 2 to 5 m.
Crystalline basement	-	Granitoid dominant with doleritic intrusions.	Depth to basement varies <10 m to >30 m.

2.4.2 Bedrock mineralisation

The laterite layer hosts the bauxite resources which are proposed to be mined. The lateritic (bauxite) horizon is on average 2 to 3 m thick with ore blocks varying in size from approximately 0.5 to 150 ha in area.

Development of bauxite ore has been especially pronounced along the flanks and upper slopes of ridges. It generally occupies gently sloping (3° to horizontal) upland areas with an average elevation of 280 to 300 m above sea level, and high annual rainfall, although is limited and sometimes absent in the lower lying valleys, where it has been eroded.

Steeper slopes may have a thin cover of partly transported laterite with bedrock near the surface. Above 340 m the laterite is often penetrated by bedrock which rises above the general topographic level. Below 200 m drainage has removed pre-existing laterite. Blocks of laterite, released by headward erosion of streams, decay to lateritic gravels on the lower slopes of valleys, which pass laterally into alluvial sands and silt in the valley floors (Hickman et al, 1992).

Bauxite deposits typically occur as irregularly shaped lenses on the flanks of plateaus. Critical to this is the laterite position on the slopes (Figure 2.8): erosion generally dominates on steeper slopes which prevent accumulation and effective bauxite formation, whereas flat areas lack the necessary subsurface water flows which drive the removal of clays and the enrichment of soluble silicate minerals.

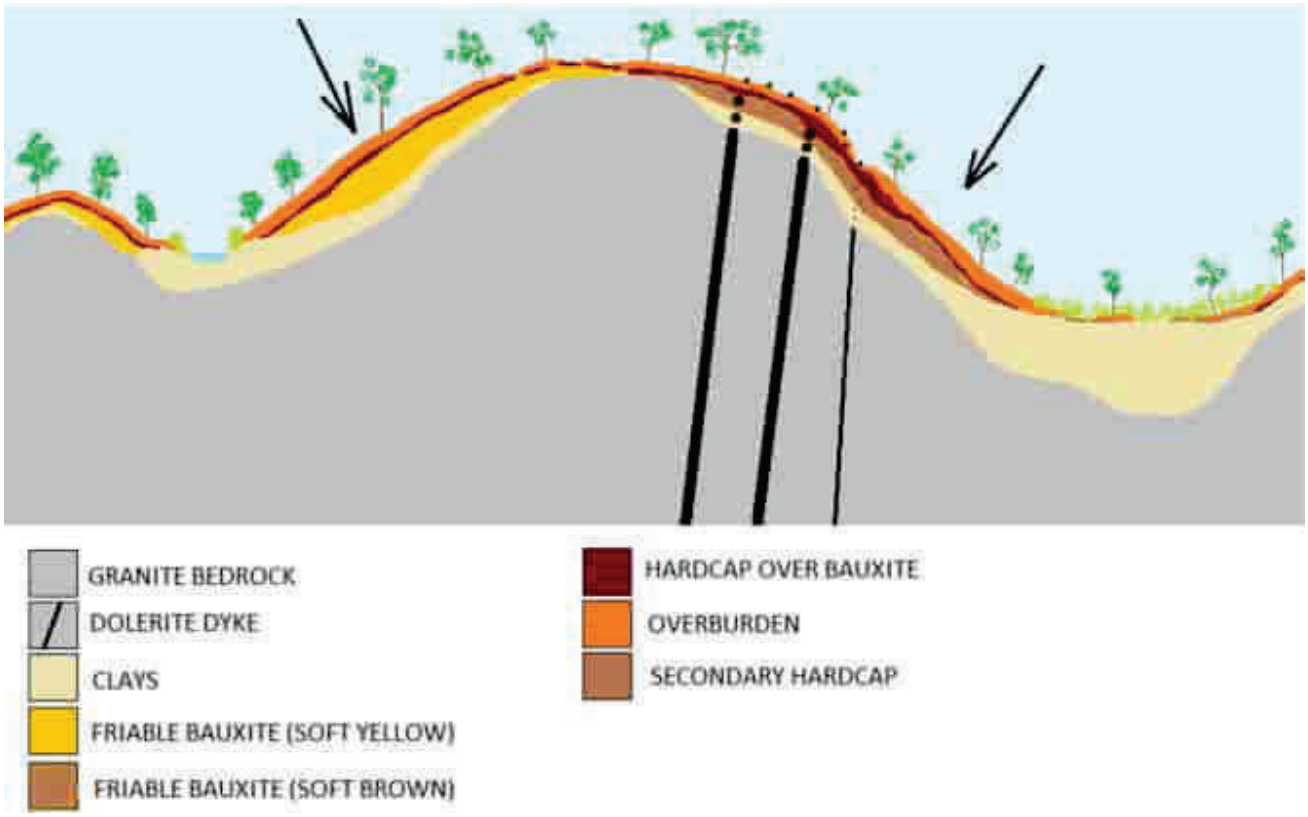


Figure 2.8 Bauxite deposit formation along the Darling Scarp (Alcoa, 2021)

2.4.3 Soils

Superficial soils on the Darling Plateau comprise a thin veneer of topsoil comprising sand and silt over a sandy gravel overburden layer (Hickman, 1992), (Kew & Gilkes, 2007). The overburden typically ranges from about 0.2 to 4 m thick, averaging about 0.5 m thick, and is underlain by lateritic bauxite which comprises a caprock (duricrust) layer and underlying friable fragmental layer. The caprock layer is discontinuous and varies from absent to a thickness of a few metres.

The bauxite friable fragmental layer beneath the overburden and/or caprock contains nodules, pisoliths, and weathered rock fragments set in fine-grained, loose earths or sands. The friable fragmental layer is typically about 2 m thick but can be up to 10 m thick on the Darling Plateau (Hickman, 1992).

Beneath the bauxite layers, mottled, pallid and saprolite clay layers are present. These are typically 20 to 30 m thick, and transition firstly into weathered saprock and then fresh bedrock (Hickman, 1992). These underlying layers form the pit floor following bauxite mining.

The soil catena of the Darling Plateau varies from the lateritic uplands (Dwellingup system) to the valleys (Yarragil system). The regolith is partially eroded in minor valleys, with the upper lateritic layers often absent and replaced by colluvial or alluvial deposits.

Where soils on the upper and mid slopes comprise shallow gravelly sands, those on the lower slopes and valleys comprise thicker deposits of finer grained soils including silts, clays and loams ((Hickman, 1992), (Fordyce, et al., 2007). (Churchward & McArthur, 1980) describe the soils of the minor valleys (Yarragil system) as orange earths and those of the major valleys (Murray system) as comprising red and yellow earths with some red and yellow duplex soils.

Table 2.4 provides a summary of the typical stratigraphy defined by Alcoa across their Darling Range deposits. The caprock and friable zones represent the primary horizons of economic interest due to their concentrations of alumina.

Table 2.4 Alcoa's Darling Range deposit typical stratigraphic column

Stratigraphic horizon	Typical thickness	Description
Overburden	0 to 0.5 m	Mixed soils and clays, high in organic matter, generally forming a thin layer which can penetrate deeper if the underlying caprock surface is variable.
Caprock	1 to 3 m	Ferricrete formed by the remobilization of iron into a layer comprising iron and alumina-rich nodules which can exhibit the highest alumina concentrations across the deposit. Highly variable in thickness but generally 1 m to 3 m with a sharp contact against the underlying Friable Zone.
Friable zone	3 to 5 m	Leached horizon resulting in the accumulation and enrichment of bauxite minerals. The friable zone comprises a mixture of the overlying hardcapping, clasts, aluminium and iron rich nodules, and clays. Upper contact with the hardcap is variable, although often comprises a sharp or transitional boundary in places.
Basal clay	--	Kaolinitic clay horizon which, transitions into a saprolitic zone above unweathered basement. This horizon is typically used as a marker indicating the full bauxite zone has been intersected and where drilling is often stopped.

A generic soil and bedrock profile after bauxite mining in the Darling Range, as developed by (Anand & Paine, 2002) is also presented in Figure 2.9. In this figure, quartz-rich (Zm) regolith is composed mostly of quartz and kaolin (kaolinite and/or halloysite) with various amounts of iron oxide cementation. This material occurs in the arenose zone and parts of the mottled zone using the terminology of (Anand & Paine, 2002). The arenose zone derived from granite represents a concentration of angular quartz grains in a grain-supported fabric. The mottled zone consists of segregations of subdominant red and orange colours, which are partly or wholly cemented by goethite and/or hematite. In contrast, clay-rich (Zp) regolith has a clay-supported fabric typical of the plasmic zone and where segregations of goethite and hematite are less abundant.

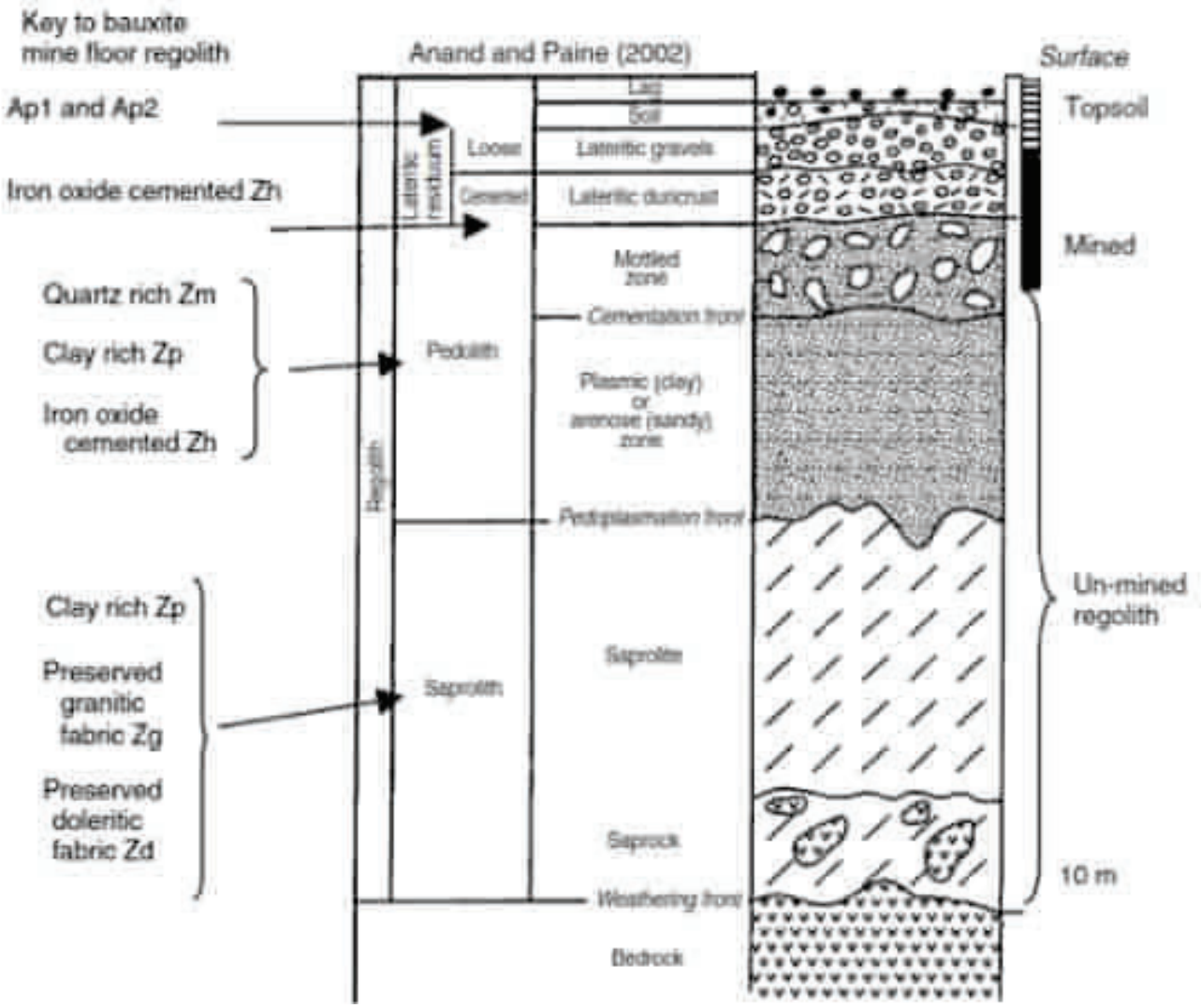


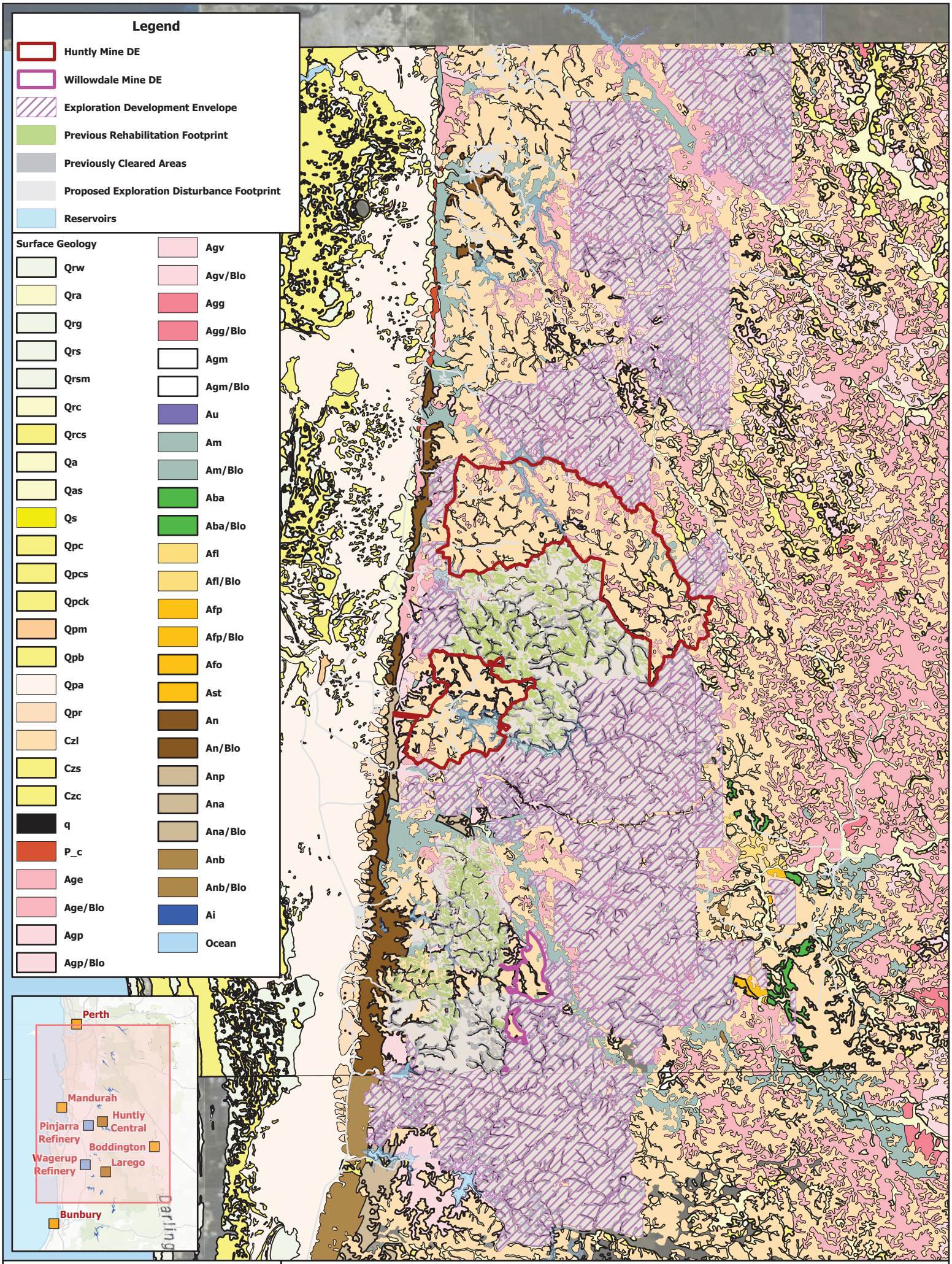
Figure 2.9 Key to bauxite mine floor regolith (Kew & Gilkes, 2007).

2.4.4 *Acid forming materials*

The Darling Plateau has not been mapped by State Government for the presence of acid sulfate soils (ASS), nor are there published studies into the presence of acid forming materials in the regolith or bedrock. Soils or sediments that are of most concern for ASS are those which formed within the last 10,000 years, when seawater inundated coastal plains and sulfate mixed with land sediments containing iron oxides and organic matter (DER, 2015). This resulted in formation of ASS as iron sulfides in waterlogged environments, with such processes not expected to have occurred in the Darling Plateau given its elevation and lack of recent sea inundation.

It is noted though that ASS may though form in inland wetlands and seasonally waterlogged / inundated swamps in valley floors where sufficient iron, sulfate and organic matter is present. In stating this however, there is a lack of site-specific soil and groundwater data with which to confirm the presence or absence of ASS in swamps either the Huntly or Willowdale DEs.

Acid forming materials may be present as sulfide-bearing minerals in those rocks of the Darling Plateau. Chemical assay of granite and dolerite bedrock to about 0.1 per cent has not identified the presence of sulfur (Hickman, 1992). It is therefore unlikely that trace quantities of sulfur in bedrock have sufficiently accumulated in the lateritic upper regolith during the weathering process such that there is a high risk of acid formation during bauxite mining.



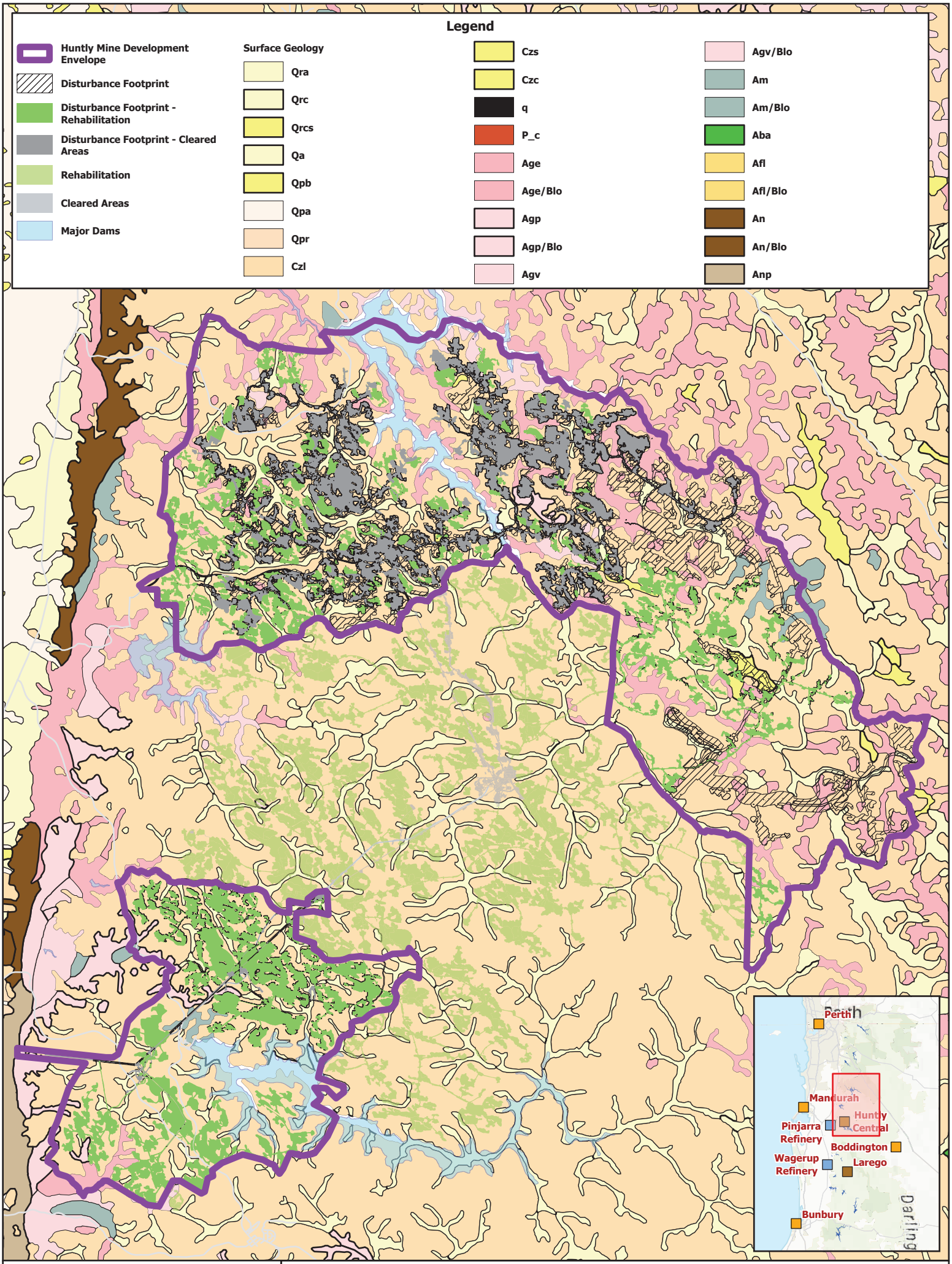
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Figure 2-10 Regional Geology of the Area

Scale: 1:500,000 at A4

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Figure 2-11 Surface Geology of Huntly DE

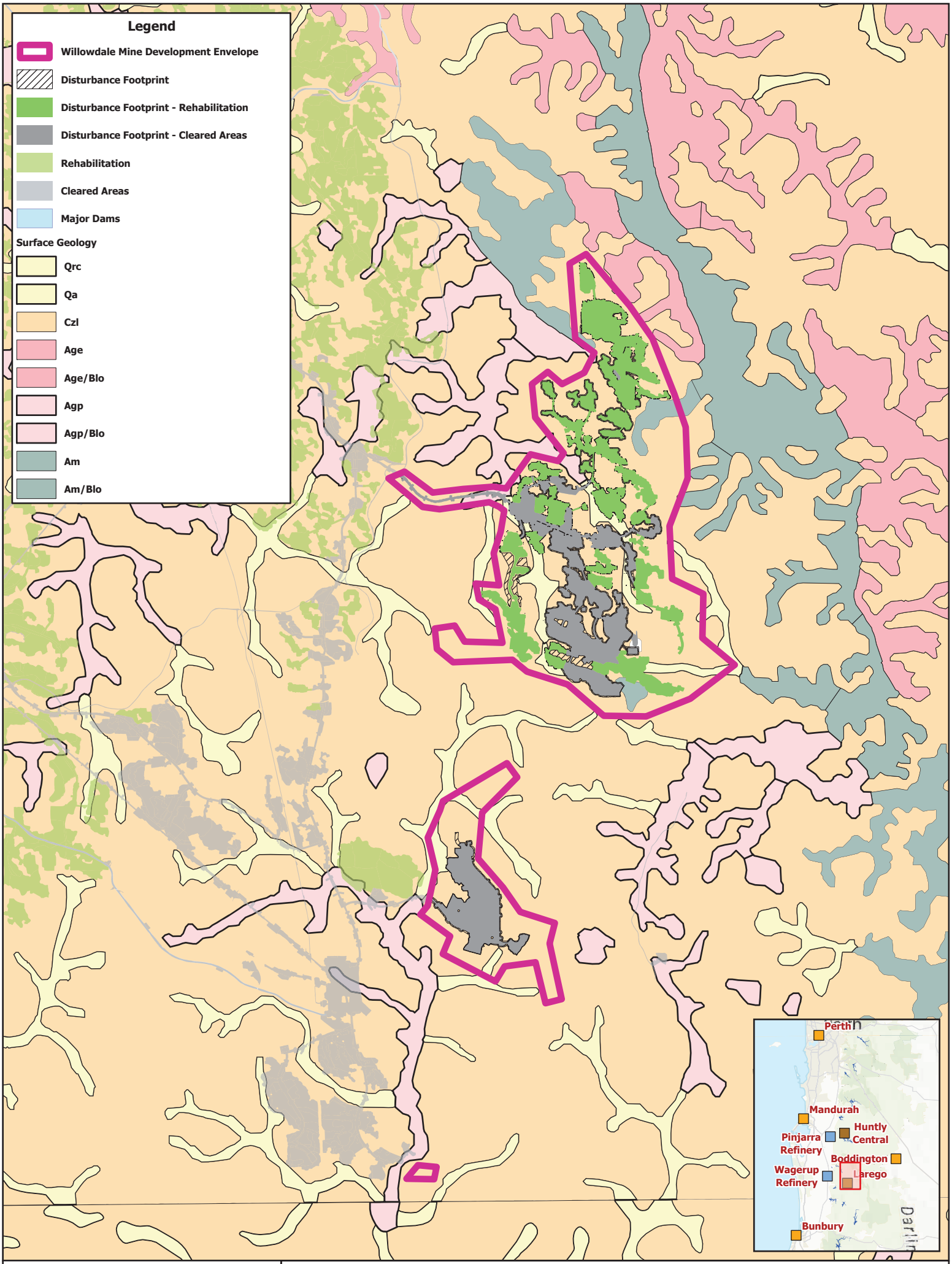
Kilometres
0 1 2 4 6 8 10

Scale: 1:175,000 at A4

Date Printed: 31/10/2024

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Bauxite mining on the Darling Range
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Inland Waters Baseline Assessment

Figure 2-12 Surface Geology of Willowdale DE

Kilometres
0 0.5 1 2 3 4 5

Scale: 1:75,000 at A4

Date Printed: 31/10/2024

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2.5 Land use and activities

The surface waters within the Proposal Mine DEs and the catchments the DE are located within are utilised for social, cultural and economic landuses as follows.

- Huntly DE:
  - Recreation and tourism uses: Serpentine Dam, Serpentine River downstream
  - Cultural heritage sites: registered Aboriginal cultural heritage sites along the Serpentine and South Dandalup rivers.
  - Public water supplies: Serpentine, Serpentine Pipehead, North Dandalup and South Dandalup dams.
  - Agricultural site: farm adjacent to the Serpentine Main Dam.
  - Industry (timber).
- Willowdale DE:
  - Recreational uses: camping, swimming and canoeing along Murray River downstream of Willowdale mining DE, including Logue Brook.
  - Cultural heritage sites: Murray River registered Aboriginal cultural heritage site.
  - Public water supply: Stirling and Samson Brook dams.
  - Industry (timber).

2.5.1 Public Drinking Water

Alcoa's mining lease is located within drinking water catchments which are classified as a Priority 1 Public Drinking Water Source Area (PDWSA). Both mining DEs are located within the drinking water catchment areas (refer Section 3.1.2).

The Water Corporation (WC) has a responsibility for controlling access within PDWSAs and Reservoir Protection Zones (RPZs). RPZs are defined in the Metropolitan Water Supply, Sewerage, and Drainage By-laws 1981, and generally extend to 2 km from the top water level of any reservoir, back into the defined PDWSA. RPZs are located within both mine sites, surrounding the Serpentine Main, Serpentine Pipehead, North Dandalup, South Dandalup, Samson, and Stirling dams.

At Huntly, the mining areas intercept Serpentine, Serpentine Pipehead, North Dandalup, Conjurunup Creek Pipehead, South Dandalup, and South Dandalup Pipehead PDWSAs. The two water supply dams (Serpentine and North Dandalup) release limited flows (<10% of inflow) to maintain downstream beneficial uses. Alcoa has some minor infrastructure located within the South Dandalup PDWSA.

Desalination inputs from the Integrated Water Supply Scheme (IWSS) are released to these reservoirs. These inputs are substantial and are projected to make up an increasing proportion of the source water in the future. The Willowdale mine region intercepts the catchments of the Harvey, Stirling, Logue Brook and Sampson Brook dams (Figure 3.3). Two of these dams, Stirling and Sampson Brook, are used for drinking water purposes and their catchments comprise PDWSAs.

Catchment access is restricted, with permissible activities listed in Source Water Protection plans for each PDWSA. The PDWSAs at Huntly and Willowdale are predominantly managed as Priority 1 with small areas of private land managed as Priority 2. The source water is treated with chlorine, and then transferred to the Integrated Water Supply Scheme (IWSS) for distribution to downstream customers.

2.5.2 Mining

The region is part of an ancient landscape with deeply weathered soils and lateritic profiles, which are ideal for bauxite formation. Mining occurs within the Huntly and Willowdale DEs, specifically for bauxite (noting that copper and gold is mined on the eastern margin of the Darling Plateau at the Boddington Mine).

2.5.3 Agriculture

In addition to mining, the regions also support agricultural activities on the margins of the Darline Plateau. The Mediterranean climate, with hot, dry summers and mild, wet winters, is conducive to livestock farming and crop cultivation.

2.5.4 Timber industry

The landscape features a mix of native bushland, and forested areas, particularly jarrah forests. The Jarrah Forest is an interim Australia bioregion which is divided into two sub-regions, the Northern Jarrah Forest (NJF) and Southern Jarrah Forest (SJF).

The NJF has been subject to widespread timber harvesting since the 1870's. The NJF subregion within ML1SA predominantly comprises juvenile to immature forest structures (assuming maturity as early as 70 years), reflecting the widespread timber harvesting over the last century (Alcoa 2023–2027 MMP).

2.5.5 Parklands and reserves

A review of the Western Australia regional land use mapping ((Landgate, 2024) indicates State Forest is the predominant regional land use within both DEs. Approximately 370 ha of the Huntly DE is within the Serpentine National Park, whilst approximately 80 ha of the Willowdale DE is within Conservation Park.

2.6 Ecology

The Huntly and Willowdale mines are located within the Southwest Botanical Province, within the Jarrah Forest bioregion and Northern Jarrah Forest (NFJ) subregion as described by the Interim Biogeographic Regionalisation of Australia.

The Jarrah Forest is classified as an open forest in its northern extend and as a tall forest in its southern extent. In lower rainfall areas towards the east, trees decrease in size (height), forming woodlands or low forests.

The NJF subregion is broadly characterised by Jarrah Forest on ironstone gravels and Marri-Wandoo woodlands on loamy soils with sclerophyll understory.

3 Existing conditions

This section describes the existing baseline hydrological environment for the Huntly and Willowdale DEs.

3.1 Surface water hydrology

The generalised hydrology of the Huntly and Willowdale DEs have not been assessed previously in detail. Hydrological conditions are assumed to be comparable to previously studies areas of Myara North and Holyoake.

3.1.1 Regional surface water setting

Waterways

The Huntly and Willowdale DEs are located in the catchments of the Serpentine, Murray, and Harvey rivers. These rivers originate within the Darling Plateau, generally between about 250 and 350 m above sea level (asl), and flow westward off the Darling Plateau, through valleys in the Darling Scarp, and onto the Swan Coastal Plain (SCP).

The SCP is made up of deep sediments deposited on the ocean floor or washed down from the Darling Scarp, with sandy dunes to the west and the flat Pinjarra Plain to the east. Land surface of the SCP ranges from sea level up to 50 m near the Darling Scarp, to sea level along the coastal extent.

Wetlands of significance

The Huntly mine is located approximately 30 km east of the Peel-Yalgorup wetland system, a designated *Ramsar* Wetland of International Importance (refer Figure 3.1) which is also mapped under the Directory of Nationally Important Wetlands.

The Serpentine, Murray, and Harvey rivers all wind through the SCP towards the coast and discharge to the Peel-Harvey Estuary, which itself also forms part of the Peel-Yalgorup Ramsar site.

The Serpentine River turns south due to the coastal dunes, before emptying into the Peel Inlet.

The Murray River emerges from the Darling Scarp near Pinjarra and traverses the SCP before emptying into the eastern margin of the Peel Inlet.

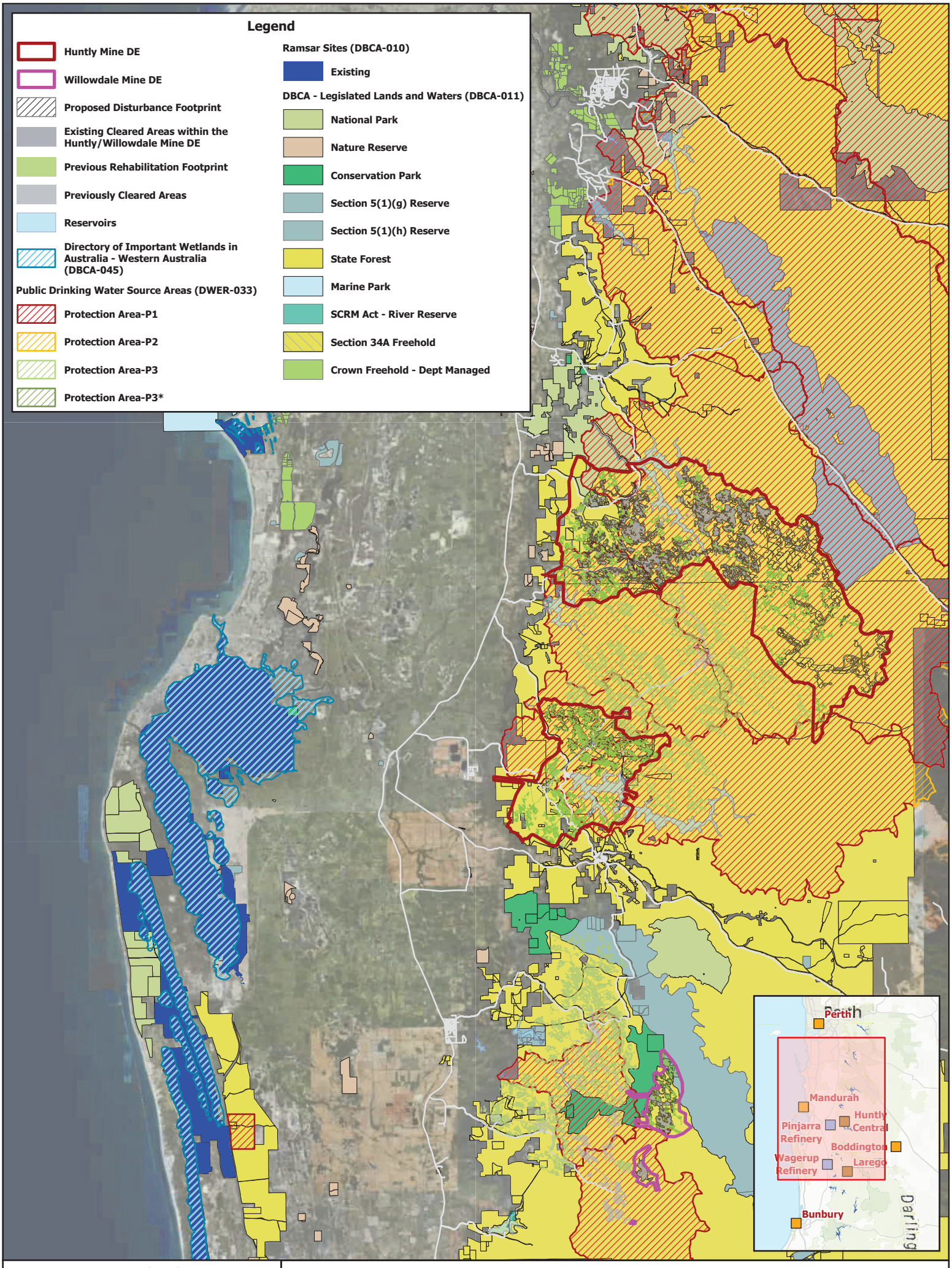
The Harvey River discharges into the extreme southern end of the Harvey Estuary, which in turn feeds into the south-western corner of the Peel Inlet.

The SCP has been heavily developed for urban and agricultural use. Extensive farming on the Pinjarra Plain has led to high nutrient levels and pollution in the Peel-Harvey Estuary. Along with river diversions, farming poses a major threat to the environmental health of the Peel-Yalgorup Ramsar site (Alcoa, 2023).

Sensitive receptors relevant to the identified environmental values (as listed in the ESD) are summarised in the following bullet points; the location of those in the Huntly and Willowdale DE regions are shown on Figure 3.4 and Figure 3.5.

- Rivers, creeks and tributaries including:
  - the Murray, Serpentine, South Dandalup, North Dandalup, Harvey, Harris and Canning rivers
  - Wongong, Gooralong, Big and Drakes brooks, and
  - tributaries of the above.
- Lakes including:
  - Lake Brockman, Lake Navarino, Lake Moyanup, Lake Kabbamup, Yourdamung Lake, Lake Banksiadale, and
  - riparian areas and buffers associated with these lakes.

- Wetlands including:
  - conservation category wetlands
  - resource enhancement wetlands, and
  - valley floors and associated buffers.
- Groundwater and surface water resources (Proclaimed and unclaimed areas) under the *Rights in Water and Irrigation Act 1914.*
- Public Drinking Water Source Areas (PDWSAs), including but not limited to:
  - the Serpentine, Serpentine Pipehead, North Dandalup Pipehead, South Dandalup, Harvey, and Stirling dam catchments
  - the Gooralong Brook, North Dandalup and Pinjarra Water Supply Catchment catchments, and
  - the Murray River Water Reserve.
- Waterbodies providing habitat for threatened, priority or conservation significant aquatic fauna.
- Dams and Reservoirs, including but not limited to:
  - the Harvey, Serpentine, South Dandalup, North Dandalup and Stirling dams, and
  - Other dams/reservoirs sited along major waterways and tributaries of the study area.



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Figure 3-1 Location of the Peel-Yalgorup Ramsar Site

Kilometres
0 5 10 15 20 25

Scale: 1:400,000 at A4

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3.1.2 Local surface water setting

3.1.2.1 Huntly DE

The Huntly mining DE includes areas within the Serpentine Main dam, Serpentine Pipehead dam, North Dandalup dam, South Dandalup dam, and the Conjurunup Creek Pipehead dam catchments; these are shown in Figure 3.2.

In the Serpentine Dam catchment, tributaries generally flow from the southeast, continuing northwest to join the Serpentine River and Big Brook River before reaching the Serpentine Dam. The Serpentine Dam collects water from a 664 km^2 catchment and has a full supply capacity of 137.7 gigalitres (GL). The catchment is proclaimed under the Metropolitan Water Supply Sewerage and Drainage Act 1909 (MWSSD Act) and is primarily classified as a Priority 1 Public Drinking Water Source Areas (PDWSA), albeit with some private lands within the catchment classified as Priority 2. The reservoir is surrounded by a 2 km wide 'reservoir protection zone' (RPZ) around its top water level, which includes the reservoir itself and is contained wholly in the catchment area.

Serpentine Pipehead Dam was constructed to supplement natural flows into Serpentine Dam. Water from this dam is released into the Serpentine Pipehead catchment (which has an area of 28 km^2 and a capacity of 2.6 GL), and then piped to the integrated water supply (Department of Water, 2007).

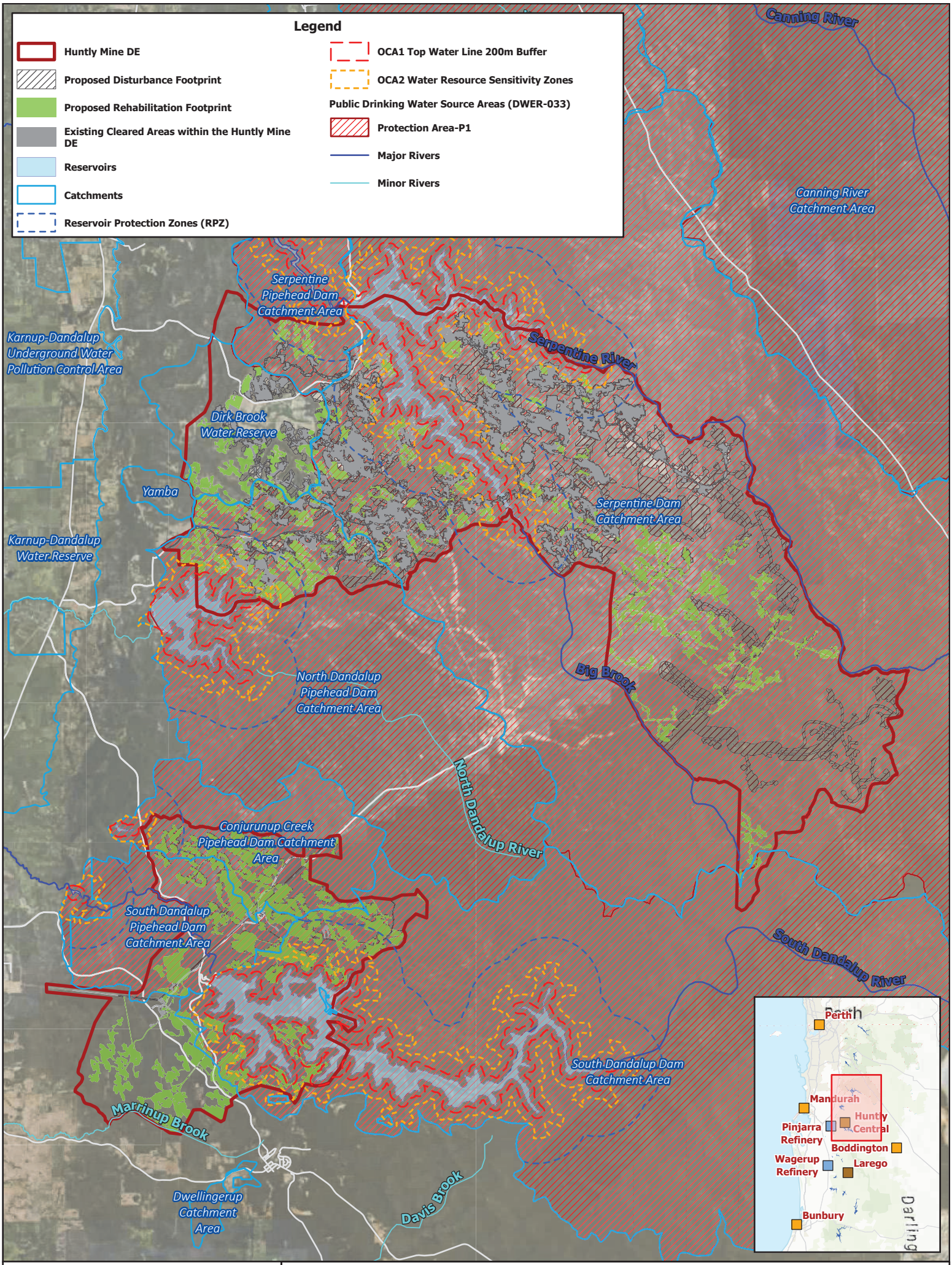
The North Dandalup catchment has a capacity of 75 GL and a surface area of 153 km^2. Between 1912 to 2000, the long-term average volume of water entering the North Dandalup Pipehead Dam was about 28.8 GL per year; however, since 1975 this has decreased to about 18.7 GL per year due to declining inflows attributable to low rainfall (Department of Environment, 2005).

The South Dandalup River and Conjurunup Creek, the two major tributaries of the South Dandalup Dam catchment, flow from east to west and then enter the South Dandalup Dam. This dam has a capacity of 208.2 GL and is the largest reservoir supplying the Integrated Water Supply Scheme (IWSS).

The catchment South Dandalup dams covers 311 km^2 and is proclaimed under the MWSSD Act 1909. Like Serpentine Dam, the catchment is predominantly classified as a priority 1 PDWSA, with a small area of private land managed as a priority 2 PDWSA. It is also connected to the South Dandalup Pipehead Dam, which acts as a pump back for South Dandalup Dam, adding to the available water for supply (Alcoa, 2023).

The Conjurunup Creek catchment and dam are located between the South and North Dandalup catchment areas, covering a total area of 39.2 km^2. From 1948 to 2000, the mean annual streamflow of Conjurunup Creek was 9.5 GL (Department of Environment, 2005); however, since the 1970s there has been a significant reduction in streamflow due to low rainfall, with average annual streamflow only about 7.4 GL between 1975 and 2004.

The Conjurunup Creek dam has a capacity of 190,000 m^3. It has a full supply level of 209 m AHD, with water from the Conjurunup Creek Pipehead Dam pumped to the North Dandalup Pipehead Dam which supplies the IWSS (Department of Environment, 2005).



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Figure 3-2 Huntly Regional Surface Water Setting

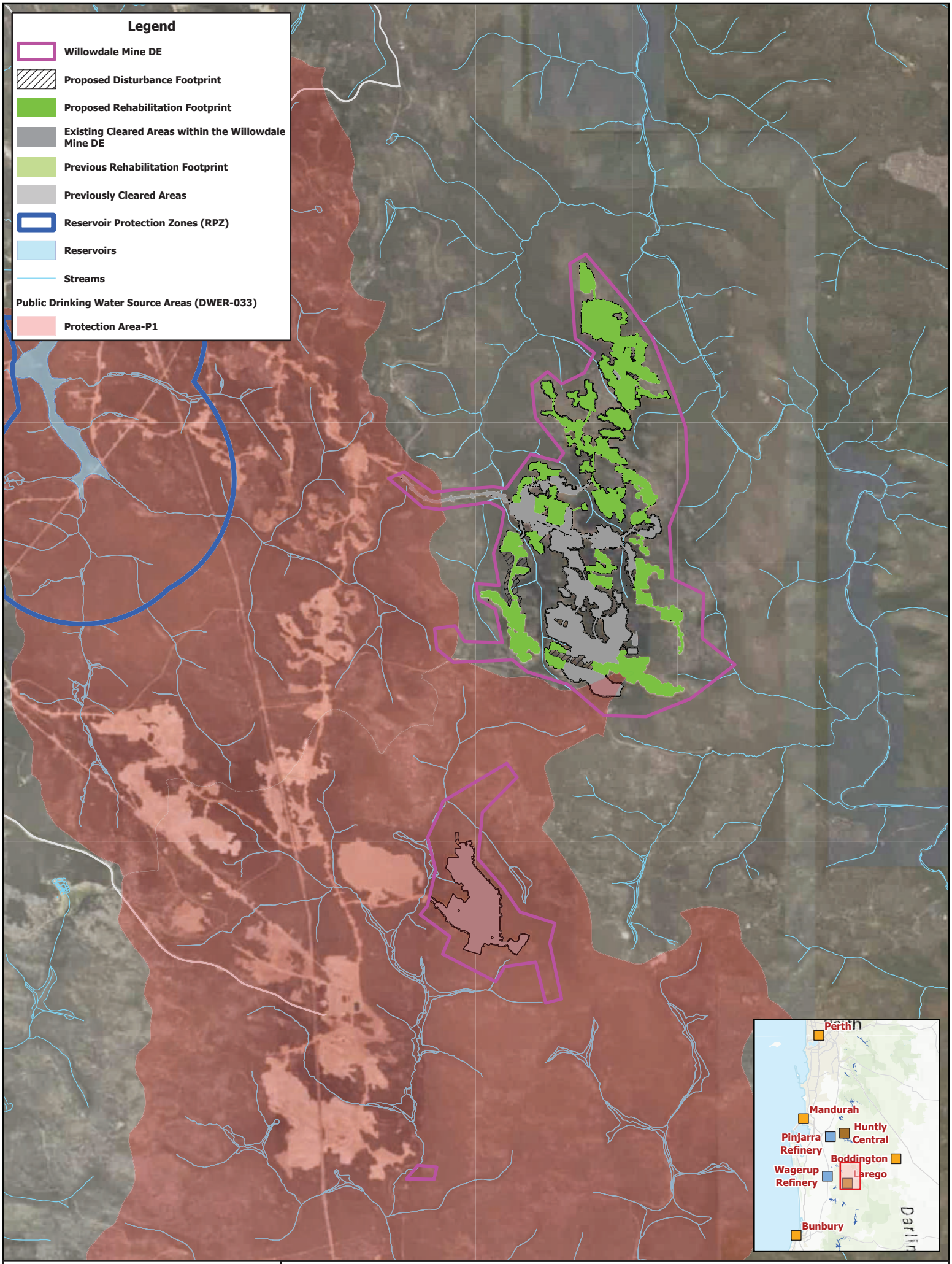
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Date Printed: 22/11/2024

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Figure 3-3 Willowdale Regional Surface Water Setting

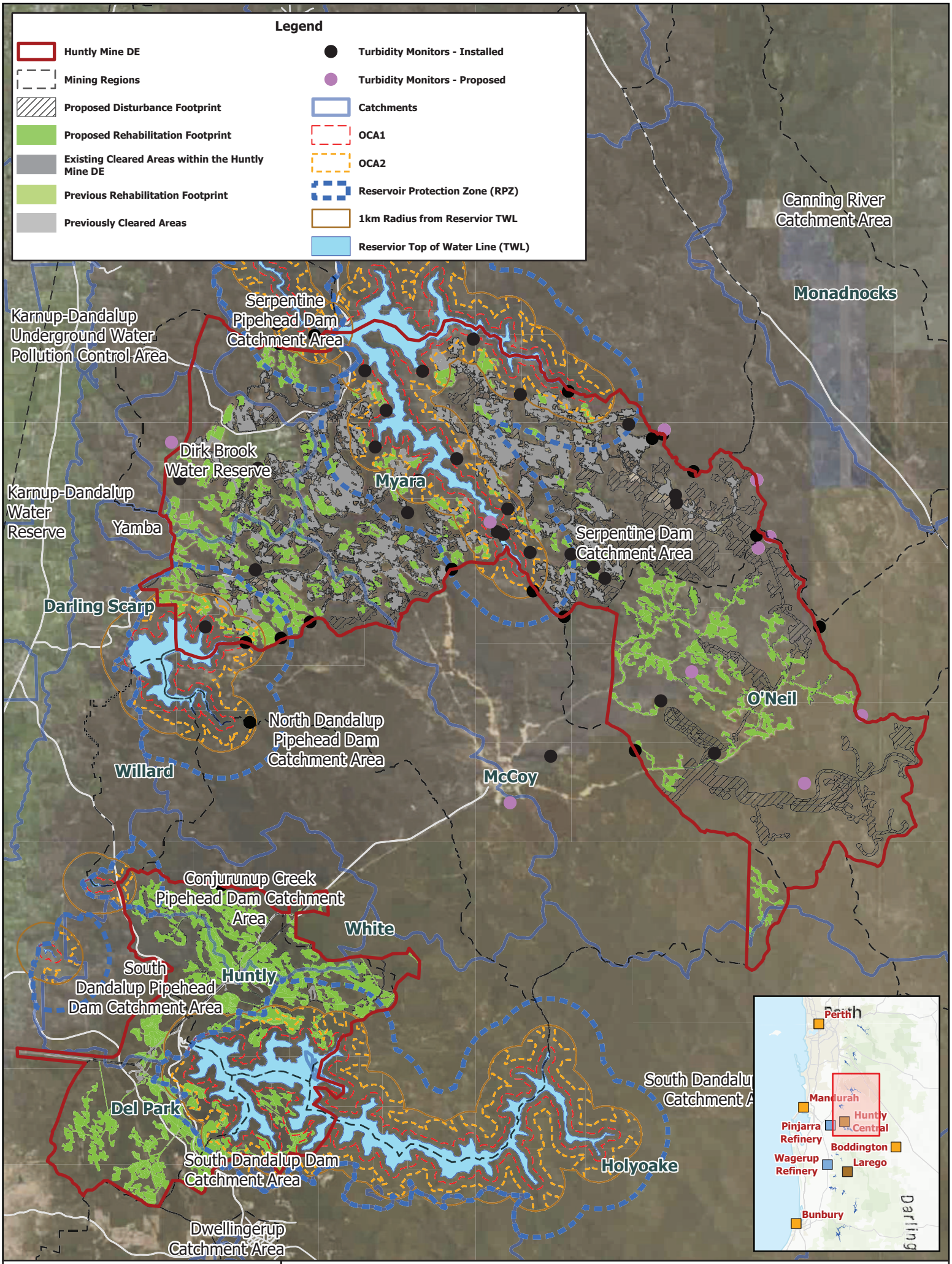
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Scale: 1:75,000 at A4

Date Printed: 22/11/2024

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Alcoa



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Figure 3-4 Huntly Mine Region Local Surface Water Setting

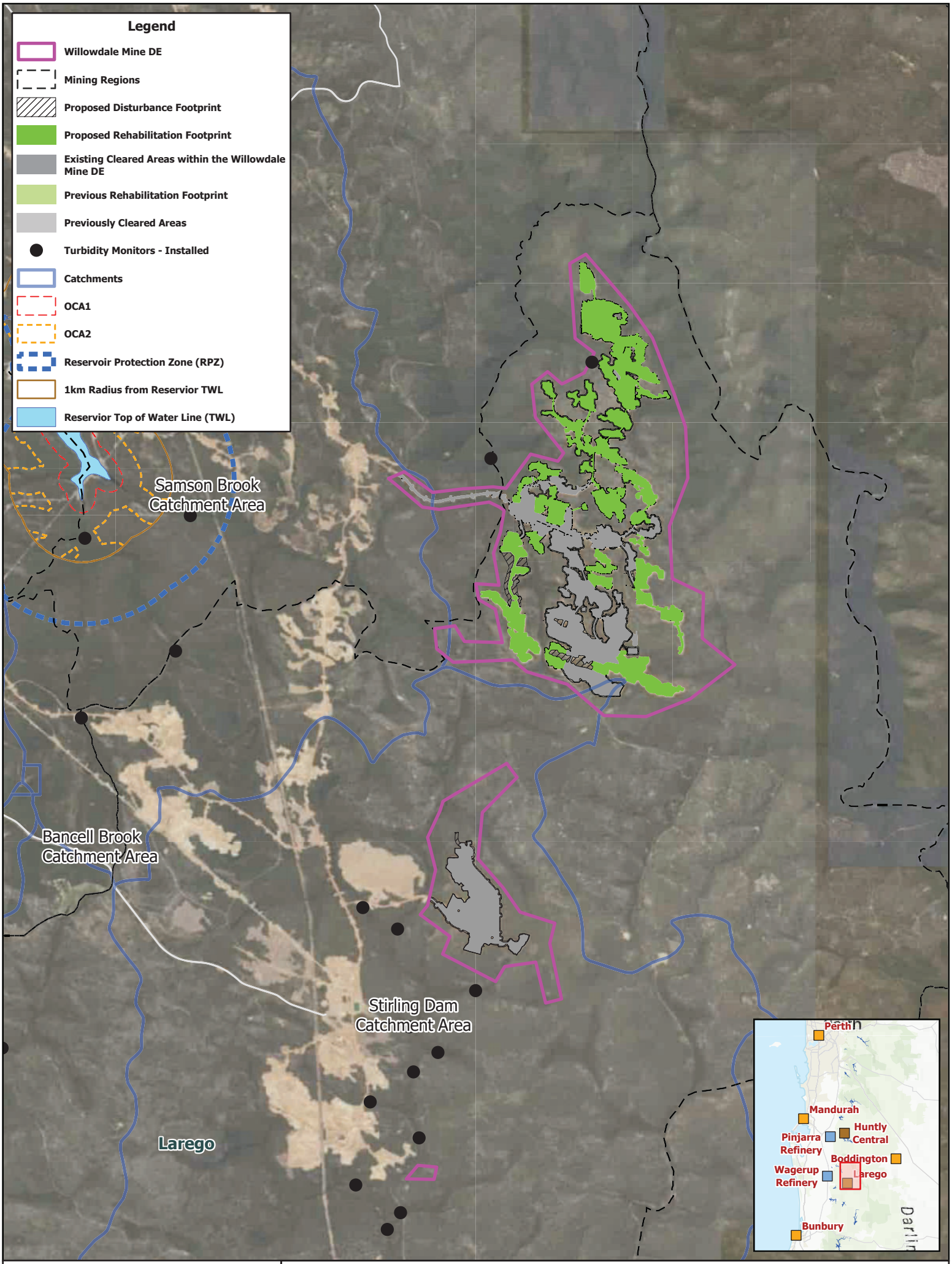
Kilometres
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Scale: 1:175,000 at A4

Date Printed: 18/11/2024

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Alcoa



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Figure 3-5 Willowdale Mine Region Local Surface Water Setting

Kilometres
0 0.5 1 2 3 4 5

Scale: 1:75,000 at A4

Date Printed: 18/11/2024

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Alcoa

3.1.2.2 Willowdale

The Willowdale mining DE extends over the catchments of both the Murray and Harvey rivers. At Willowdale DE, the Murray River flows north-northwest and eventually into the Peel Inlet and stretches 134 km into the Peel Region. It flows approximately 25 km downstream of Pinjarra townsite and discharges into the Peel Inlet, part of the Peel-Yalgorup System Ramsar wetlands.

The Murray River is one of few rivers close to Perth that has no dams used for public water supply, leaving its natural flow intact.

Downstream of the Willowdale DE, the Murray River runs through Lane Poole Reserve, a protected forest area with several recreational facilities enabling camping, swimming and canoeing activities.

The Harvey River catchment intersects with the Willowdale mine regions and is regulated by five dams, two of which (Stirling and Samson Brook) supply the IWSS. The Stirling Dam catchment has an area of 254 km^2 and is primarily classified as a Priority 1 PDWSA. Elevation in the catchment ranges from 80 m AHD at the reservoir to 320 m AHD at the head of the catchment, with water in this reservoir mostly from surface runoff over the winter months. There is though subsurface inflow year-round due to the gravelly nature of the geology in the Darling Range.

3.1.3 Streamflow

The Department of Water and Environmental Regulation (DWER) monitors streamflow and water levels through its network of gauging stations, with continuous data available on Water Information Reporting (DWER, 2024). Table 3.1 provides the location details of three DWER gauging stations relevant to Huntly DE (Figure 3.4). There are two active gauging stations located at Serpentine River and Big Brook, both upstream of the Serpentine Main Dam, another two stations (614007 and 614122) near the South Dandalup Dam, which were decommissioned in 2017.

An active streamflow monitoring station is located upstream of Stirling Dam (613002 at Harvey River, Dingo Road). This station; however, is located 15 km downstream of the Willowdale Mining DE and therefore has not been considered in this document.

Table 3.1 Gauging stations relevant to Huntly DE

Site ID	Site name	Coordinates	Data type	Data temporal range	Status
614035	Serpentine River – River Road	Latitude -32.45° south Longitude 116.24° east	Streamflow	1982 – 1998, and 2008 – present.	Active
			Water level	1982 – 1999, and 2008 – present.	Active
614037	Big Brook – Oneil Road	Latitude -32.51° south Longitude 116.19° east	Streamflow	1983 – present.	Active
			Water level	1983 – present.	Active
614007	South Dandalup Trib – Del Park	Latitude -32.67° south Longitude 116.04° east	Streamflow	1974 – 2017.	Inactive
			Water level	1974 – 2017.	Inactive
614122	Conjurunup Creek – Conjurunup	Latitude -32.59° south Longitude 116.02° east	Streamflow	2008 – 2018.	Inactive
			Water level	2008 – 2018.	Inactive

Figure 3.6 and Figure 3.7 show the long-term streamflow seasonality Serpentine River and Big Brook, respectively. Each 'box whisker' represents the maximum (top blue line), 75th percentile (top of solid blue bar), mean (grey line), 25th percentile (bottom of solid blue bar) and minimum (bottom blue line) for each month. The long-term values are calculated using the entire record of monthly mean data for that month. The observed data indicates streamflow is seasonal, with higher variability during the winter months. The stream is generally dry during the summer and autumn months.

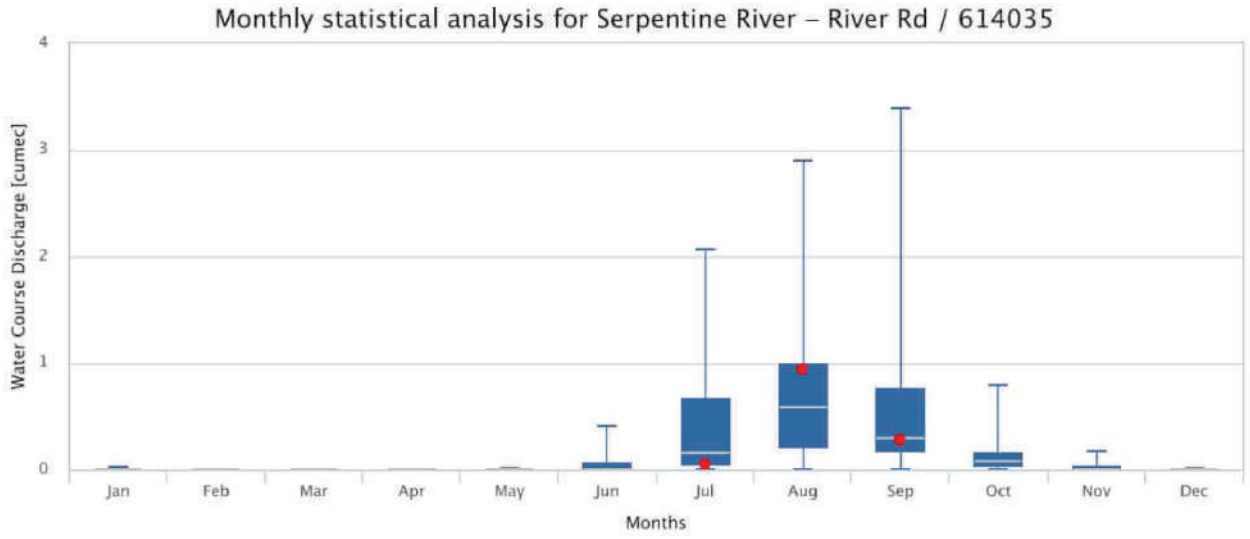


Figure 3.6 Long-term (1982-1998, 2008-September 2024) flow seasonality at Serpentine River (614035) over monthly average streamflow for 2022 (red dot)

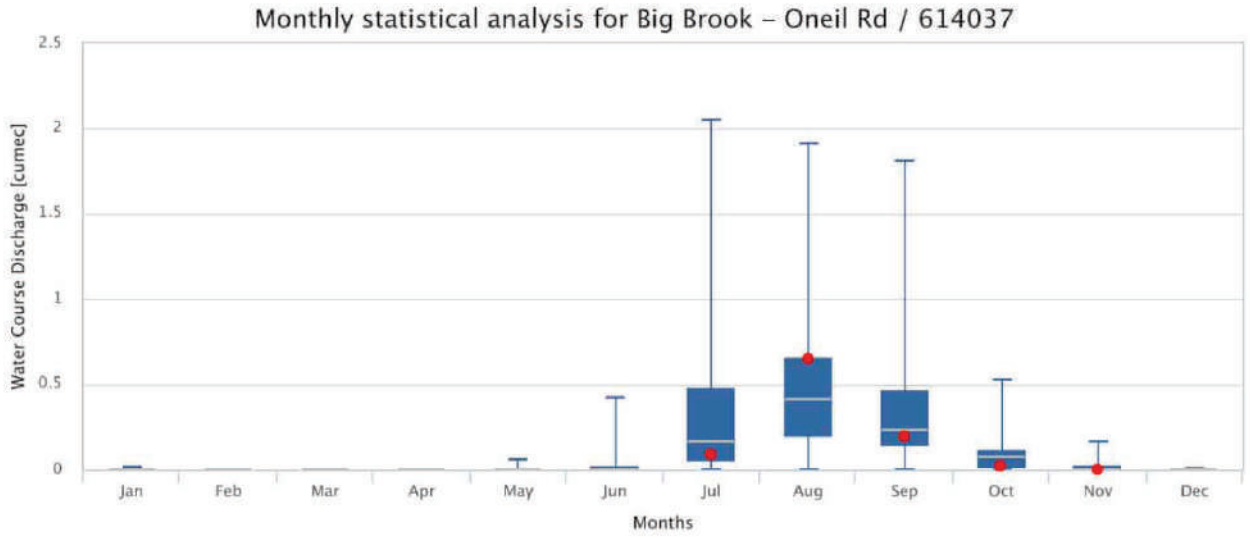


Figure 3.7 Long-term (1983- September 2024) flow seasonality at Big Brook (614037) over the monthly average streamflow for 2022 (red dot)

Figure 3.8 illustrates the long-term seasonality of streamflow at the South Dandalup Tributary (614007). The data indicates streamflow is seasonal, with greater variability during the winter months. The range of flow, however, remains relatively small, with the highest recorded streamflow being less than 0.05 cubic metres per second (m^3/s) in winter.

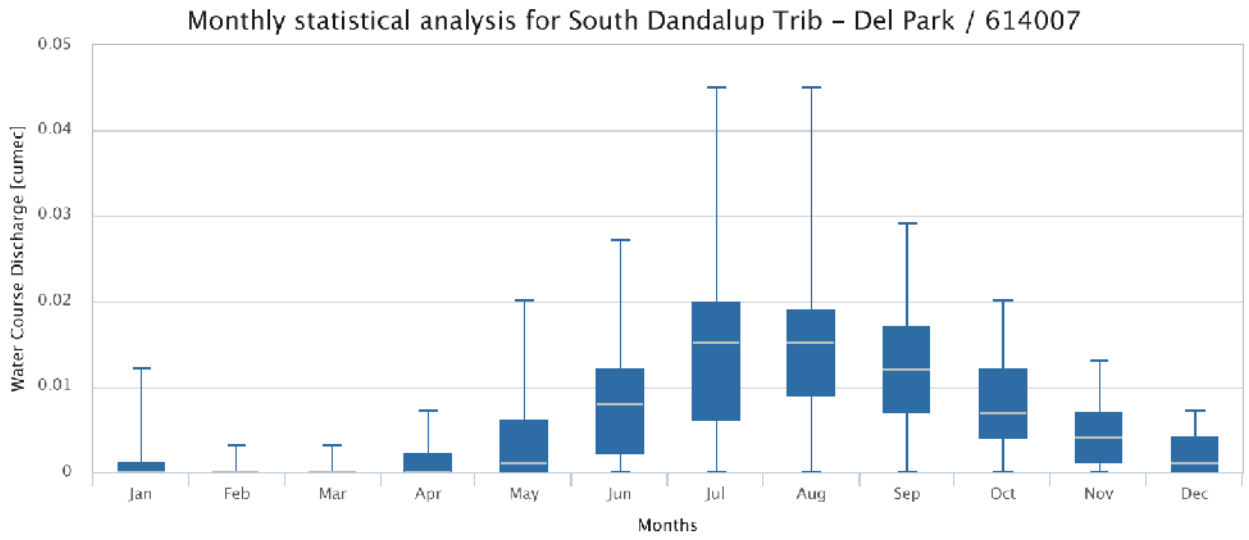
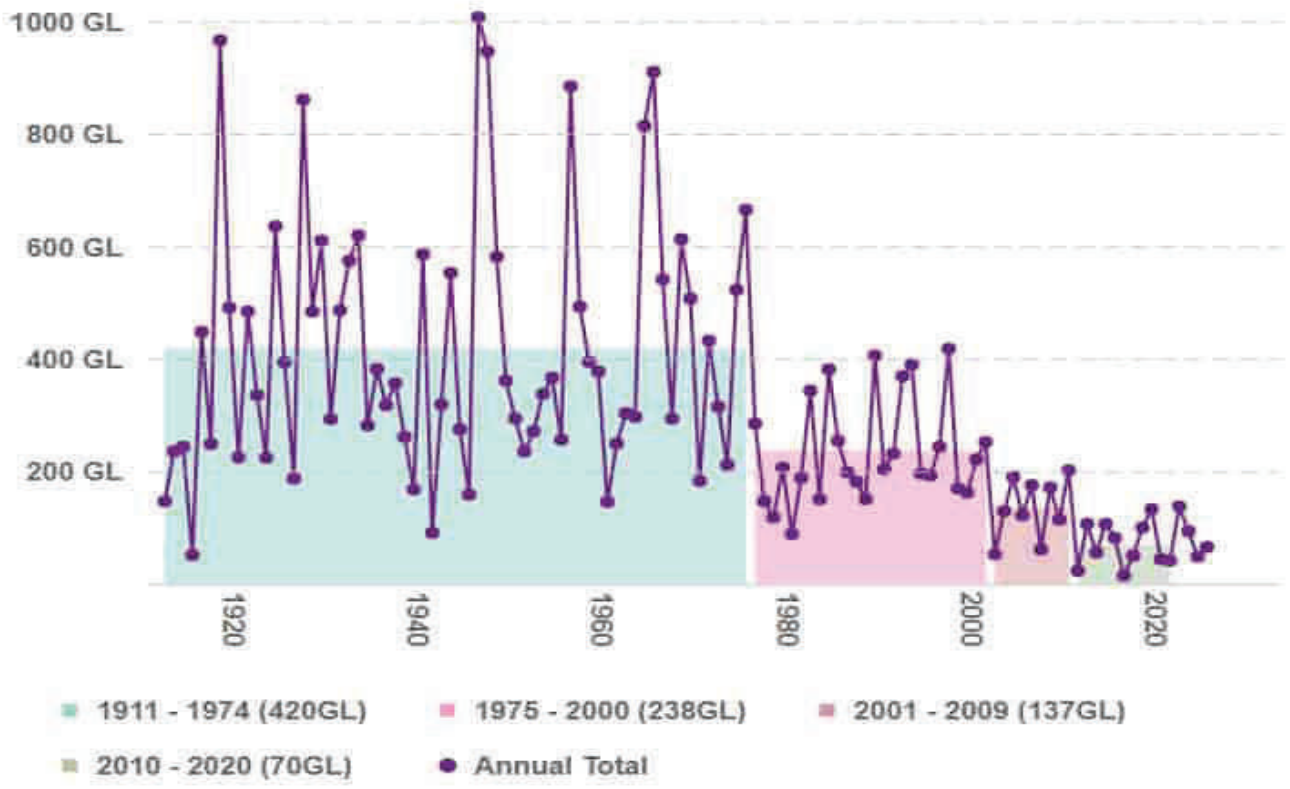


Figure 3.8 Long-term (1974–2017) flow seasonality at South Dandalup Tributary (614037)

Figure 3.9 illustrates the total annual streamflow for all dams supplying the Integrated Water Supply Scheme (IWSS). This figure indicates a significant reduction in streamflow has occurred since the development IWSS, the latest being average streamflow decreasing from 137 GL in 2009 to about 70 GL in 2020.

DWER (2017) studied the effect of rainfall on runoff by adopting the CSIRO's future climate projections ('wet', 'median', and 'dry') for 2008 to 2030. These projections utilise 45 international climate models to estimate future dam inflows. The study outcome indicates that the annual average streamflow into the Serpentine Main Dam has been declining since 1960 and is forecasted to decline further by 2030 due to projected future climate scenarios.

Despite reviewing all available data and outcomes of study, the absence of long-term historical streamflow data and spatial gaps presents significant challenges, making it difficult to identify trends or long-term changes in streamflow.



Note that the streamflow is recorded for the water year (May to April)

(Water Corporation, 2024).

Figure 3.9 Historical annual streamflow of all dams supplying the Integrated Water Supply Scheme (IWSS)

3.1.4 Surface water quality and geochemistry

This section reviews:

- available historical surface water quality and geochemistry data from DWER
- outcomes of surface water quality monitoring at Huntly Mine, within the Myara North and Holyoake mine region, which may be representative of hydrological and hydrogeological conditions at the Huntly DE, due to its adjacent location
- those summaries of surface water quality assessments conducted by Alcoa at the relevant dams within the mining DEs, and
- those summaries of previous surface water quality assessments conducted by the Government of Western Australia at the relevant dams within the mining DEs.

When considering the information presented in the following subsections, it should be noted there is often insufficient continuous surface water quality monitoring or sampling by DWER and Alcoa in those streams and tributaries within the Huntly and Willowdale DE.

3.1.4.1 Salinity

DWER monitors salinity and water temperature at several locations within the Huntly DE. Data ranges for Big Brook and South Dandalup tributary monitoring stations are presented in Table 3.2.

There are no DWER water quality monitoring stations within the Willowdale DE. It is noted, however, that whilst the upper reaches of the Harvy River flow adjacent to Keats and Wills mine regions of Willowdale DE, there are no major tributaries mapped, and the number of suitable water quality sampling locations from within the DE remains uncertain. This is recognised as a data gap.

Table 3.2 Surface water quality monitoring stations relevant to Huntly DE

Site ID	Site name	Coordinates	Data type	Data temporal range	Status
614037	Big Brook – Oneil Road	Latitude -32.51° south Longitude 116.19° east	Temperature	1995 – present	Active
			Electrical conductivity	1995 – present	Active
614007	South Dandalup Trib – Del Park	Latitude -32.67° south Longitude 116.04° east	Temperature	2001 – 2009	Inactive
			Electrical conductivity	2001 – 2009	Inactive

The long-term salinity trend at Big Brook is shown in Figure 3.10. Historical data indicates that the surface water is generally fresh, with a long-term average electrical conductivity (EC) typically below 350 microSiemens per centimetre (µS/cm).

Salinity levels are higher and more variable during winter and spring months. In October 2022, salinity at Big Brook was recorded at approximately 500 µS/cm, likely due to low streamflow (refer to Figure 3.7). Additionally, elevated salinity may be attributed to increased groundwater discharge during these months due to seasonally high groundwater fluctuations whereas during the summer autumn months the salinity record is more reflective of episodic rainfall runoff only.

Figure 3.11 presents the long-term salinity trend in the South Dandalup Tributary. This data indicates surface water is generally fresh with a long-term average salinities less than 300 µS/cm. There is less variability in salinity from August to January, as shown by the smaller 25th to 75th percentiles, however, the cessation of salinity data monitoring after 2009 has created a data gap. The salinity trends observed may indicate streamflow (at the monitored location) has a greater reliance on groundwater on baseflow throughout the year, compared to monitoring data from Big Brook.

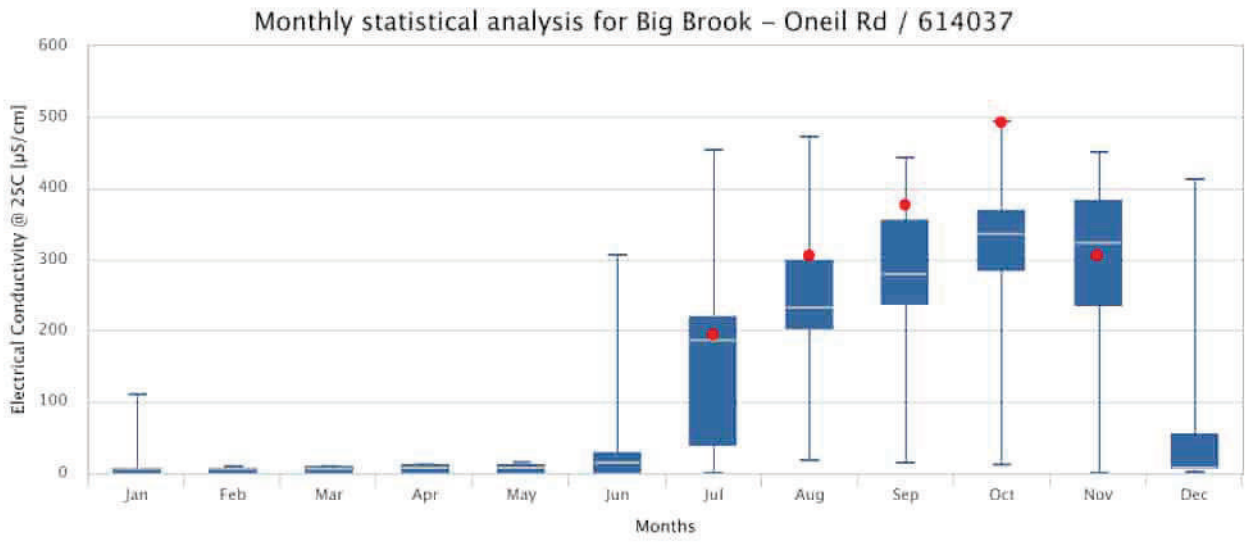


Figure 3.10 Long-term salinity trend at Big Brook (614037) over the monthly average salinity for 2022 (red dot)

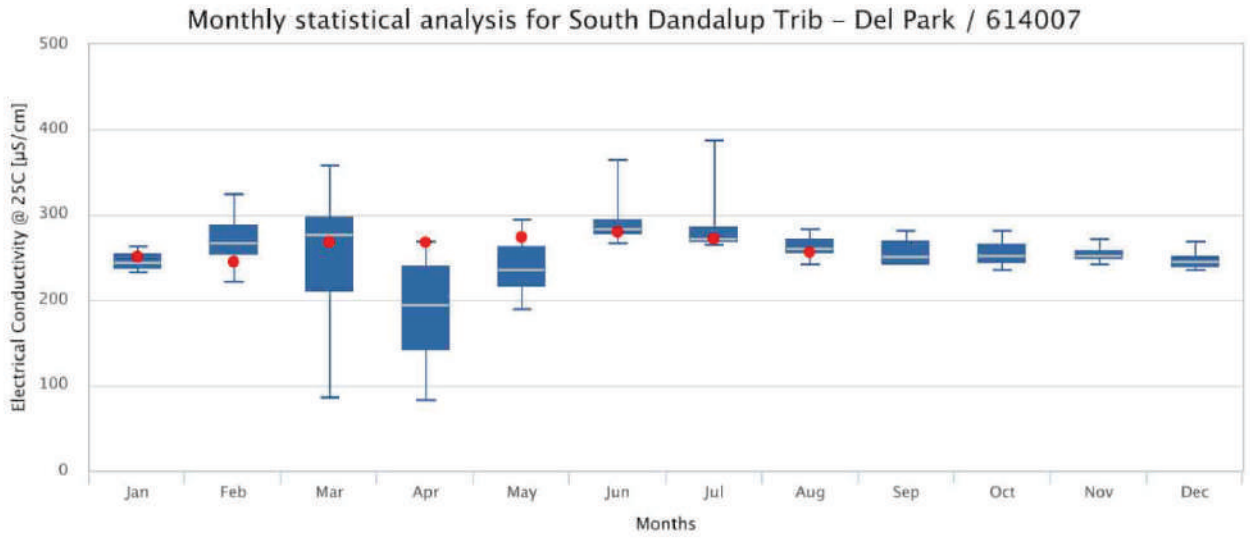


Figure 3.11 Long-term salinity trend at South Dandalup Tributary (614007) over the monthly average salinity for 2009 (red dot)

GHD (2022) reported that salinity levels measured at Huntly Mine within the Myara North mine region typically ranged from 174 to 587 µS/cm. It also noted salinity measurements in the Holyoake mine region varied between 109 and 368 µS/cm, indicating the presence of fresh water between August 2020 and January 2021.

3.1.4.2 Turbidity

As there is no continuous turbidity data available on the DWER Water Information Reporting, a summary of the previous turbidity data monitoring outcomes (GHD, 2022) is presented in this section.

Adjacent to Huntly DE, surface water sampling events were conducted monthly between August 2020 and January 2021 within the Huntly mine regions Myara North and Holyoake by GHD (2022). Overall, surface water is relatively clear across all sites, with turbidity up to 10 nephelometric turbidity units (NTU) reported in the Myara North, and turbidity of up to 40 NTU at Holyoake mine region.

Figure 3.12 compares turbidity data from an instream logger (identified as SW08) installed in the Serpentine River (614035) (GHD, 2022). The logger was installed at the main branch of the Serpentine River downstream of the Huntly Mining DE, upstream of Serpentine Main Dam. Turbidity data from this instrument indicates that the surface water was relatively clear during the monitoring period between 1982 and 1998, with average turbidity below 20 NTU.

Turbidity measurements recorded at SW08 in 2020 also remained below this limit. The data presented highlights that turbidity values are comparable along the Serpentine River, at the monitored locations.

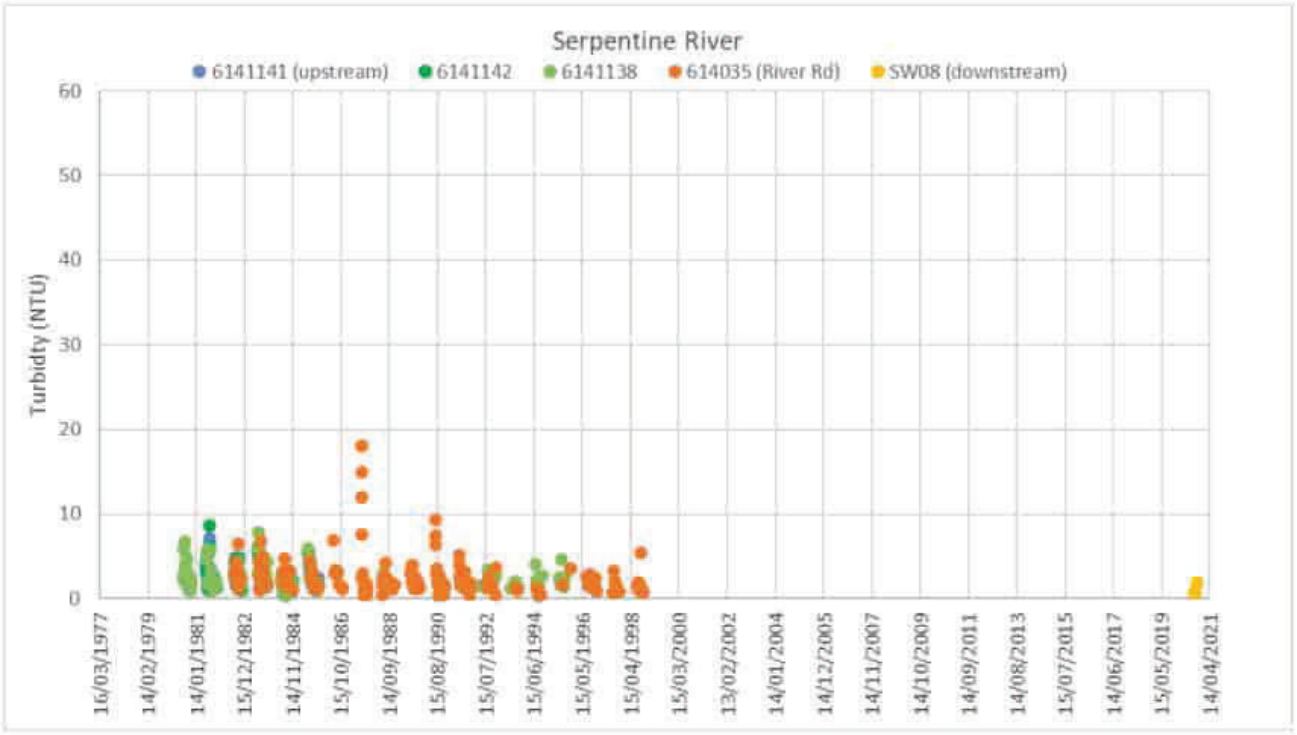


Figure 3.12 Comparison of long-term turbidity at Serpentine River (614035) to turbidity data recorded at SW08 (GHD, 2022)

For both Huntly and Willowdale DE, continuous turbidity data has recently been collated across the Huntly and Willowdale mines (Rare Environment, 2024) by Alcoa using its Water Quality Monitoring Systems (WQMSs). Under Schedule 1, Division 2 ("Controls on activities") of the Environmental Protection (Darling Range Bauxite Mining Proposals) Exemption Order 2023, a drainage incident is defined as 'runoff from a disturbance area to the surrounding environment of surface water that has a turbidity of at least 25 NTU for a period of at least 1 hour'. In line with this definition:

- a 'true' stream turbidity exceedance event is that is caused by an actual increase in stream water turbidity, whilst
- a 'false' stream turbidity exceedance event is that caused by factors other than an actual increase in stream water turbidity (i.e., organic debris covering the monitor such as sticks, leaves, algae, stream water turbulence or air bubbles and fluctuating water levels that intermittently cover the monitor lens and then recede) (Rare Environment, 2024).

For the Huntly DE, a total of 10 potential drainage or 'true' incidents were identified from that data collected during May 2024, with subsequent investigations indicating these events were not mining related ((Rare Environment, 2024). For June 2024, 38 potential turbidity events identified, but again no evidence of mining contribution was found (Rare Environment, 2024).

For Willowdale DE, a total of three events were flagged in May 2024 where turbidity levels above 25 NTU occurred for an hour or more. In June 2024, one potential turbidity event during the reporting period for further investigation, with the outcome of this suggesting this incident was not mining related (Rare Environment, 2024).

3.1.4.3 Metals

Dissolved metal concentrations have been measured in the Myara North and the Holyoake mine region surface water sampling events between August 2020 to January 2021 (GHD, 2022).

For both regions, concentrations of arsenic, beryllium, boron, cadmium, chromium, mercury, selenium, and vanadium were below the lower order of analytical reporting (LOR) for all samples.

When detected, concentrations of other heavy metals were below drinking water guidelines. There were though a few occasional exceedances of the ANZG 95% and 99% freshwater species protection assessment criteria for zinc.

No other exceedances of the ANZG 95% or 99% freshwater species protection criteria were reported.

Overall, the surface water metal concentrations are typical of 'natural' conditions and representative of the geological setting (GHD, 2022).

3.1.4.4 Nutrients

For Myara North and Holyoake mine regions, nutrient concentrations are typically low and consistent with the land use (i.e., predominantly forested catchments with little to no notable nutrient sources). At most sample sites nutrient concentrations reported less than the LOR or below available criteria, with sampling and analysis indicating the following.

- All samples for nitrite (reported as nitrogen) and filterable reactive phosphorus returned concentrations of less than their respective LORs (GHD, 2022).
- Concentrations of total oxidised nitrogen and total nitrogen were detected at one location.
- Four samples reported total phosphorus concentrations marginally more than the ANZECC upland rivers default trigger value.
- Several samples reported marginally elevated total nitrogen and total Kjeldahl nitrogen levels above the ANZECC South-western Australia default guideline values.

3.1.4.5 Microbiological contaminants

Escherichia coli (E. coli) and enterococci are used as the primary indicator of faecal contamination of drinking-water supplies (NHMRC & NRMMC, 2011). The Australian Drinking Water Guidelines (ADWG) suggest E. coli and enterococci should not be detected in any 100 mL sample of drinking water, whilst the World Health Organization (WHO) notes a zero count of E. coli per 100 mL of water is considered safe for drinking. Conversely, (Odonkor & Mahami, 2020) note a count of 1 to 10 MPN[2]/100 mL is regarded as low risk for drinking water supplies, whilst a count of 11 to 100 MPN/100 mL is medium risk.

In the Myara North and Holyoake mine regions, microbiological parameters such as enterococci and E. coli were detected at all sampling sites; this is consistent with the presence of fauna species within the land use setting. E. coli concentrations ranged from less than 1 organism/100mL to 200 organisms/100mL, while enterococci concentrations ranged from less than 1 organism/100mL to 90 organisms/100mL (GHD, 2022).

Furthermore, the Government of Western Australia has conducted testing on raw water at the adjacent dams within the mining DE, including Serpentine Main, North Dandalup, South Dandalup, and Conjurunup Creek Pipehead dams. A summary of the test results is presented in the following bullet points.

- For the Serpentine Main Dam, water was tested on a weekly to monthly basis between January 2000 to March 2006. Analysis showed that positive E. coli counts were recorded in 40% of samples, with 1% of these samples having concentrations exceeding 20 CFU[3]/100 mL (Department of Water, 2007).
- For North Dandalup Dam, samples were collected and analysed between November 2013 and October 2018. Positive E. coli counts were recorded in 22 % of samples, although no sample had E. coli counts greater than 20 MPN/100mL (Department of Water and Environmental Regulation, 2019).
- For South Dandalup Dam, testing was carried out between July 1999 and July 2004. Positive E. coli counts were recorded in 34% of samples, with 7% exceeding 20 CFU/100 mL (Department of Environment, 2005).

[2] Most probable number (from laboratory analysis of water samples).

[3] Colony-forming units, with a colony-forming unit being where a colony of microbes grow on a petri dish from one single microbe.

- For the Conjurunup Creek Pipehead Dam, positive thermotolerant coliform counts were recorded in 90% of samples between July 1999 to July 2004, with 44% of samples exceeding 20 CFU/100mL (Department of Environment, 2005).

3.1.4.6 Other potential contaminants

Other potential surface water contaminants at the Myara North and Holyoake mine regions were assessed by GHD. A summary of this assessment follows.

- All samples analysed for the following volatile and semi-volatile organic compounds returned results below laboratory LORs:
  - BTEX compounds, namely benzene, toluene, ethylbenzene and toluene
  - total recoverable hydrocarbons compounds[4], and
  - explosives.
- Per- and polyfluoroalkyl substances (PFAS) compounds were below the LOR in all but nine locations, with all detections below the drinking water assessment criteria.
- Samples analysed for pesticides were below the LOR in all but one location; dieldrin (an organochlorine pesticide which has a low solubility and therefore is persistent in the environment) was detected in one sample at a concentration less than the drinking water assessment criteria.
- Samples analysed for polycyclic aromatic hydrocarbons (PAHs) were below the LOR in all but one location.

  In that sample in which PAH was detected, the sum of PAHs exceeded the drinking water guideline of 0.01 µg/L, with a concentration of 0.039 µg/L, with this predominantly comprised of naphthalene. This sample was collected from a catchment in which a controlled burn was carried out in late September 2020, and the PAH detection thought to be related to the presence of residual ash in soil and surface water; wildfire is a natural source of PAHs, with studies noting that burned soil and wildfire ash report concentrations of PAHs, particularly naphthalene (Choi, 2014). Field notes describing observations of the Environmental Scientist who collected this sample indicated the surrounding forest was still smoking at the time of sampling, with a smell of recent fire.

3.1.4.7 Other aesthetic and health related water quality data

In addition to microbial data, the Government of Western Australia assessed health-related and aesthetic water quality for the Serpentine, North Dandalup, South Dandalup, Conjurunup Creek Pipehead, and Stirling dams.

Aesthetic water quality analyses for raw water from Serpentine Main Dam are summarised in Table 3.3, these are based on water quality monitoring carried out between January 2000 and February 2006. While there have been occasional exceedances of aesthetic water quality guidelines, the median values for all parameters over the six-year sampling period fall within the ADWG guideline values (Department of Water, 2007).

[4] Total recoverable hydrocarbons analysis is a nonspecific quantitative screening tool used to determine the quantity of organic compounds in a water sample, including petroleum hydrocarbons, and is limited to those organic compounds that can be extracted by solvent (dichloromethane) and detected by GC-FID (gas chromatography-flame ionisation detector).

Table 3.3 Aesthetic water quality measured for period January 2000 to February 2006 at Serpentine Main Dam (Department of Water, 2007)

Parameter	Units	Aesthetic Guideline Value	Serpentine Main Dam			
			Range			Median
Turbidity	NTU	5	0.4	-	14	0.9
Colour	HU	15	2	-	9	3
Conductivity	mS/m	-	25	-	36	32
Iron (unfiltered)	mg/L	0.3	0.05	-	0.46	0.15
Manganese (unfiltered)	mg/L	0.1	0.002	-	0.22	0.026
Aluminium	mg/L	0.2	<0.008	-	0.14	0.038
Sodium	mg/L	180	35	-	51	44
Potassium	mg/L	-	0.8	-	2.2	1.6
Calcium	mg/L	-	2.4	-	4	3.2
Magnesium	mg/L	-	4.4	-	7	5.5
Alkalinity (as HCO_3^-)	mg/L	-	8.1	-	18.6	13.5
Chloride	mg/L	250	62	-	84	76
Sulphate	mg/L	250	8.5	-	13	10
Silicate (as SiO_2)	mg/L		<2.2	-	3.8	3.1
Filterable Organic Carbon	mg/L	-	2	-	3.8	2.4
Hardness (as $CaCO_3$)	mg/L	200	24	-	39	31
pH		6.5 - 8.5	6.3	-	7.58	7.23

Health-related water quality parameters measured at the source between May 2000 and February 2006 are summarised in Table 3.4. There have been no recorded exceedances of health-related guidelines.

Table 3.4 Health related water quality parameters measured for period May 2000 to February 2006 at Serpentine Main Dam (Department of Water, 2007).

Parameter	Units	Health guideline value†	Serpentine Main Dam	
			Range	Median
Sulfate	mg/L	500	8.5 – 13.0	10.0
Manganese	mg/L	0.5	0.002 – 0.220	0.026
Nitrate + nitrite as nitrogen	mg/L	11.3	0.011 – 0.190	0.04

Note: † A health guideline valie is the concentration or measure of a water quality characteristic that, based on present knowledge, does not result in any significant risk to health of the consumer over a lifetime of consumption *NHMRC & ARMCANZ, 2004).

For the North Dandalup Dam, raw water was analysed for aesthetic water quality and health-related chemicals between November 2013 to October 2018. Aesthetic water quality analyses are summarized in Table 3.5, while health-related water quality parameters detected in the source are summarised in Table 3.6. These health-related chemicals include inorganics, heavy metals, industrial hydrocarbons, and pesticides.

While there have been occasional exceedances of aesthetic water quality guidelines, the median values for all parameters over the five-year sampling period are within the ADWG guideline values (Department of Water and Environmental Regulation, 2019).

Table 3.5 Aesthetic water quality measured for period November 2013 to October 2018 at North Dandalup Dam (Department of Water and Environmental Regulation, 2019)

Parameter	Units	ADWG aesthetic guideline value[1]	North Dandalup Dam	
			Range	Mean
Chloride	mg/L	250	31–80	66.5
Colour (true)	TCU	15	<1–7	1.5
Hardness as $CaCO_3$	mg/L	200	30–56	40.7
Iron unfiltered	mg/L	0.3	0.008–0.180	0.042
Manganese unfiltered	mg/L	0.1	<0.002–0.012	0.005
Silicon as SiO_2	mg/L	80	0.7–3.3	1.8
Sodium	mg/L	180	19–43	34.5
Total filterable solids by summation	mg/L	500	114–173	159
Turbidity	NTU	5	<1.0–***9.2***	1.5
pH measured in laboratory	no units	6.5–8.5	6.75–***8.92***	7.59

[1] An aesthetic guideline value is the concentration or measure of a water quality characteristic that is associated with good quality water

Table 3.6 Health-related water quality measured for period November 2013 to October 2018 at North Dandalup Dam

Parameter	Units	ADWG health guideline value[2]	North Dandalup Dam	
			Range	Mean
Barium	mg/L	0.7	0.0018–0.016	0.0013
Boron	mg/L	4	0.03–0.70	0.199
Manganese unfiltered	mg/L	0.5	<0.002–0.012	0.005
Sulfate	mg/L	500	1.5–12	7.6
Fluoride laboratory measurement	mg/L	1.5	0.20–0.85	0.46
Iodide	mg/L	0.5	0.05–0.05[3]	0.05

[2] A health guideline value is the concentration or measure of a water quality characteristic that, based on present knowledge, does not result in any significant risk to the health of the consumer over a lifetime of consumption (NHMRC & NRMMC 2011)

[3] This result corresponds to the one sample taken during the reporting period

For the South Dandalup Dam and South Dandalup Pipehead Dam, raw water quality was monitored between July 1999 to July 2004. Aesthetic quality analyses for raw water are summarised in Table 3.5. Although occasional exceedances of aesthetic water quality guidelines were observed, median values for all parameters were within the ADWG guideline values (Department of Environment, 2005), except for aluminium. Note that, in the absence of specific guidelines for raw-water quality, all results have been compared with the ADWG values set for drinking water, which define the quality requirements at the customer's tap. However, the raw-water data presented does not represent the quality of drinking water distributed to the public.

Table 3.7 Aesthetic water quality measured for period July 1999 to July 2004 at South Dandalup Dam and South Dandalup Pipehead Dam

Parameter	Units	Aesthetic Guideline Value	South Dandalup Dam	South Dandalup Pipehead Dam
			Min-Max Median	Min-Max Median
pH		6.5 – 8.5	7.01 – 7.56 7.27	6.44 – 7.22 6.87
Turbidity	NTU	5	0 – 10 1.2	0.6 – 274 6.6
Colour	TCU	15	2 – 8 3	5 – 80 10
Conductivity	mS/m	-	23 – 42 29	18 – 38 26
Total Dissolved Solids	mg/L	500	124 – 185 143	130 – 210 158
Iron (unfiltered)	mg/L	0.3	0.04 – 0.95 0.09	0.152 – 5 0.825
Manganese (unfiltered)	mg/L	0.1	0.002 – 0.026 0.007	0.012 – 0.4 0.048
Aluminium (unfiltered)	mg/L	0.2	0.01 – 0.24 0.026	0.022 – 2.6 0.34
Sodium	mg/L	180	32 – 44 37	30 – 52 42
Potassium	mg/L	-	0.95 – 2 1.4	0.65 – 2 1.2
Calcium	mg/L	-	2.4 – 4 3.2	2 – 4.8 3
Magnesium	mg/L	-	4 – 6 4.8	4 – 7.5 5
Hardness (as $CaCO_3$)	mg/L	200	23 – 33 28	20 – 43 29
Alkalinity (as HCO_3)	mg/L	-	8.3 – 16.3 12.4	7 – 25 12
Chloride	mg/L	250	53 – 104 66	54 – 96 75
Sulphate	mg/L	250	6.5 – 15 10	6 – 14 7
Silica (as SiO_2)	mg/L	-	2.2 – 3.5 2.7	4.7 – 9 8.1
Filterable organic carbon	mg/L	-	2.2 – 5.2 3.2	1.2 – 5.6 8.1

Source: Department of Environment (2005)

Health-related water quality parameters measured at detectable levels at South Dandalup Dam and South Dandalup Pipehead Dam between July 1999 and July 2004 are summarised in Table 3.8. These parameters include barium, boron, fluoride and iodide, noting there have been no recorded exceedances of health-related guidelines.

Table 3.8 Health-related water quality measured for period July 1999 to July 2004 at South Dandalup Dam and South Dandalup Pipehead Dam

Parameter	Units	Health Guideline Value*	South Dandalup Dam	South Dandalup Pipehead Dam
			Min-Max Median	Min-Max Median
Barium	mg/L	0.7	0.0095 – 0.014 0.012	0.019†
Boron	mg/L	4	0.02 – 0.03 0.029	Not Detected
Fluoride	mg/L	1.5	<0.1 – 0.65 <0.1	<0.1 – 0.15 <0.1
Iodide	mg/L	0.1	0.08†	Not Detected

* A health guideline value is the concentration or measure of a water quality characteristic that, based on present knowledge, does not result in any significant risk to the health of the consumer over a lifetime of consumption (NHMRC & ARMCANZ, 1996).

† Single detection only.

Source: Department of Environment (2005)

Aesthetic water quality analyses for raw water samples collected from the Conjurunup Creek Pipehead Dam between July 1999 and July 2004 are summarised in Table 3.9 and have been compared with the ADWG values set for drinking water. While there have been occasional exceedances of aesthetic water quality guidelines, the median values for all parameters over the entire sampling period fall within the ADWG guideline values (Department of Environment, 2005).

Table 3.9 Aesthetic water quality measured for the period July 1999 and July 2004 at Conjurunup Creek Pipehead Dam

Parameter	Units	Aesthetic Guideline Value	Conjurunup Creek Pipehead Dam	
			Range	Median
pH		6.5 – 8.5	6.39 – 7.61	6.87
Turbidity	NTU	5	0 – 4.8	0.45
Colour	TCU	15	3 - 15	6
Conductivity	mS/m	-	19 - 42	25
Total Dissolved Solids	mg/L	500	113 - 224	140
Iron (unfiltered)	mg/L	0.3	0.10 – 0.65	0.16
Manganese (unfiltered)	mg/L	0.1	0.004 – 0.022	0.006
Aluminium (unfiltered)	mg/L	0.2	0.02 – 0.4	0.1
Sodium	mg/L	180	30 – 54	37
Potassium	mg/L	-	0.5 – 1.8	1.4
Calcium	mg/L	-	1.6 - 7	2.6
Magnesium	mg/L	-	3.4 – 7.5	4.4
Hardness (as $CaCO_3$)	mg/L	200	18.2 - 49	24
Alkalinity (as HCO_3)	mg/L	-	4.8 - 31	9.6
Chloride	mg/L	250	54 - 99	65
Sulphate	mg/L	250	6 – 9.5	7
Silica (as SiO_2)	mg/L	-	4.5 – 7.9	6.6
Filterable organic carbon	mg/L	-	1.4 – 3.8	2.4

Source: Department of Environment (2005)

Raw water from Conjurunup Creek Pipehead Dam is analysed for chemicals potentially harmful to human health, including inorganics, heavy metals, industrial hydrocarbons and pesticides. Health-related parameters detected in the source are summarised in Table 3.10, and there have been no recorded exceedances of health-related guidelines.

Table 3.10 Health-related water quality measured for the period July 1999 and July 2004 at Conjurunup Creek Pipehead Dam

Parameter	Units	Health Guideline Value*	Conjurunup Creek Pipehead Dam	
			Range	Median
Metals				
Barium	mg/L	0.7	0.015 – 0.021	0.015
Boron	mg/L	4	<0.02 – 0.02	0.02
Inorganics				
Nitrate + Nitrite (as N)	mg/L	11.3	<0.002 – 0.008	No Detection

* A health guideline value is the concentration or measure of a water quality characteristic that, based on present knowledge, does not result in any significant risk to the health of the consumer over a lifetime of consumption (NHMRC & ARMCANZ, 1996).

Source: Department of Environment (2005)

For the Stirling Dam, water samples were collected from the outlet to the dam between April 1998 to March 1999. There were only six parameters assessed in these samples, with results summarised in Table 3.11. All parameters over the sampling period were within the NHMRC ADWG guideline values (NHMRC, NRMMC, 2011).

Table 3.11 Water quality monitored for the period April 1998 to March 1999 at the outlet to Stirling Dam

Parameter	Range of monitored values	NH & MRC Australian drinking water guideline (1996)
Turbidity	0.4–0.9 NTU‡	5 NTU
pH	6.66–7.21 pH units	6.5–8.5 pH units
Colour	0.7–4.0 TCU†	15 TCU
Iron	0.037–0.078 mg/L	0.3 mg/L
Manganese	0.002–0.018 mg/L	0.1 mg/L
Aluminium	0.008–0.037 mg/L	0.2 mg/L

Notes: ‡ Nephelometric turbidity unit

† True colour units

Source: Water and Rivers Commission (2000)

A review of water quality sampling and analysis completed at Serpentine Main, North Dandalup, South Dandalup, South Dandalup Pipehead, Conjurunup Creek Pipehead, and Stirling dams indicate both health-related and aesthetic parameters generally fall within acceptable limits as defined in the Australian Drinking Water Guidelines. Although occasional exceedances of aesthetic guidelines were observed, median values over extended monitoring periods remained within ADWG standards, whilst no recorded exceedances of health-related guidelines were observed.

It should be noted that in the absence of specific guidelines for raw-water quality, all results were compared with the ADWG values set for drinking water; these define the quality requirements of water at a customer's tap. However, the raw-water data presented does not represent the quality of drinking water distributed to the public, with that water provided to consumers expected to be treated prior to delivery and consumption.

Potential data gaps in the water quality assessments for the dams could involve several considerations:

— Temporal gaps: there may be periods without data collection, which could miss seasonal variations or short-term extreme events.

— Spatial gaps: sampling taken at the dams might not be near or at the downstream of the mining DEs.

— Parameter gaps: not all possible/relevant contaminants have been tested for, notably metals and metalloids.

— Frequency of monitoring: infrequent sampling might not capture rapid changes in water quality.

3.1.5 Existing water use entitlements

The take of surface water from watercourse or water body, or groundwater located within the mining DEs is regulated by Rights in Water and Irrigation Act 1914; this is implemented to protect the state's water resources and promote the sustainable and efficient use of water.

The Western Australia Water Register (DWER, 2024) provides information on valid surface water licences, such as management group, location and volume for each entitlement. However, authorisation purposes, maximum rate, volumetric limits and flow conditions are not available on the Water Register.

There are six existing water licences which reside across the Huntly mining DE. One is in Karnet, within the Huntly East region, while the remaining licences are located near the South Dandalup Dam. Information regarding these water licences is summarised in Table 3.12.

Table 3.12 Existing surface water licences within the Huntly mining DE

Licence Number	Volume of entitlement (ML)	Expiry date	Area	Sub-area	Users
083356	70	16/09/2034	Murray River Catchment	Marrinup Brook	Alcoa ML1SA
056734	26,900	30/06/2027	Dandalup River Catchment	South Dandalup	State Forest No. 14
056736	6000	30/06/2027			
063409	500	16/09/2034			Alcoa ML1SA
153635	30	16/09/2034			
171958	282.6	21/06/2034	Serpentine River Catchment	Karnet	Karnet Prison Farm

3.2 Hydrogeology

The generalised hydrogeology of the Huntly and Willowdale DEs have not been assessed previously in detail. Hydrogeological conditions are assumed to be analogous to adjacent catchments / studies areas (such as Myara North and Holyoake).

3.2.1 Regional hydrogeological setting

The Darling Plateau was formed by a marginal upwarping of the Yilgarn Block, a relatively stable shield area which forms a major part of the Great Plateau of Western Australia (Schofield & Bartle, 1984). The Darling Plateau is characterized by sharply incised drainage lines forming dense drainage networks in the western, higher rainfall section, with these transitioning to open, flat-floored valleys in the eastern, lower rainfall section (Churchward & Dimmock, 1989), referenced in (Croton & Reed, 2007).

The primary bedrock of the Darling Plateau is granitic with this divided by the intrusion of numerous sheet-like doleritic dykes that vary in thick-ness from a few millimetres to tens of meters. Deep in situ weathering has produced a soil profile with a typical depth range of 10 to 40 m (Kew & Gilkes, 2007), referenced in (Croton & Reed, 2007).

In the western parts of the Darling Range plateau, annual rainfall exceeds 1,100 mm. This combined with the relatively shallow lateritic regolith over bedrock and high topographic relief promotes localised hydrogeological flow systems where steeper hydraulic gradients drain into an incised stream network. The clayey lateritic stratum provides greater plant available water in the unsaturated zone.

Groundwater across the Darling Plateau occurs within:

— the weathered zone of the crystalline rocks of the Yilgarn Craton, which variably includes those lateritic soils which are mined in the Willowbank and Huntley DEs

— in fractures (including faults, shear zones and joint networks) of the crystalline basement rocks, and

— sediment deposits along drainage and/or palaeodrainages (GHD, 2021).

Groundwater has been an active part of lateritisation across the Darling Plateau, particularly in the development of the duricrust or caprock above the weathered saprolite clays. The formation of caprock has been driven by groundwater flow, and where present has a notable influence on the presence and movement of groundwater in the Huntly and Willowdale DEs.

The caprock layer is mostly found on most slopes. It may however also be found in valley floors due to the accumulation of iron brought by groundwater flow and its precipitation due to evapotranspiration or exposure to the surface.

Owing to its geological evolution, the caprock layer is of varying thickness, often discontinuous, and absent where basement rock outcrops. Of hydrological significance, root channels penetrate vertically in the caprock via fissures and discontinuities. These forming preferential flow paths for the movement of groundwater infiltrate, thereby enabling significant vertical fluxes from the shallow weathered zone to move into the deeper aquifers of weathered saprolite and saprock.

A generally low-yielding regional fractured rock basement aquifer system typically underlies the unconfined aquifer, particularly in the east of the Darling Range.

Shallow perched aquifers are also present in alluvial and colluvial sediments accumulated in drainage lines in the wet season. These aquifers form highly localised water bearing zones or occasionally local aquifers (in those instances where there is a higher degree of more permeable, interconnected, coarse-grained material that remains saturated year-round), however may prove to be unreliable water sources owing to their fragmented distribution, variability in permeability and temporal variability in recharge from ephemeral creeks. These aquifers usually do not confine those aquifers in the weathered or fresh bedrock and may form localised zones of recharge (seepage) to the underlying aquifers.

Within the unconsolidated system, previous studies (GHD, 2021a) further categorise the aquifer several sub-aquifer units but these are generally considered to be interconnected and largely unconfined. The hydrostratigraphy is summarised in Table 3.13 alongside the corresponding geological unit:

Table 3.13 Generalised hydrostratigraphy in the Huntley and Willowbank DEs

Aquifer	Sub-unit	Description	Corresponding geological unit/s
Unconsolidated	Shallow weathered zone	Comprising shallow gravely to sandy sediments, lateritic caprock and friable upper saprolite. Given sufficient thickness can possess significant storage, infiltration and flow capability. May contain a seasonally driven perched aquifer. ***The zone can contain the economic bauxite and be subject to mining***	Overburden and lateritic bauxite
	Deep weathered zone	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. The aquifer has some storage potential but limited bulk permeability (due to comprising largely clays)	Saprolite
	Transition zone	Transition zone from lateritic saprolite to weathered / fresh basement. Referred to as saprock. Typically, has enhanced permeability due to coarse nature of materials.	Saprock
	Transported sediments (alluvial)	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.	Valley alluvium
Fractured rock	Basement bedrock	Primary porosity likely to be very low. Permeability and yields are dependent on structural features such as faults and dolerite dykes. Facture development and connectivity of the fractures may have enhanced permeability along strike.	Crystalline basement

3.2.1.1 Shallow weathered aquifer

Churchward and Dimmock (1989) presented a generalised soil profile of the NJF developed on the rocks and soils of the Yilgarn Block. This included a schematic and description of a shallow soil profile some 1 to 3 m thick, with the generalised surficial profile comprising three zones, each defined by the geomorphic setting in the undulating Darling Plateau as follows:

— topographically elevated areas: where vuggy and permeable lateritic duricrusts are common

— middle slopes: where the shallow zone is dominated by moderately permeable sandy and pisolitic gravels, and

— lower slopes and valley floors: which largely comprise medium to low permeability sands and loamy deposits.

Where laterite, pisolitic, and sandy sediments occur, these can form decent localised aquifers in the wet season. The continuity and permeability of these sediments though and their inherent capacity to transmit infiltrated rainfall is not well understood, however the downward percolation of rainfall infiltration is expected in areas where underlying saprolite is penetrated by macropore features such as those formed by tree roots (Churchward and Dimmock, 1989).

Due to the inferred large heterogeneity of the surficial sediments, Churchward and Dimmock suggest there is some form of hydraulic discontinuity between that groundwater in the surface sediments, and that in the underlying weathered bedrock. As such these water resources may form localised shallow aquifers which discharge to drainage lines during and following wet season rainfall events, with this water likely to merge with baseflow in the slopes surrounding the drainage lines, particularly where these drainage lines intersect the regional water table (GHD, 2021).

3.2.1.2 Deep weathered aquifer

The deeper weathered aquifer is dominated by the saprolitic clay profile formed from the deep weathering of the basement rocks. This zone is typified by its moderate-to-high storage capacity yet low permeability, with groundwater ‘yields’ typically encountered at the transitional zone between the saprolitic clays and the (underlying) slightly weathered to fresh basement within adjacent DEs (GHD, 2021).

3.2.1.3 Fractured bedrock aquifer

The fractured bedrock aquifer (FBA) has not been studied in detail given that:

(i) mining does not extend below the saprolite, and

(ii) interactions with FBA are limited.

Permeability and yields in the FBA are dependent on fracture development and the connectivity of the fractures, with structural features such as faults and dykes potentially forming zones and features of enhanced permeability. In stating this however, this aquifer is generally expected to be of low permeability and limited storage as evidenced by generally low bore yields of limited duration.

Overall, groundwater resources in the FBA and its utilisation are typically low given:

— the forested (and undeveloped) nature of the catchments

— the low likelihood and expectation of ‘useable’ yields, and

— the higher likelihood of finding suitable groundwater resources in those aquifers overlying the FBA.

3.2.2 Groundwater depths, elevations and flow directions

At the regional scale, groundwater is likely to mirror topography and flow generally westward, discharging:

(i) into local surface water systems, or

(ii) to and along those riparian zones in hydraulic connection with nearby streams.

The incised nature of the plateau may give preference to several local groundwater flow systems contrary to generalised regional flow (GHD, 2022).

At the local scale, groundwater elevations within all aquifers appear to follow topography, typifying those in topographically driven groundwater flow system (Toth, 2009). As such groundwater elevations are highest in areas of highest topography and lowest in areas of lowest topography (e.g., valleys). Where groundwater levels intersect the base of streams, groundwater discharges provide baseflow following winter rains (topped up aquifer storage and groundwater levels).

Groundwater is also expected to be lost from these flow systems via evapotranspiration in riparian zones.

Alcoa retain an expansive monitoring network across the Darling Plateau. The groundwater monitoring bore networks for subsets of the Huntly mine area (Myara mine region) and the Willowdale mine area (Larego mine region) are shown on Figure 3.13 and Figure 3.14 with average depth to water presented for each bore. Whilst the data has not been analysed in detail, the following can be gleaned from the groundwater monitoring bores relevant to the Proposal DEs:

Within the Myara mine region:

- Measured depth to groundwater is variable, ranging from at surface (i.e., discharging to streams and ground surface) to greater than 30 metres below ground level (m bgl).
- Shallow groundwater depths (typically <2m bgl) are generally observed in proximity to drainages.
- Deep groundwater levels (>10 m bgl) are generally observed 'away' from mapped surface drainage features, along ridge lines, or at the very top of first order drainage features.

Within the Larego mine region:

- Similar to Myara, depth to groundwater ranges from near surface (i.e., where discharging) to greater than 30 m bgl.
- The distribution of shallow groundwater (<2 m bgl) is mapped within surface drainage features but also a few instances where shallow groundwater is observed on topographic ridge lines (note these data may not be verified).
- Deep groundwater levels are consistent, observed along ridge lines or at the upper reaches of first order drainage features.

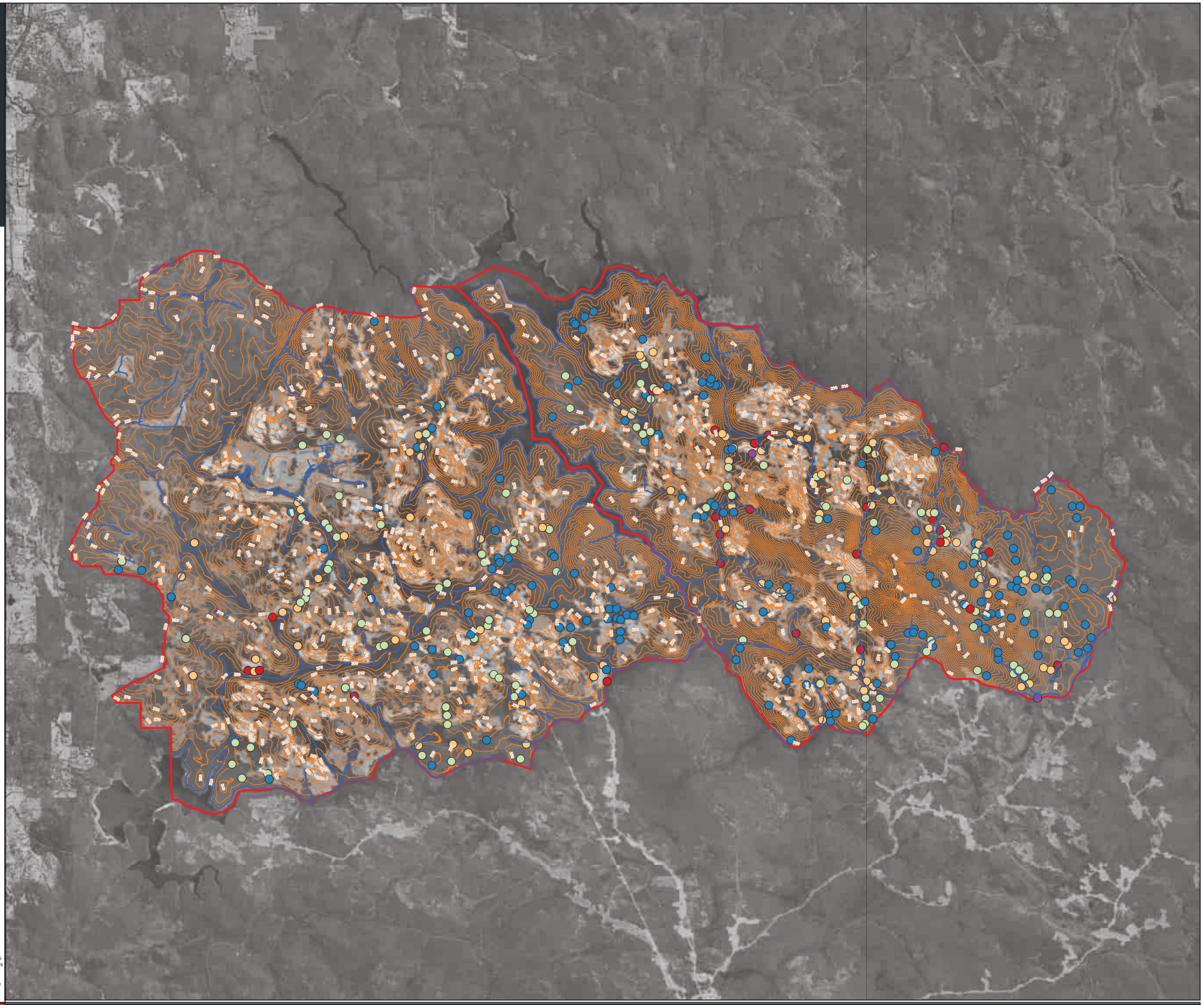
Adjacent Studies

Within the Huntly mine a detailed assessment of groundwater levels (GHD, 2021) concluded the following:

- In the Myara North DE, with is adjacent to the Myara DE:
  - Groundwater elevations subtly mimic surface topography, with groundwater often deeper beneath ridges and upper hill slopes, and 'shallower' close to topographic lows
  - In topographically elevated areas such as hills and ridges, the depth to groundwater is typically between 15 to 30 m bgl
  - Close to valley floors (where GDEs may exist) and along creek lines, the depth to groundwater is typically less than 5 m bgl, and occasionally less than 3 m bgl as shown in Figure 3.13, and
  - Groundwater elevations show strong seasonal variations, often in the order to 1 to 5 m between seasons.
- In the Holyoake DE, which is 18 km south of Myara and 6 km east of Huntly, (GHD, 2021) noted:
  - the depth to groundwater in this DE is typically greater than 10 m bgl
  - the average depth to groundwater is deeper than that in those catchments to the north (Myara North), and
  - potential GDEs mapped in this DE are likely dependent on the seasonal saturation of shallow perched aquifers close to and along valley floors (i.e., they are likely only partially dependant on groundwater).

Baseline Report

Figure 3.13
Huntly



LEGEND

DTW (mbgl)

- -2 - 0.0
- 0 - 2
- 2 - 5
- 5 - 10
- 10 - 30.6
- Huntly Streams

Boundaries

- Huntly East
- Huntly West
- Elevation LiDAR (mAHD)

ESRI

0 2.4 4.8 km

Coordinate System: AGD84 / AMG zone 50

Scale correct when printed at A3
1:120000

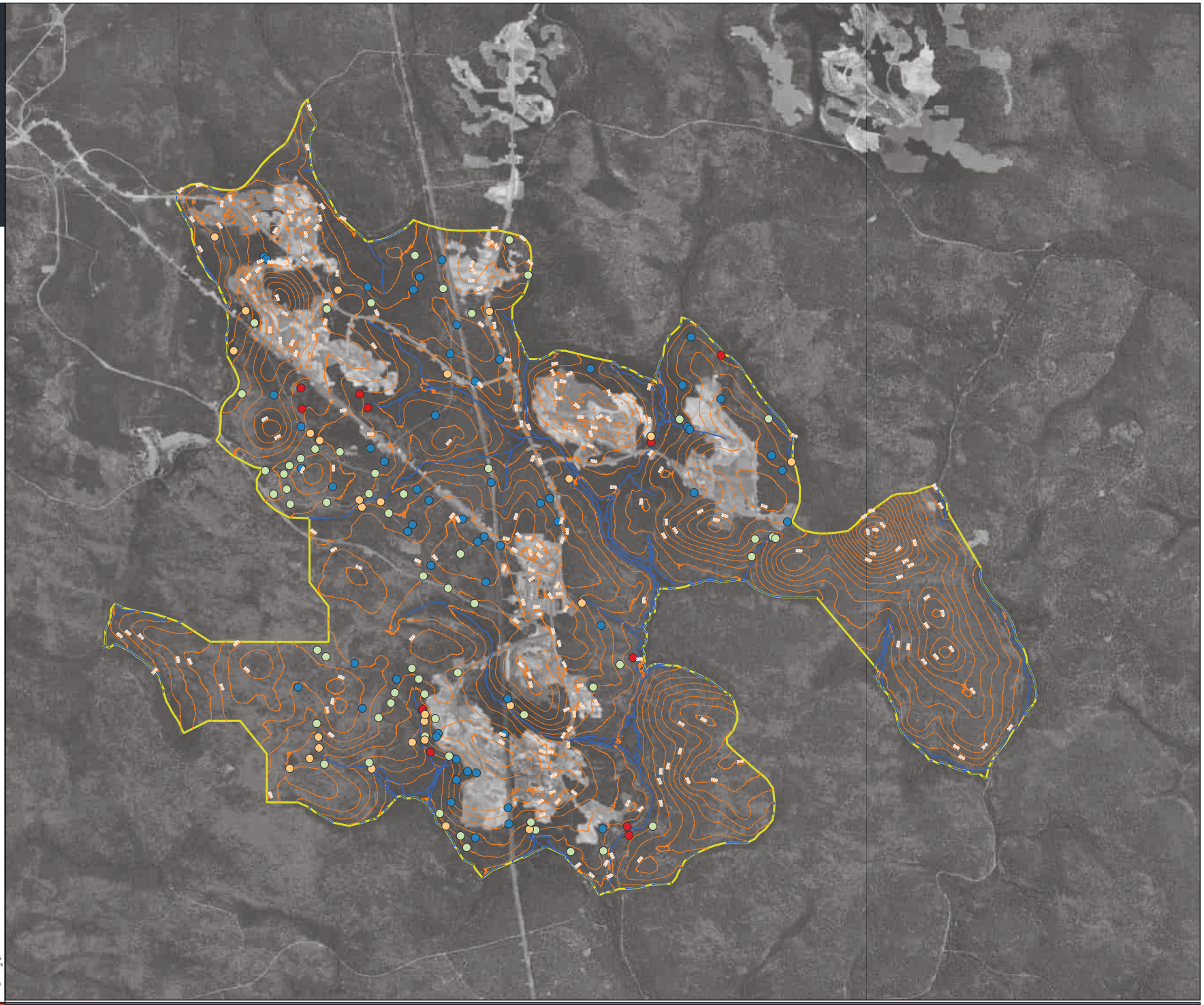
This map was created by:
Manuel Diaz

Data Source:
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Baseline Report

Figure 3.14
Larego (Willowdale)



LEGEND

DTW (mbgl)

- -2 - 0.0
- 0 - 2
- 2 - 5
- 5 - 10
- 10 - 30.6
- Larego(Willowdale) Streams

Boundaries

- Larego(Willowdale)
- Elevation LiDAR (mAHD)

ESRI

0 1.2 2.4 km

Coordinate System: AGD84 / AMG zone 50

Scale correct when printed at A3
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This map was created by:
Manuel Diaz

Data
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Trends in groundwater levels

Long-term mapping produced by WA Department of Primary Industries and Regional Development indicates limited public groundwater elevation data is available across the (Western) Darling Plateau. Government monitored groundwater sites are generally located:

- either along the Swan Coastal Plain (west of the Plateau), or
- sporadically across the east of the Darling Range and forested areas, focusing on the agricultural regions where groundwater usage is expected to be higher.

Due to the physiographic, climatic and groundwater use differences in the regions, data from the SCP and that area to east of the Darling Range has not been considered to assess groundwater characteristics and trends for relevance to the study area.

Long-term monitoring (by Alcoa) across the region indicates groundwater elevations across the Darling Plateau, and thus the broader mining lease, have been declining since the 1990s; this reflects a similar occurrence (i.e., decline in precipitation) in rainfall patterns (GHD, 2021) (Grigg & Hughes, 2018).

An assessment of trends from Alcoa's groundwater bore network between 1990 and 2020 (GHD, 2022) indicated:

- changes in groundwater elevations in bores in the Myara North DE ranged between +1.5 m and -10 m (refer Figure 3.17), and
- changes in groundwater elevations in those bores in the Holyoake DE ranged between -5 m and -15 m (refer Figure 3.18).

Within the Myara mine region:

A robust groundwater elevation dataset is available for the Huntly mine within and outside the Mine DE. An assessment of trends between 1990 and 2020, from the Alcoa groundwater bore network, indicates changes in groundwater elevations have ranged between:

- increases of up to 1.5 m, and
- decreases of as much as 15 m.

The long-term decline in groundwater levels is reflective of the long-term rainfall trend (cumulative deviation from monthly means) and is likely linked to the long-term drying climate experienced in the south-west region of WA since the 1970s.

Steady trends in groundwater elevations, deviating from the long-term rainfall trends can be observed where active mining has occurred. Rising groundwater elevations trends appear to commence around 2010-2011.

Within the Larego mine region:

Groundwater elevations data from within the Willowdale DE are limited to 2022 onwards. Within this time period, groundwater levels are observed to fluctuate seasonally, generally within a 5 m range, with steady increases in groundwater elevations observed near active mine areas.

Mining-induced changes of groundwater elevations:

Clearing of vegetation and removal of ore during mining results in an increase in groundwater recharge rates and a reduction in transpiration losses from the groundwater system. This results in increased groundwater elevations at and downgradient of these areas, colloquially also known as 'groundwater mounding', which can:

- result in the 'water logging' of soils, particularly downgradient of both cleared and mining areas, and
- alter the hydrological regime to nearby GDEs and terrestrial vegetation habitats.

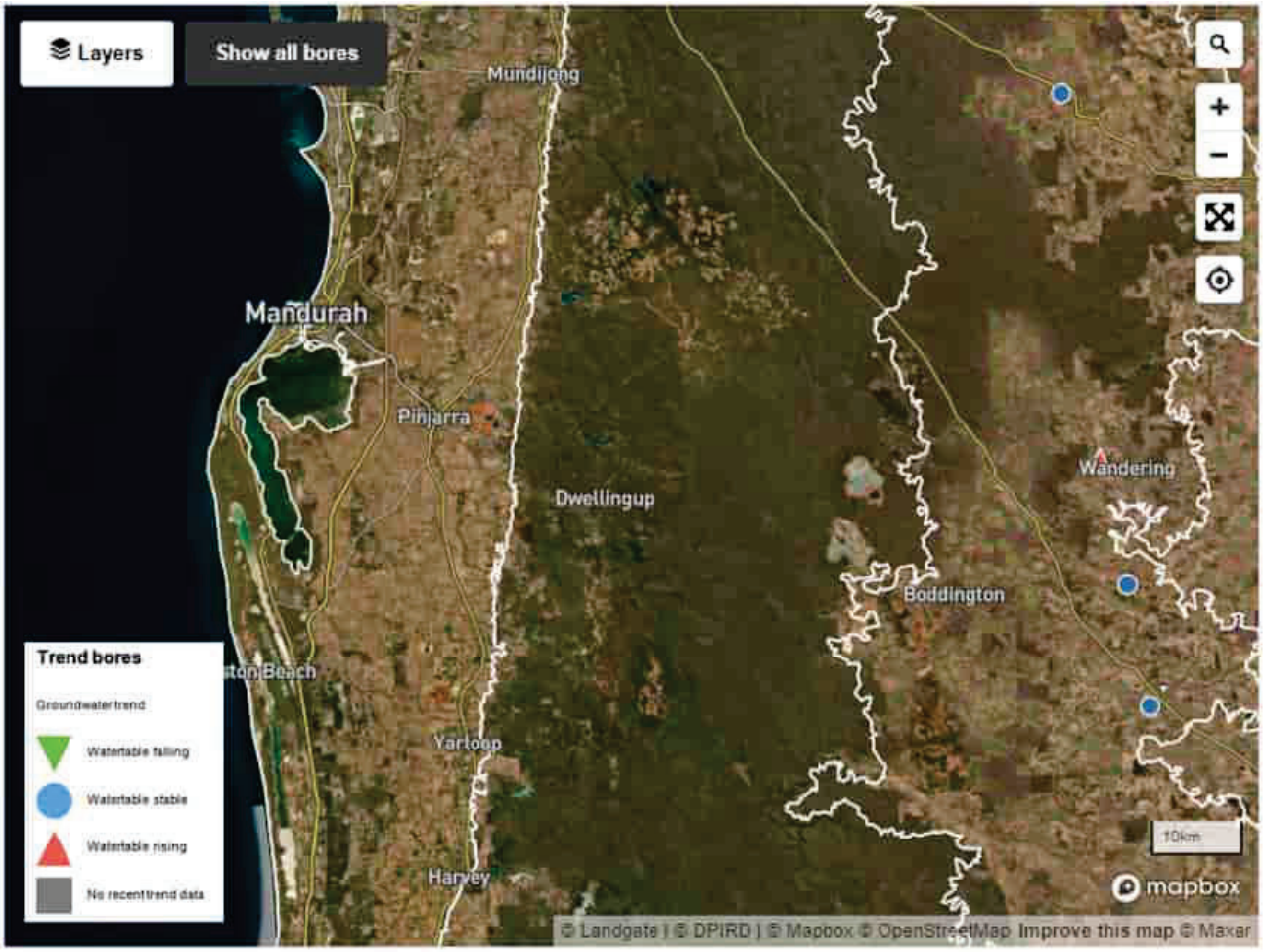
The influence of mining activities on groundwater elevations in both the Huntley DE (Myara mine region) and Willowdale (Larego mine area) is exemplified on Figure 3.19 to Figure 3.22. These figures show depth to groundwater

measurements with time (hydrographs) at various locations within selected catchments in these mine areas, with notable observations including the following.

The depth to groundwater in undisturbed catchments is typically greatest with increased distance from local waterways (such as beneath and close to catchment divides), and shallowest closer to these streams. This is well typified by those groundwater elevation trends shown on Figure 3.19 and Figure 3.21, which also show variations in groundwater depths are typically greatest in the mid-catchment and mid-slope areas.

In those catchments which have not yet been cleared, hydrograph trends show some influence from long-term climate cycles and significant rainfall events, in this instance declining trends during periods of long-term below average annual rainfall (as shown by the declining trend of the CDFM). The influence of long-term trends on groundwater depths is most evident in the upper portion of catchments (refer to monitoring location X4228-1A in Figure 3.19), whilst the influence of shorter-term above average rainfall events on groundwater depths are more evident in the central to lower portions of catchments (refer to monitoring location L4301-1A in Figure 3.19).

- In those catchments where clearing and/or mining has been carried out, the depth to groundwater often decreases (i.e., the elevation of the watertable increases – in response to increase in rainfall infiltration potential and reduction in transpiration losses), regardless of the geomorphic position of work activities occurring in the catchment (i.e., lower slopes, mid-slopes or upper slopes). This is best typified by those groundwater depth changes shown in Figure 3.20 which show:
  - marked decreases in the depth to the watertable in the mid and upper reaches parts of this catchment (locations X4213-2A and X4217-1A), and
  - the complete waterlogging of soils and discharge of groundwater at the surface at lower elevations via mine-induced seeps and bogs, particularly along the mid to lower slopes of these catchments (X4221-1A).



Source: DPIRD (2021)

Figure 3.15 DPIRD Groundwater level monitored bores in the Alcoa Project region

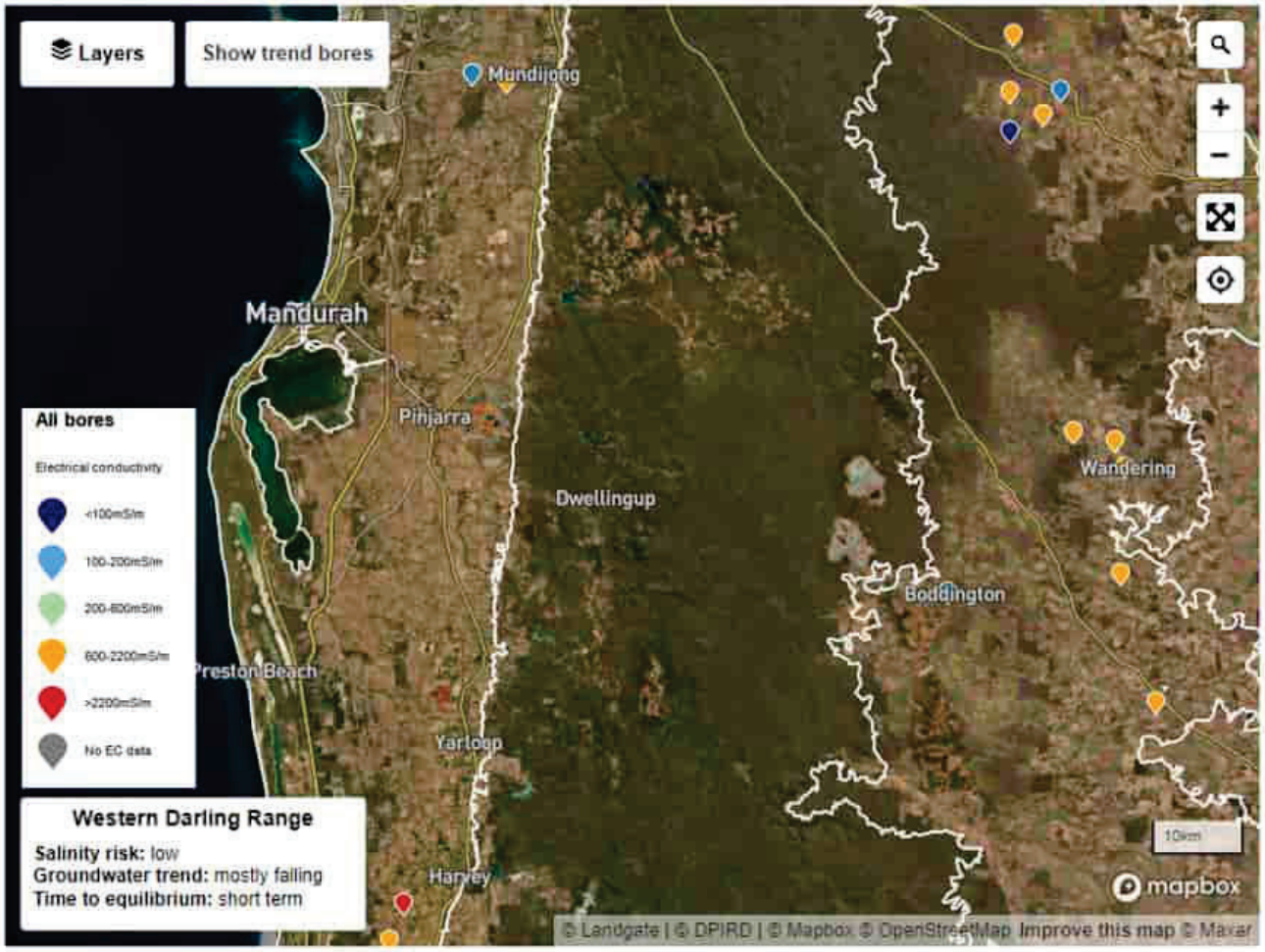


Figure 3.16 DPIRD Groundwater quality monitored bores in the Alcoa Project region

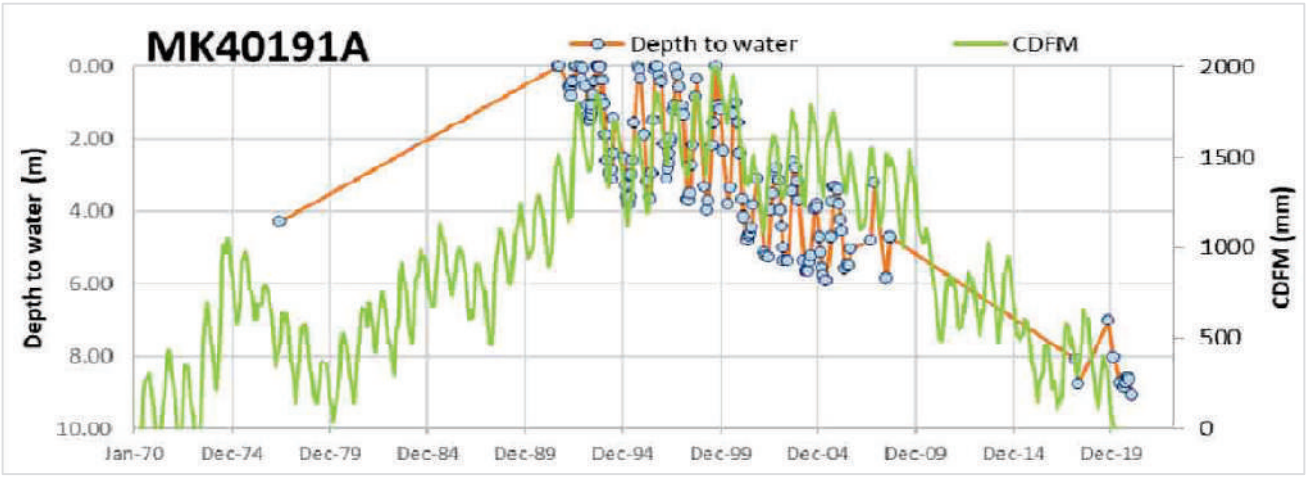


Figure 3.17 Long-term groundwater level trends at bore MK40191A (located within Myara North, north of Huntly DE) compared with cumulative deviation from mean monthly rainfall

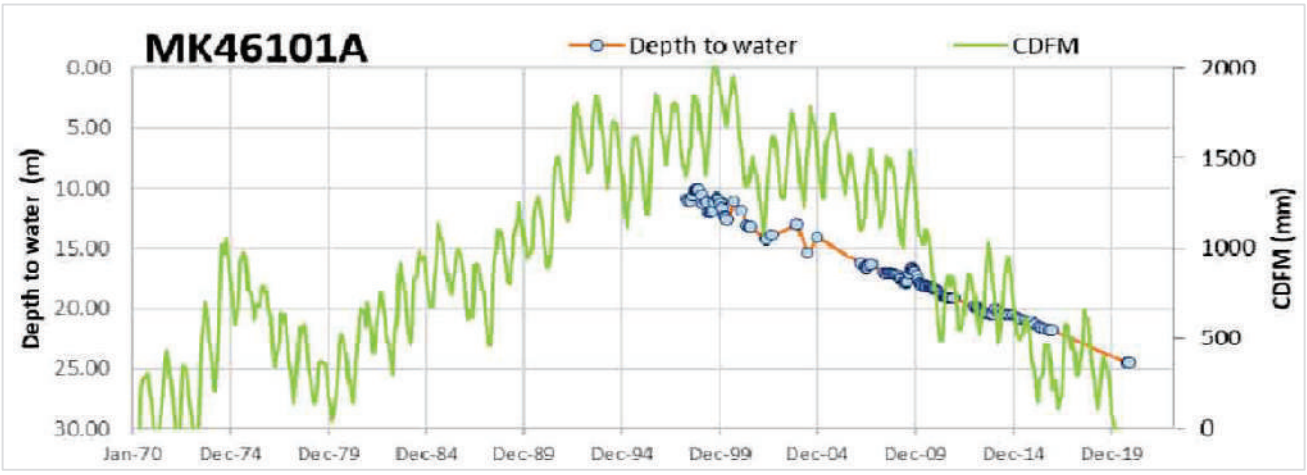


Figure 3.18 Long-term groundwater level trends at bore MK46101A (located within Holyoake, north of Willowdale DE) compared with cumulative deviation from mean monthly rainfall

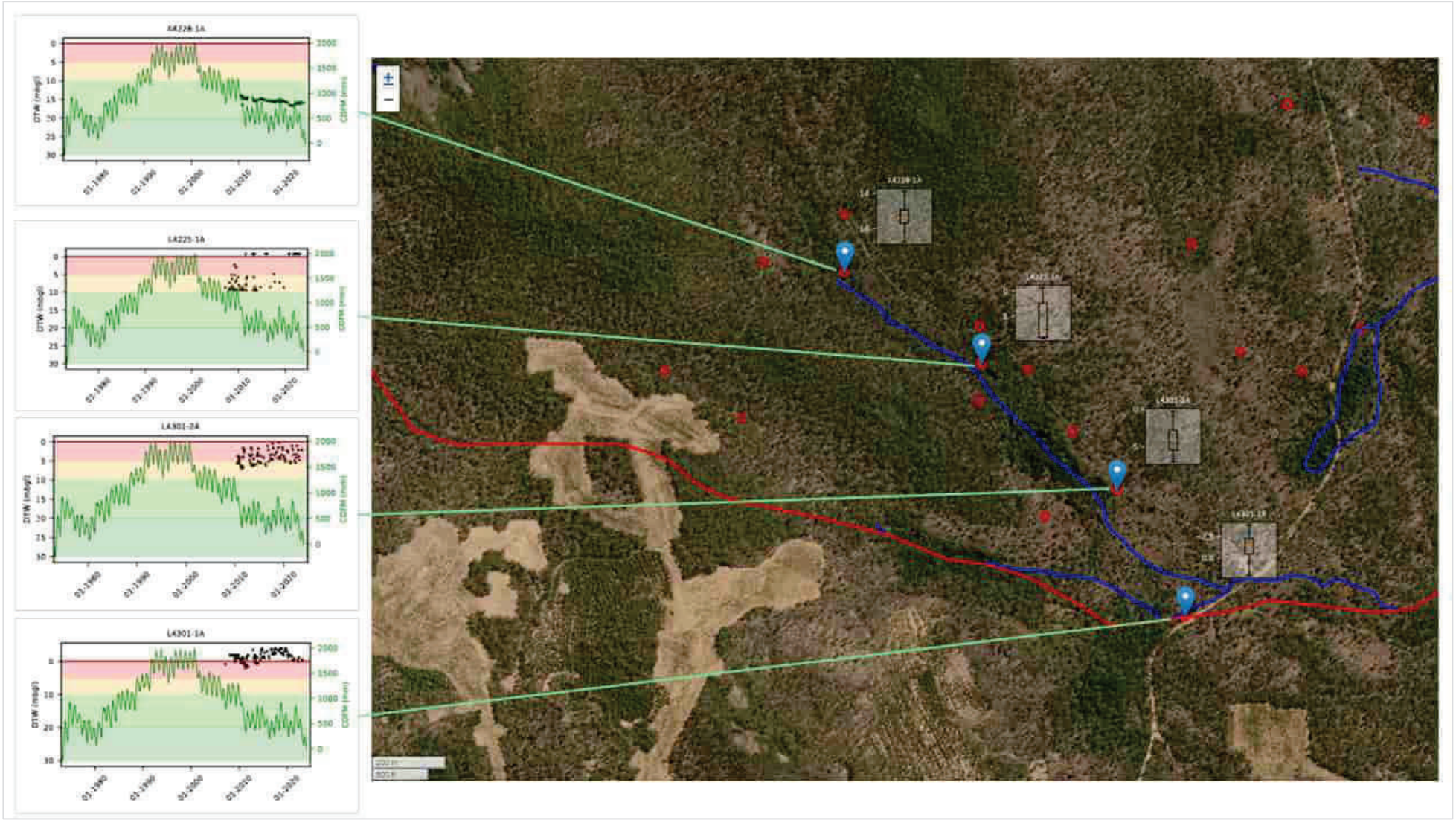


Figure 3.19 Groundwater level trends (bores K4228-1A, L4225-1A, L4301-2A and L4301-1A) within Myara mine region (Huntly DE) in undeveloped portion of catchment compared with cumulative deviation from mean monthly rainfall

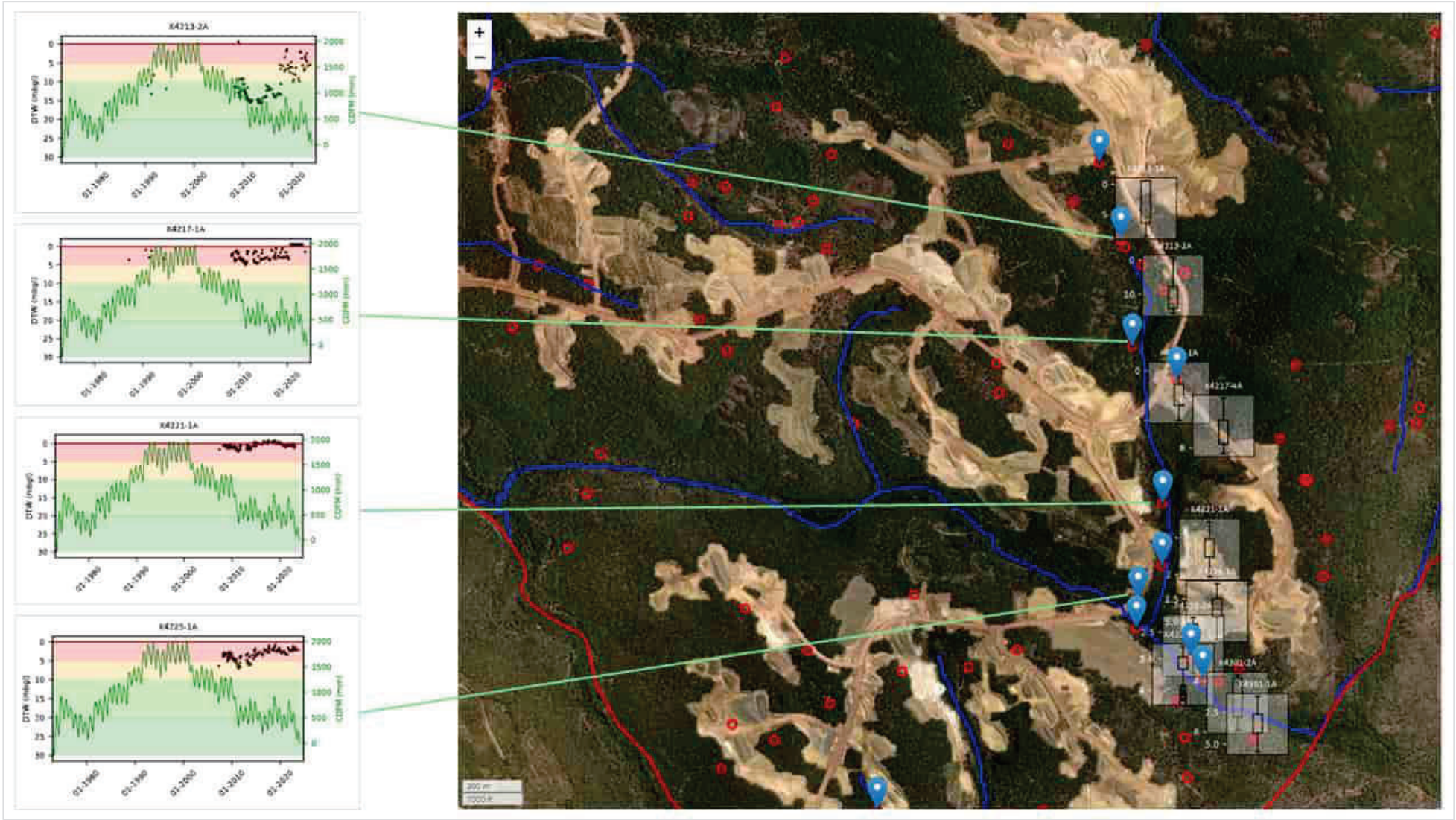


Figure 3.20 Groundwater level trends (bores X4213-2A, X4217-1A, X4221-1A and X4225-1A) within Myara mine region (Huntly DE) in a mined portion of catchment compared with cumulative deviation from mean monthly rainfall

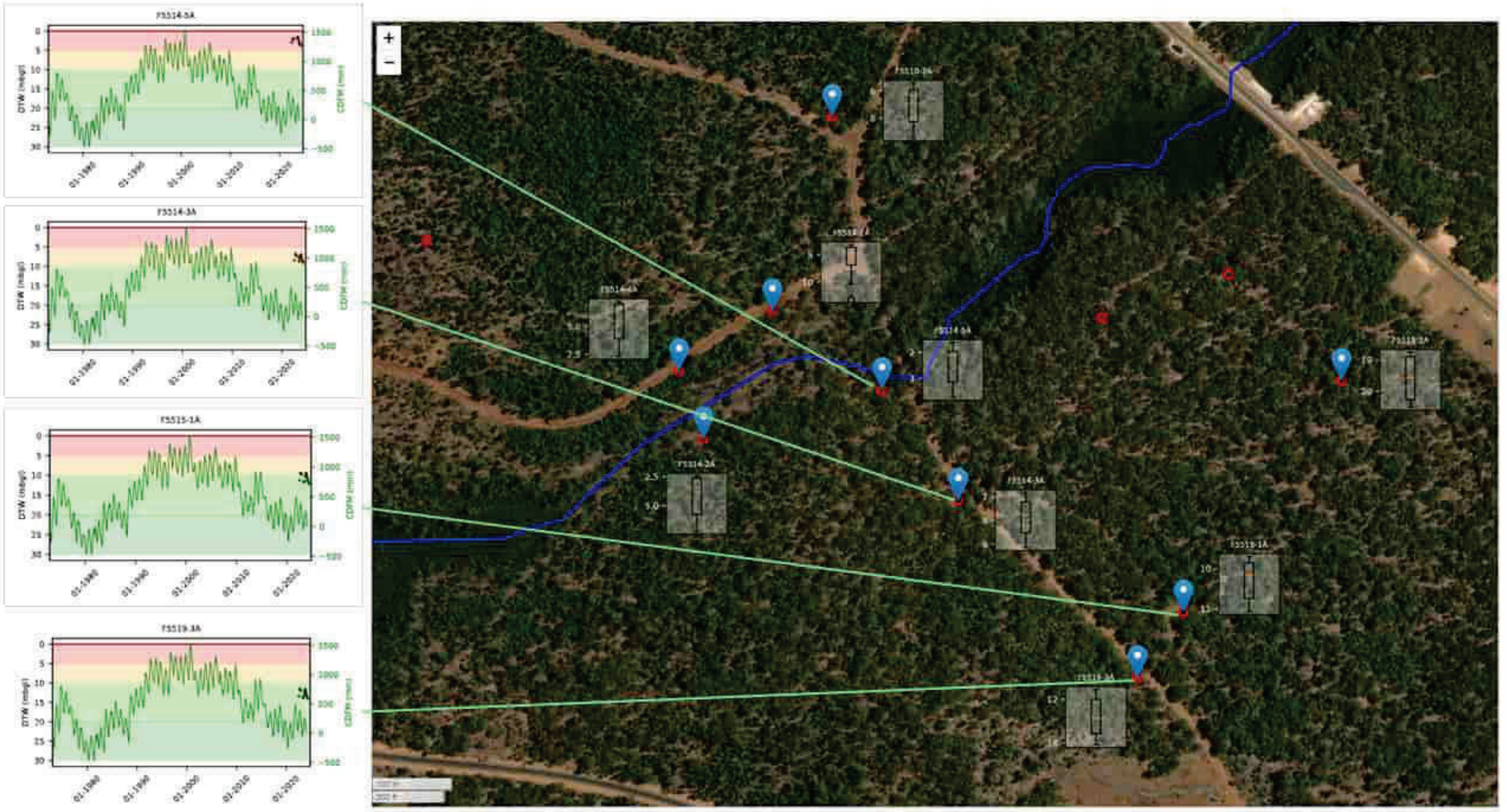


Figure 3.21 Groundwater level trends (bores F5514-5A, F5514-3A, F5515-1A and F5519-3A) within Larego mine region (Willowdale DE) in undeveloped portion of catchment compared with cumulative deviation from mean monthly rainfall

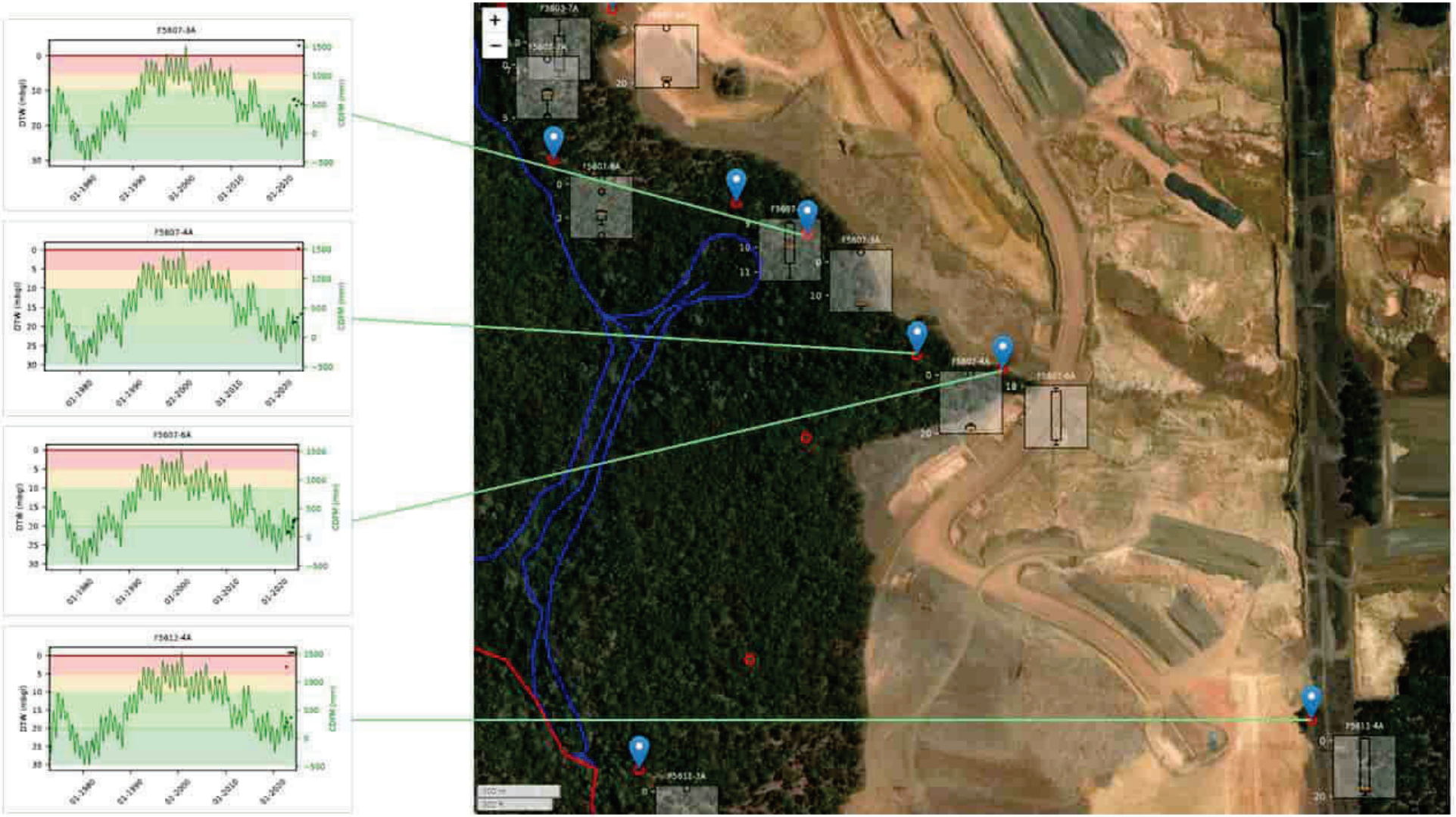


Figure 3.22 Groundwater level trends (bores F5607-3A, F5607-4A, F5607-6A, F5612-4A) within Larego mine region (Willowdale DE) in a mined portion of catchment compared with cumulative deviation from mean monthly rainfall

3.2.3 Recharge

Near-surface laterite can be quite permeable promoting direct infiltration of rainfall. Duricrust, caprock layers, and the underlying low permeability lateritic clays generally impede the vertical movement of infiltrate, rather promoting the lateral movement of groundwater in temporal perched / interflow, albeit with subordinate percolate downwards into the deeper aquifer, or taken up via transpiration. Griff & Kinal (2020) noted that in some local catchment of the Darling Range groundwater recharge may be facilitated by root channels and discontinuities in the regolith.

The downward drainage of rainfall infiltrate into the deeper unconsolidated aquifer is often enhanced by root channels of well-established jarrah forest. These features form preferential flow paths allowing infiltrate to move more rapidly to the underlying cemented layers and deeper clay zones of the laterite profile (Grigg & Kinal, 2020), (GHD, 2022).

Estimates of groundwater recharge from rainfall infiltration using the chloride mass balance method suggests such recharge varies between about 45 and 61 mm/yr, decreasing from the western to eastern boundary of the development envelope (GHD, 2022).

3.2.4 Discharge

Groundwater discharge occurs mostly via evapotranspiration through vegetation that can access the water table (GHD, 2021). Discharge also occurs where groundwater elevations intersect the base of the creek drainages providing baseflow contribution (following winter rains which top up aquifer storage and elevate groundwater levels).

Tree cover of the jarrah forests remove water stored and/or transmitted in both saturated and unsaturated zones, with root systems of some trees extending 40 m below ground (Advisian, 2024). Macfarlane et al (2017) noted although jarrah forest may access deep groundwater owing to great tree rooting depths, use of deep groundwater is likely to be limited, and trees are likely to be largely reliant on soil water stored in the unsaturated zone above the watertable. Water use by jarrah is very likely to be facultative because there have been no reports of jarrah deaths in response to falling watertables in stream zones, recognising northern jarrah forest watertables fall at average rates up to 0.5 m/year. Deaths of trees have, however, been associated with areas of shallow soil near rocky outcrops, high elevations and steep slopes.

Work from across the Darling Range catchments indicates groundwater contributions to streamflow varies significantly, including in some years being the dominant proportion of some streams baseflow (Grigg & Kinal, 2020), (GHD, 2022). Landscape groundwater storage capacity, strongly controlled by regolith depth, is a key factor controlling the extent of groundwater discharge to surface water (Advisian, 2024).

Groundwater (and surface water) derived from the Myara / O'Neil mine region of the Huntly DE will primarily discharges into the Serpentine Dam catchment, the Serpentine Pipehead Dam catchment and the North Dandalup Dam catchment. Groundwater derived from the Huntly and Del Park mine regions within Huntly DE will primarily discharge to the South Dandalup Dam cachment, the South Dandalup Pipehead catchment and a small portion discharging into the Conjurunup River Pipehead catchment

At Willowdale DE, the Keats mine discharges primarily westward primarily into the Murray River catchment. The Tasman and Wills mine regions are situated in the upper reaches and adjacent to the Harvey River and Stirling Dam catchment.

3.2.5 Surface water and groundwater connectivity

Despite the lack of observational data within the Huntly and Willowdale DE, the nature of and the processes involved in surface water – groundwater connectivity where studied are considered representative of general conditions across the Darling Plateau.

Groundwater interacts with surface water across the Darling Plateau and plays an important role in streamflow generation (Kinal & Stoneman, 2012). Such flow can be supported directly or indirectly by deep groundwater either as groundwater discharge or facilitated from shallow throughflow, with these processes confined to valley floors and adjacent to lower slopes (Grigg, 2017). As such, surface water and groundwater are hydraulically connected in streams, swamps and downstream reservoirs, with surface water seasonally or at least intermittently connected to both the regional (or in some instances perched) water table and the interflow vadose zone; this is supported by observations from streamflow monitoring which demonstrates a correlation and concurrence of streamflow with elevated groundwater levels (Grigg & Kinal, 2020).

Where studied, direct groundwater discharge has been observed to range from only a minor component of streamflow (Kinal & Stoneman, 2012), to interflow and groundwater discharge being the dominant streamflow generating processes (Croton & Reed, 2007). Indirect discharge of groundwater, particularly during high rainfall periods contributes to stream flow by amplifying other streamflow generating processes (i.e., surface runoff and throughflow) (Kinal & Stoneman, 2012).

Depth to groundwater is a key attribute for groundwater discharge. Where groundwater levels are sufficiently shallow, conditions are likely dependent on oscillating groundwater levels and contributions are expected to vary throughout the year in association with the seasonal responses (Grigg & Kinal, 2020).

Implications of a longer-term climatic trends on catchment water resources and hydrological regimes have been studied in detail across the Darling Plateau. Significant declines in rainfall since at least the mid-1970s has resulted in declining catchment storage (Kinal & Stoneman, 2012). In the Del Park mine region of the Huntly DE, seasonal stream flows were strongly collated to periods of connection between groundwater and the stream channel, noting that where studies, groundwater had become disconnected from surface waters from 2010 onwards (Grigg & Kinal, 2020).

Near-surface groundwater flow is also often able to support short term surface flows in streams when activated by winter rainfalls. The near-surface flow component is likely to merge with baseflow in lower slopes surrounding the streams where these sufficiently cut into the regional water table. In the Serpentine Dam catchment (Myara North mine region, refer Figure 2.1), stream gauge records confirmed surface water flows are relatively short-lived following winter rains, often ceasing to flow within two to three weeks following peak streamflow. This short duration of flow following rainfall suggests streamflow is significantly derived from catchment runoff and short-term storage contributions, such as interflow, and that baseflow contributes to a lesser extent (GHD, 2021).

Further analysis of streamflow toward the end of spring and moving into summer months resulted in greater contributions to streamflow baseflow, as seasonally elevated groundwater levels facilitated longer term baseflow discharge (likely weeks to months) whilst interflow contributions typically become shot lived. (GHD, 2021). The observations are supported by salinity monitoring data, which indicate winter rains lead to low salinity streamflow at the start of winter (i.e., dominated by surface and near-surface flow), which then transition to periods of higher salinity more typical of groundwater.

Only very few rivers of the Darling Range are perennial (pers. comm Alcoa, 2024). Rivers of the region are generally perennial in their lower reaches (e.g., across the SCP). It is suggested that the natural flow regime of the upper Harvey River was perennial pre dam construction (DWER, 2024). Many of the rivers and creek systems will become completely dry post summer and into the start of autumn (refer Serpentine, Big Brook, and South Dandalup river streamflows, Figure 3.6, Figure 3.7, and Figure 3.8). The perennial nature of the region's hydrology experiences annual baseflow recession due to declining groundwater discharge as groundwater levels fall below the river / creek inverts during the post summer months and into the start of autumn.

During the late summer and autumn months the absence of surface water flows elevates the importance of shallow groundwater accessible to GDEs and wetlands, particularly at the base of slope and across the valley floors. 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 evapotranspiration, groundwater may continue to exfiltrate to the creek or support sufficiently shallow water table in the riparian zone accessible for the support of vegetation communities.

3.2.6 Hydraulic properties

Average hydraulic conductivity of the regolith is estimated between 0.3 and 0.6 metres per day (m/day) (GHD, 2021) for the transition zone of the unconsolidated aquifer with estimates ranging between <0.05 and 1.2 m/day; generally the highest hydraulic conductivity values were returned from bores screened in the basement saprock to highly weathered granite, indicative of discrete high permeable zones within this unit.

Where present at or near the surface sands and gravels, interflow can have significantly higher hydraulic conductivities, particularly those on mid slopes and valley floors. Clays in the overlying saprolite are inferred to be less permeable with hydraulic conductivity values typically less than 0.001 m/day.

(GHD, 2021) sited an internal report for Alcoa "Hydraulic Properties of Darling Range Soils" (Raper & Croton, 1996) to provide parameter values for relevant lithologies as follows:

- *Upper slopes: 0.06 to 10 m/d, with representative values approximately 0.5 m/d. The gravelly sands vary between 3 to 20 m/d with average of 6.8 m/d*
- *Mid-slopes tend to have less permeable soil cover ranging 0.02 to 4 m/day with an average of less than 0.2 m/d.*
- *The valley floors have "heavier" soils between 0.001 to 1.6 m/d. (Average of 0.013m/day)*
- *Duricrust is described as not highly permeable but with vertical holes of higher permeability. They are described as constituting 15 % of the horizontal area of the layer. The friable zone below the duricrust has typically K = 0.2 to 1 m/d, with occasional presence of low permeability clays.*
- *Saprolite (mottled and pallid zones), because of its high clay content is less permeable with a representative value of 0.01 m/d.*
- *The weathering zone between the fresh crystalline basement and saprolite has representative hydraulic conductivity of 0.225 m/d (similar to slug testing results)*
- *Hydraulic conductivity (horizontal) of the deep aquifer "may be highly variable on the local scale but appears to be uniform at the regional scale". Pumping tests conducted in the Darling Range (five tests in total but not in the Myara North mine region) indicate geometric mean of hydraulic conductivity of 0.59 m/d (0.17 to 1.6 m/d). The average vertical hydraulic averages between 0.1 and 0.22 m/d.*

The storativity range of the transition zone was stated by Raper and Croton (1996) to be between 0.0037 to 0.1 (dimensionless), with an average value of about 0.01.

Bulk permeability and storage properties of the fractured basement are expected to be very low given the crystalline nature of the bedrock. Higher values will be observed where secondary porosity features (i.e., faults / fractures, discontinuities) are present and developed.

3.2.7 Groundwater salinity and geochemistry

3.2.7.1 Salinity

Salinity data collected for the Alcoa project across the Darling Plateau (at Myara North and Holyoake) indicate groundwater is fresh to brackish as follows.

- An increase in median salinity is observed both:
  - from north (Myara North) to south (Holyoake) across Alcoa's project DEs (refer to Figure 3.24 where salinity is measured as total dissolved solids concentrations – TDS), and
  - from west to east across the Darling Plateau.

  The median salinity on the western margin of the plateau is around 200 mg/L, increasing to 400 mg/L on the eastern site of the plateau (refer to Figure 3.23).

- Within the Yarragil 4X sub-catchment, which is situated within the 1,100 mm/year annual rainfall isohet (Kinal & Stoneman, 2012), groundwater salinity is generally less than 1,000 mg/L.
- At Myara North (within the Serpentine reservoir catchment), groundwater is generally fresh with salinity concentrations typically less than 1,000 mg/L.

Inspection of regional data suggest long-term salinity trends in groundwater may be less attributed to the changing climate, than compared with water levels. Declining, stable and increasing salinity trends are observed at bores where predominantly declining water level trends are observed (GHD, 2021).

(Grigg & Kinal, 2020) also note salt deposition from oceanic spray (transferred by rainfall) and dry fallout is largely stored in the deep weathered bedrock zone, with relatively little salt stored in the near surface horizons, including the shallow weathered sub-aquifer unit.

Groundwater salinity information from nearby and adjacent mining regions, indicates that the average salinity of the groundwater increases from west to east. At the Huntly Mine, an average of close to 200 mg/L in the western parts increases to an average of close to 400 mg/L in the eastern parts (based on 5 km spaced north-south windows) (GHD, 2021). The groundwater salinity trends at Huntly mine (observed in Myara North sub region) appears to be relatively stable over the three decades of monitoring (1990 to 2020).

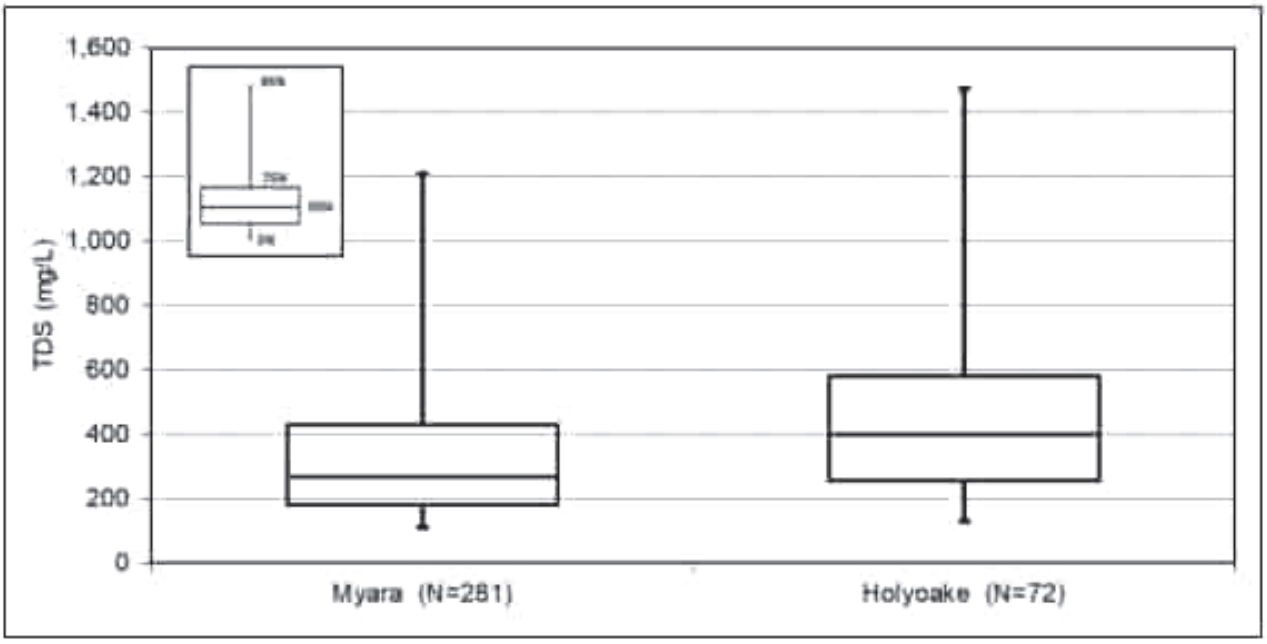


Figure 3.23 Groundwater salinity box and whisker plots for Myara and Holyoake, showing regional variation [after GHD (2021)]

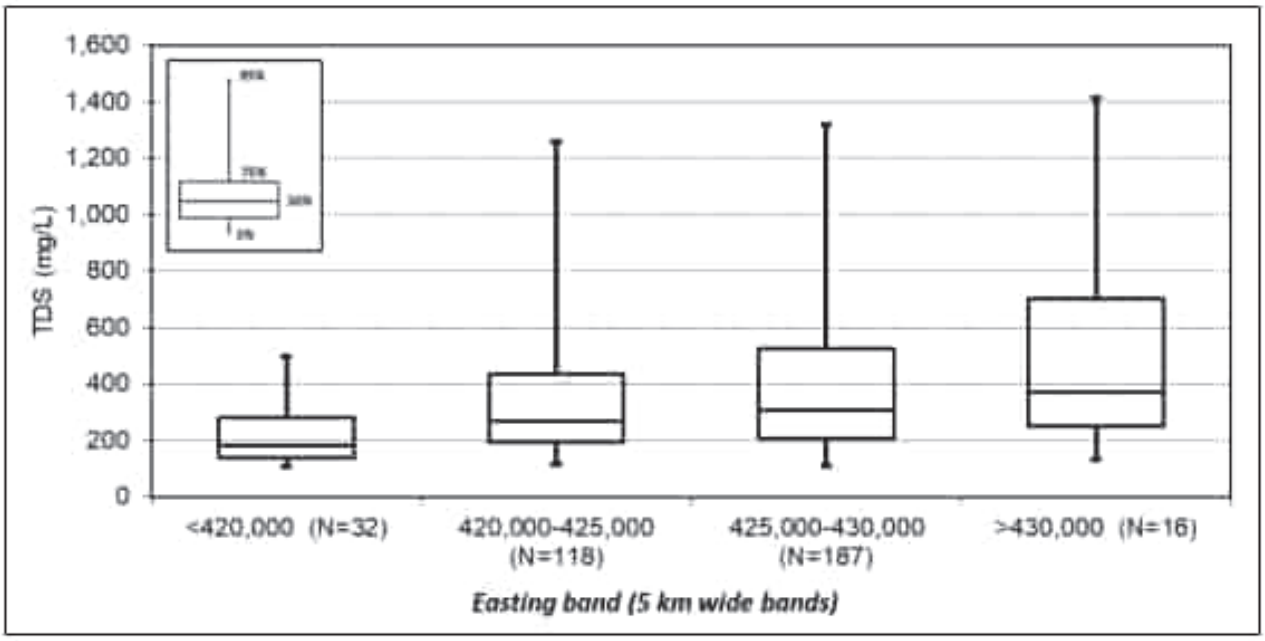


Figure 3.24 Groundwater salinity box and whisker plot (grouped by bore's Easting) (at Myara North, adjacent to Huntly DE) [after GHD (2021)]

3.2.7.2 Dissolved metal concentrations

A review of groundwater data collected from Huntly mine regions Myara North and Holyoake indicate various dissolved metals concentrations exceed guideline criteria for drinking water (manganese), 95th percentile freshwater ecosystem health (arsenic, cadmium, chromium, copper, lead, nickel, and zinc) at some monitored bores.

Dissolved metal concentrations in samples collected from Alcoa's monitoring bore network were considered typical of 'natural' (unimpacted) conditions, representative of the highly leached and now largely inert geological units in which these bores are screened (GHD, 2022).

3.2.7.3 Other groundwater quality parameters

Nitrogen and phosphorus concentrations were detected in groundwaters at the Huntly mine. Concentrations of ammonia, total nitrogen and total phosphorus in some bores exceeded adopted guideline criteria (ANZECC, 2000) for upland river ecosystems (GHD, 2022).

Low concentrations of PFAS have been detected in some groundwater bores within Alcoa's mining areas. Detections though were below the drinking water assessment criteria and are not expected to influence ecological systems and receptors in Alcoa's DEs (GHD, 2022).

Minor detections of hydrocarbons, both recoverable hydrocarbons (TPH) and PAH, have also been observed in groundwater samples collected from the Huntly DE. These however are considered to be attributable to drilling activities (in particular the installation of groundwater monitoring bores) and/or related to short-term impacts from bushfires (GHD, 2022) (refer to Section 3.1.4.6), rather than being associated with the direct or defuse release of chemicals associated with active mining works.

3.2.8 Groundwater resource designation

Neither the Huntley nor Willowdale DEs are situated in Proclaimed Groundwater Areas. Under the Rights in Water and Irrigation Act 1914, the Huntley Mine is located upstream (i.e., upgradient of, and not within) the Serpentine (GWA), with groundwater in this GWA managed in accordance with the *Waangaamaap – Serpentine groundwater allocation statement*. Alcoa's Willowdale is similarly located upstream of the Murray GWA.

3.2.9 Groundwater users

Users of groundwater considered and discussed in this section include groundwater accessed for anthropogenic requirements (such as potable and not potable uses) and generally accessed via groundwater bore supplies, and environmental users.

3.2.9.1 Existing entitlements

Licenced groundwater entitlements across the Darling Range area are limited. Most are located west of the Darling Scarp, likely accessing groundwater from aquifers of the Swan Coastal Plain, and only minor and sporadic licences evident across the Darling Plateau; refer to Figure 3.25.

One groundwater licence is identified southeast of Pinjarra at Dwellingup (Licence No. 84636); this licence allows the Shire of Murray an allocation of 15,000 kL/annum from the fractured rock aquifer until August 2033.

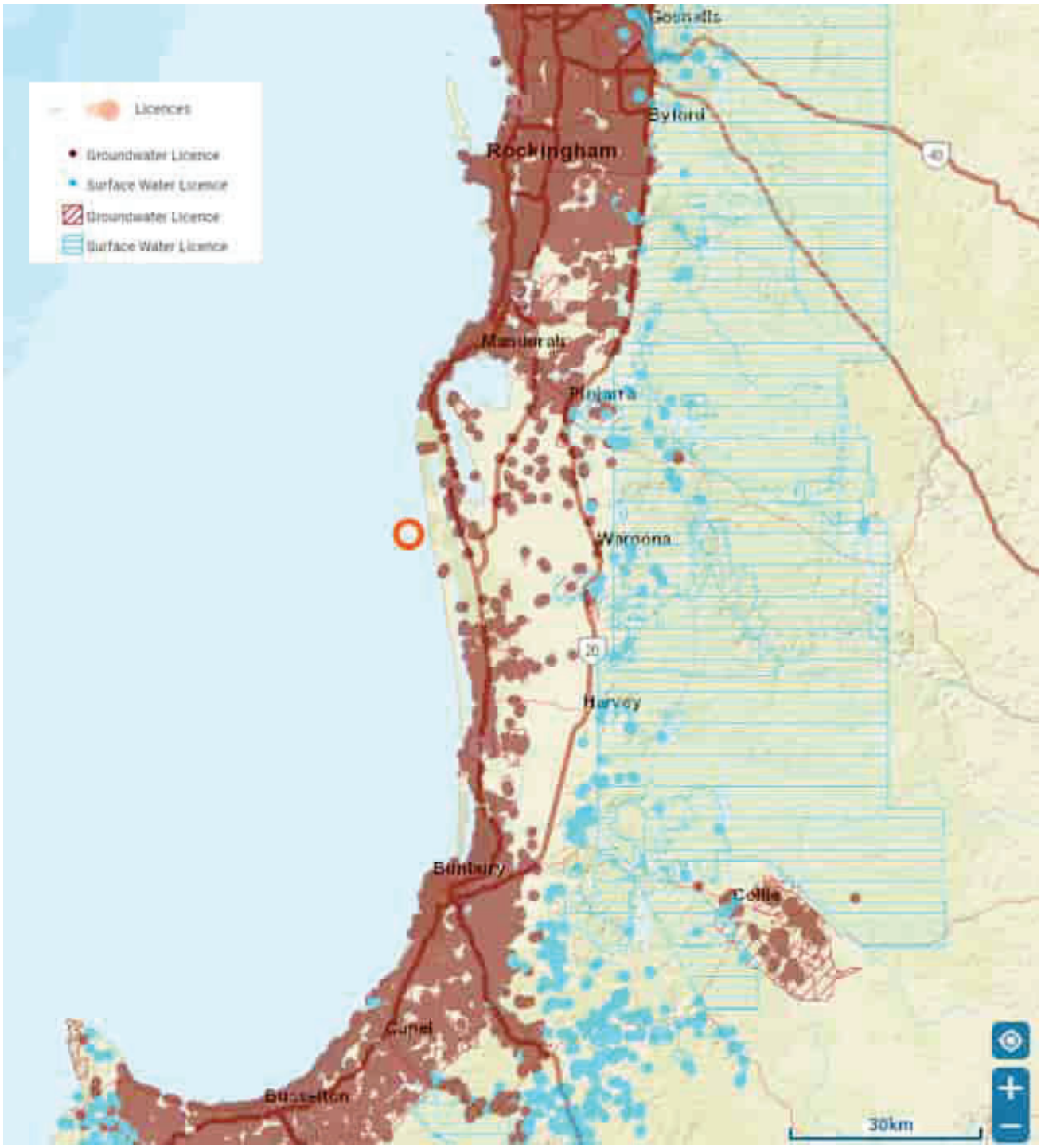


Figure 3.25 Existing surface water and groundwater entitlements (after (DWER, 2024)

3.2.9.2 Aquatic fauna

A desktop assessment completed for the Huntly mine regions of Myara North and Holyoake, as reported by (GHD, 2022) stated the following with respect to aquatic fauna environmental value.

Mine regions within the Huntly mine area (Myara North and Holyoake) are expected to support aquatic habitats which are likely to be dominated by first-order seasonal creek lines and ephemeral headwater swamps/damplands (Inflow Dependent Ecosystems) with aquatic fauna communities expected to be characterised by a high degree of seasonality and high level of species endemicity.

(WRM 2020) identified that in higher rainfall years, baseflow in higher-order streams may maintain isolated pool refuges over summer.

*Other known aquatic fauna values of the Myara North mine region include seasonal habitat for fish, crayfish and stygal amphipods. The Serpentine River, along the southern boundary of the Myara North mine region (*and relevant to the northern boundary of the Myara mine region*) supports populations of EPBC Act listed (Carter's freshwater mussel – Westralunio carteri) and protected (Minute freshwater snail – Glacidorbis occidentalis) species.*

3.2.9.3 Potential groundwater dependent ecosystems

Where groundwater is present at shallow depths it has the potential to support GDEs and wetlands, particularly during the wet summer months. Furthermore, provided (i) groundwater in those areas surrounding the drainage lines or creeks does not fall considerably below creek floor elevations, or (ii) flow gradients reduce such that incoming flow is completely utilised by riparian evapotranspiration, groundwater is expected to continue to:

— exfiltrate to creeks, thereby contributing to baseflows, and

— sufficiently maintain a shallow water table in the riparian zone that is accessible to vegetation communities.

Vegetation mapping conducted by Mattiske Consulting [(2012) and (2019)], and recent flora and vegetation surveys in the Kingsbury, Warrington, and Spion regions identified potential Groundwater Dependent Vegetation (GDV, or GDE). These GDE are identified using key indicator species that thrive in seasonally moist and wet soils found in swamps, valley floors, and lower slopes. Potential GDEs are expected to be subject to seasonal inundation and/or waterlogging due to groundwater and/or surface water flows.

Noted key plant species that are indicative of potential GDEs include *Banksia littoralis, Hakea varia, Acacia divergens, Pultenaea skinneri, Boronia molloyae, Thomasia paniculata, Astartea scoparia, Babingtonia camphorosmae, Calothamnus lateralis, E. rudis, Hypocalymma angustifolium, Hypocalymma cordifolium, Melaleuca preissiana, Melaleuca rhaphiophylla, Melaleuca lateritia, Melaleuca viminea, Regelia ciliata* and *Taxandria linearifolia*.

Mapped Vegetation Types (VT) with A, AC, AD, CW, D, DA, E, PW, SW, and W dominant VT may contain GDEs, which total 6,647 ha of the total Mine DE, including 6,386 ha of the Huntly DE and 261 ha of the Willowdale DE (Mattiske Consulting, 2021), (Mattiske Consulting, 2021). Several VTs were either not mapped or not considered to represent GDEs and have the potential to be GDEs (such as VTs AW, C, CQ and SW-D) and remain a data gap.

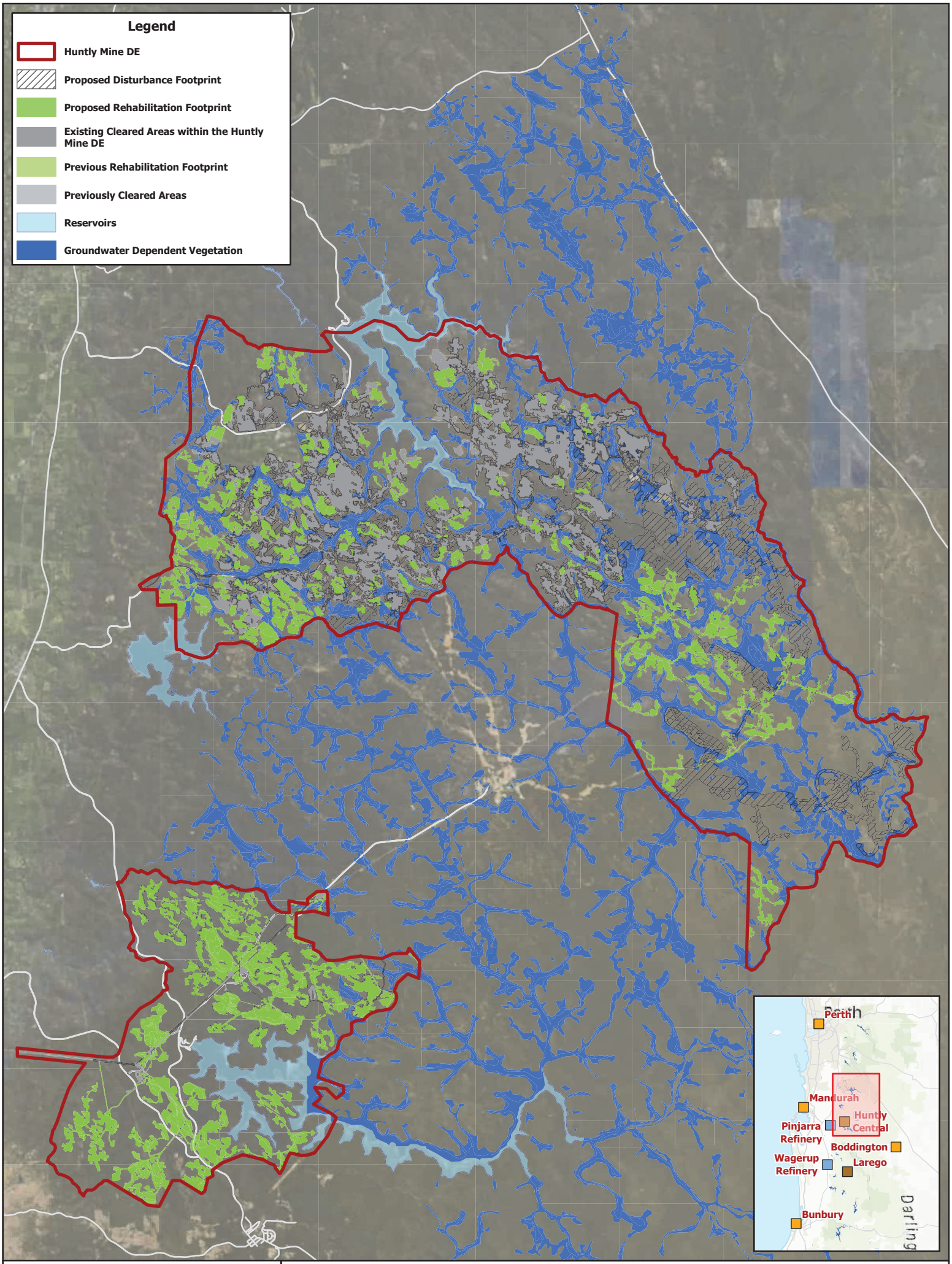
The following statement is noted by (GHD, 2022) with respect to GDE in the mine regions.

In parts of the jarrah forest, riparian vegetation is considered to be a potential GDE, particularly where groundwater contributes to baseflow or where the groundwater level is within 10 m of the natural ground surface. Potential regional-scale groundwater dependent ecosystems are associated with the following vegetation complexes that contain indicator vegetation species:

— *Swamp complex*

— *Stream zones of the Yarragil and Murray complexes, and*

— *Swamp areas in the Yarragil 2 complex.*



Bauxite mining on the Darling Range
2022 to 2026 & 2023 to 2027 (Assessment No. 2384 & 2385)
Inland Waters Baseline Assessment

Figure 3-26 Potential Groundwater Dependent Ecosystems - Huntly Mine DE

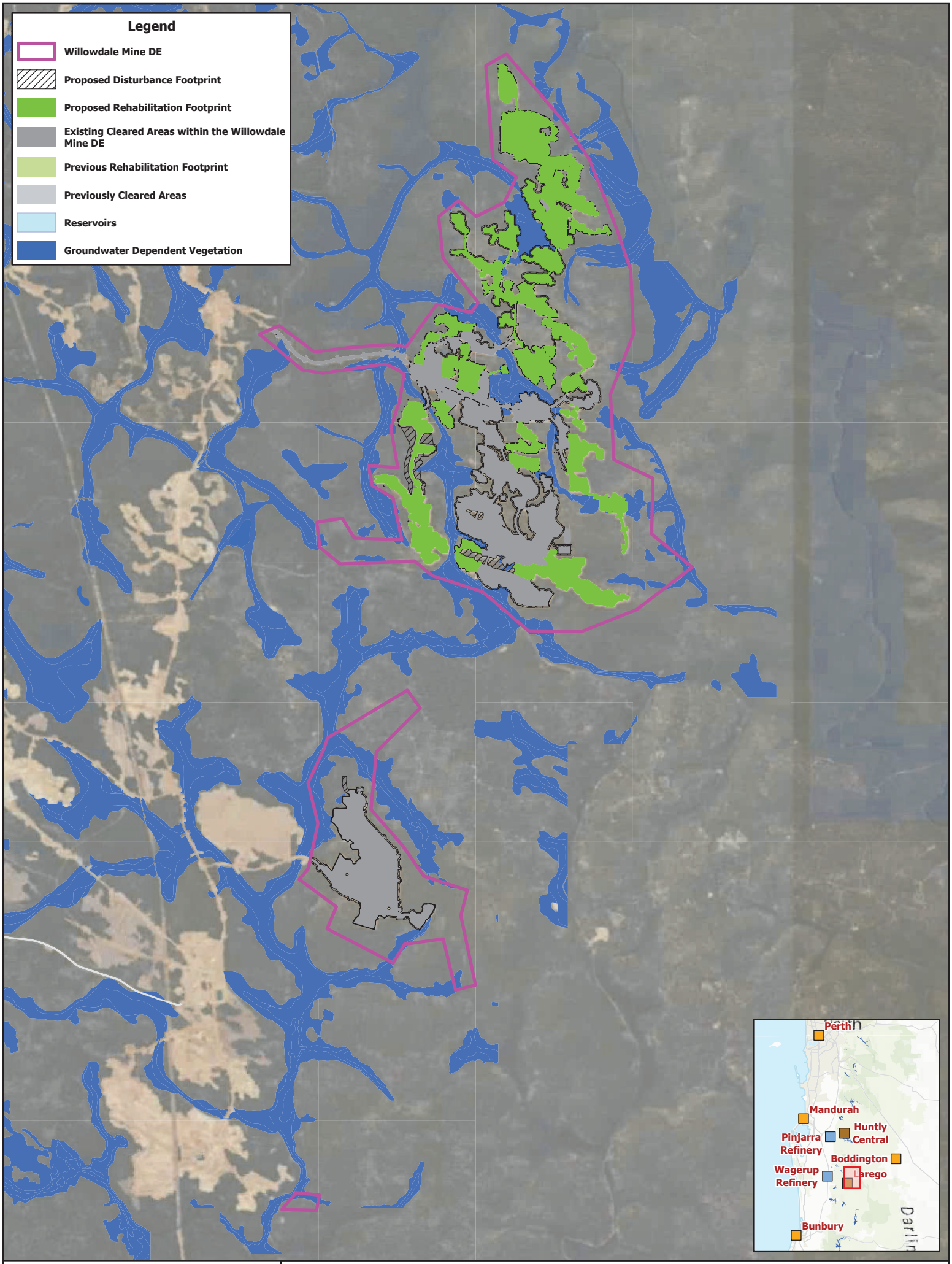
Kilometres
0 1 2 4 6 8 10

Scale: 1:175,000 at A4

Date Printed: 18/11/2024

N

Alcoa



Bauxite mining on the Darling Range
2022 to 2026 & 2023 to 2027 (Assessment No. 2384 & 2385)
Inland Waters Baseline Assessment

Figure 3-27 Potential Groundwater Dependent Ecosystems - Willowdale Mine DE

Kilometres
0 0.5 1 2 3 4

Scale: 1:60,000 at A4

Date Printed: 18/11/2024

N

Alcoa

Groundwater dependence of riparian and swamp vegetation

Studies of GDEs over the Swan Coastal Plain demonstrate groundwater dependence of some swamp vegetation found on the Darling Scarp including *E. rudis*, *Melaleuca rhaphiophylla* and *Taxandria linearifolia* (Froend and Loomes 2005). Their estimated groundwater requirements are as follows (Sommer and Froend 2010, referenced in SKM 2011):

- *E. rudis*: 0.8 to 11.7 m bgl
- *M. rhaphiophylla*: 0.8 to 9.3 m bgl, and
- *M. preissiana*: 0.2 to 13.9 m bgl.

The hydrogeology of the Darling Plateau substantially differs from the large sedimentary aquifers of the Swan Coastal Plain or the Murray-Darling floodplain, comprising a comparatively shallow lateritic regolith over bedrock subject to high topographic relief. This creates more localised and variable groundwater aquifers, with steeper hydraulic gradients draining to an incised stream network, and a thick clayey stratum that provides greater plant available water in the unsaturated zone.

Accordingly, deep rooted riparian vegetation of the Darling Plateau is likely to be adapted to higher variation in groundwater levels and a larger unsaturated zone water storage and may have a more facultative groundwater dependence compared to that of the Swan Coastal Plain. However, seasonal waterlogging and/or shallow groundwater may remain important for swamp and riparian vegetation of the Darling Plateau to outcompete and prevent incursion of terrestrial vegetation, to maintain shallow rooted wetland species and maintain a denser understorey than otherwise occurs in the upland jarrah forest.

Groundwater dependence of tree species

The groundwater dependence of terrestrial vegetation within the jarrah forest has been studied by several authors. The root system of the predominant canopy tree Jarrah (*E. marginata*) has been described as having a dimorphic structure (Kimber 1974, Dell et al. 1983, Abbot et al. 1989). This comprises dense lateral roots in the shallow soil above the lateritic duricrust / caprock, from which ‘sinker’ roots extend vertically to penetrate cracks and fissures in the duricrust and gain access to moisture bearing clay through ancient root channels created by previous vegetation. Dell et al. (1983) suggest that each tree may access 100-200 ancient root channels of up to 40 m from the surface.

Carbon et al. (1980) report that the bulk of E. marginata roots are in the shallow soil above the duricrust, which has the greatest potential to supply water in winter. While trees have deeper roots, substantial groundwater use is limited to shallower depths, being recorded in jarrah forest at sites with depths of 6 m bgl but not at 14 m bgl or 30 m bgl (Farrington et al. 2016).

Root systems of potential GDEs

When describing the root systems of the typical Jarrah Forest, (Advisian, 2024) state the following:

Along the topographical sequence, vegetation root depth is constrained by compact basement or the water table. Root systems are shallower near the valley floors or basement outcrops/highs.

Sinker roots, initiated from major laterals, descent through fissures or conduits in the caprock and enter distinct vertical channels that passed through the friable bauxitic layer and on into the pallid zone.

Trees on sites where seasonal perched water tables occur, have shallow root systems, so that they have less access to water stored in the soil profile for survival over summer than trees growing on well-drained sites.

Under certain catchment characteristics (a function of regolith depth, catchment size and inflows), groundwater can rise to the surface resulting in full root system inundation (waterlogging) in downgradient locations. This is a natural process in the Jarrah Forest, as indicated by the presence of waterlogging tolerant species such as Melaleuca preissiana, but is exacerbated by bauxite mining activities.

The spatial extent of waterlogging is largely topographically controlled; in most situations it will be confined to relatively small areas.

Groundwater dependent fauna

The alluvial/colluvial sediments within streams and swamps are subject to seasonal saturation through surface and groundwater inflows, creating hyporheic zones that may provide habitat for macroinvertebrates. These zones can provide refuge for aquatic fauna that can burrow to avoid desiccation during dry periods and/or high flow events (WRM 2021), including crustaceans, earthworms and insect larvae (GHD, 2023). Stygal amphipods have also been recovered from the hyporheic zone of streams within the Huntly Mine, which may be potential SRE fauna (WRM 2021).

Relevance to DE

Despite the lack of observational data within the Huntly and Willowdale DE, the nature of and the processes involved in surface water and groundwater connectivity observed where studies (Myara North) are considered representative of general conditions across the Darling Plateau. Depth to groundwater will be site specific and may have an impact on the proportion of DE mapped with potential GDE.

4 Environmental values

Environmental value is defined under the Environmental Protection Act 1986 as a beneficial use or an ecosystem health condition (Environmental Protection Authority, June 2018). Objectives are outlined by EPA to maintain the quality of waters to protect these environmental values.

EPA Environmental Factor Guideline for Inland Waters (EPA, 2018) discusses the potential environmental values supported by or dependent on Inland Waters (of the study area) and their significance. Environmental values for consideration include:

- Ecosystem health conditions, namely:
  - aquatic ecosystem (i.e., fresh, marine and estuarine waters) health values that relate to the ability of such ecosystems to sustain vegetation, aquatic fauna and birdlife, and the ecological processes that support them, and
  - groundwater-dependant ecosystems (such as the protection of stygofauna, phreatophytic vegetation and groundwater-dependant wetlands).
- Cultural and spiritual values.
- Other beneficial uses of water, including:
  - drinking water supplies (e.g., most notably direct consumption, but is also applicable to the use of such waters for bathing, the filling of swimming pools, food preparation and cooking)
  - non-potable use of water (e.g., irrigation of gardens or parks and reserves, washing of clothes and other items, flushing of toilets etc.)
  - recreational use (e.g., water sports and swimming)
  - agricultural use (e.g., commercial irrigation, stock watering, farm management, and produce preservation), and/or
  - industrial use (e.g., process water).

Based on the potential land use within the mining DEs as describe in Section 3.1.5, the relevant environmental values for the are defined and summarised in Table 4.1.

Table 4.1 Environmental values relevant for the mining DEs

Environmental value		Comment on Environmental Value	Guidance
Ecosystem health conditions		Aquatic ecosystems may rely on surface expression of groundwater which include the surface water courses that receive groundwater flow, groundwater fed springs and swamps and their respective biological and environmental values. The inherent value of aquatic ecosystems, habitats, and wildlife in waterways and riparian areas includes biodiversity, ecological interactions, plants, animals, key species and their habitats, as well as sources of food and drinking water. Consideration of freshwater aquatic ecosystems are relevant to the project location. Estuarine and marine ecosystems are present down catchment of the DEs, west of the Darling Escarpment and on the Swan Coastal Plain.	Aquatic ecosystems in freshwater systems are classified based on the (ANZG, 2018) and (ANZECC and ARMCANZ, 2000) default trigger values for toxicants in freshwater systems, namely the percentage protection criteria level which is dependent on the catchment level of disturbance (e.g., 95% protection level for slightly to moderately disturbed ecosystems).
Beneficial uses (BUs)	Drinking water	Suitability of the water for supply as drinking water having regard to the level of treatment of the water. Existing and proposed operations occurring within the Huntly and Willowdale Mine Des occur within catchment areas of public drinking water supply reservoirs: — Huntly: Serpentine Dam, South Dandalup Dam, North Dandalup Dam and Serpentine River downstream, and — Willowdale: Stirling Dam and Samson Brook Dam. Water from the supply catchment network is used for drinking water as well non-potable (and potentially recreational) uses of water. An inspection of the Western Australia Water Register (DWER, 2024) indicated no licensed groundwater users within both Huntly and Mine DEs.	**Potable use:** the Australian Drinking Water Guidelines (NHMRC, NRMMC, 2011) – updated September 2022 provide a framework for good management of drinking water supplies. The guidelines are not mandatory standards, however, provide a basis for determining the quality of water to be supplied to consumers in Australia. **Non-potable use (includes domestic use**): the WA Department of Health prescribes Contaminated Sites Groundwater and Surface Water Chemical Screening Guidelines (DoH, 2014) for the classification, assessment and management of contaminated sites. These are based on the National Environment Protection (Assessment of Site Contamination) Measure 1999, amended in 2013, that considers other national guidelines such as the (NHMRC, NRMMC, 2011) and the (ANZECC and ARMCANZ, 2000) guidelines. These guidelines provide a framework for the assessment of groundwater that has been affected, or may have been affected, by site contamination. (DoH, 2014) specifies guidelines for non-potable water use (including irrigation and domestic use). Guidelines are based on a default screening level that is ten times the corresponding ADWG health related guideline.

Environmental value		Comment on Environmental Value	Guidance
Beneficial uses	Cultural and spiritual value	Means scientific, social, or other significance to the present generations or past or future generation, this includes Aboriginal people or Torres Strait Islanders. Serpentine River is a registered mythological / ethnographic Aboriginal heritage site. Other major drainages of the Darling Range may hold similar values	No specific environmental quality indicators or objectives are provided for Traditional Owner cultural values, and it is not appropriate to simply consider Traditional Owner cultural values using the other environmental values as a proxy. (ANZG, 2018) outlines a process to determine whether the existing water quality guidelines can support assessment of risks of harm with respect to this environmental value but emphasises that the process does not replace the need to consult with Traditional Owners. As noted in Table 1 of ANZG: Cultural and spiritual values in the Water Quality Guidelines and other guidance, a range of existing guideline values developed for other EVs (such as guidelines for drinking water, aquatic ecosystems, recreational water, primary industries) are proposed for protecting the cultural and spiritual values, including recreational and ceremonial purposes, economic wellbeing of indigenous peoples, drinking and food. Therefore, environmental quality objectives for other EVs go some way to protecting the Traditional Owner cultural values.
Beneficial uses	Recreational (and aesthetics)	Surface water features of the Darling Ranges (e.g., Murray River) are frequently used for recreational purposes. Primary recreation uses includes swimming. Secondary recreation includes activities such as canoeing, fishing and wading. Aesthetics relate to the suitability of the water for contributing to the visual appeal of natural landscapes.	(NHMRC, 2008) aim to protect human health by ensuring recreational coastal, estuarine and freshwater environments which are accessed for various recreational water uses.

Environmental value		Comment on Environmental Value	Guidance
Beneficial uses	Agricultural	BUs of water include its suitability for irrigation, crop production, and for cleaning, drinking, and maintaining the health of livestock. The environmental value is currently not likely to be realised across the Darling Range from groundwater resources. Agricultural areas are located down catchment from public drinking water supply reservoirs along the SCP, west of the Darling Range. A particular BU would be indirectly protected by the default requirement to protect more sensitive BU higher up in the catchment. An inspection of the Western Australia Water Register (DWER, 2024) indicated very limited groundwater licenses across the Darling Range.	WA state-based guidance (DoH, 2014) specifies guidelines for non-potable water use (including irrigation and domestic use). Guidelines are based on a default screening level that is ten times the corresponding ADWG health related guideline. (ANZG, 2018) defaults to (ANZECC and ARMCANZ, 2000) for Water quality for irrigation and general water use.
Beneficial uses	Industry	Industrial uses may include activities such as process water. The environmental value is currently not likely to be realised from groundwater as the catchment is largely undeveloped and the aquifer is low yielding. A potential for use to be realised down catchment of public drinking water supply reservoirs along the SCP. The BU would be indirectly protected by the default requirement to protect more sensitive BU higher up in the catchment. An inspection of the Western Australia Water Register (DWER, 2024) indicated very limited groundwater licenses across the Darling Range.	NA.

5 Ecohydrological conceptual model

The ecohydrological conceptual model (EHCM) presented in this section has been developed based on the assessment of the site setting, the existing surface water and groundwater conditions and relevant environmental receptors as outlined in the previous sections. As per the requirements of the Environmental Scoping Document 'Bauxite mining on the Darling Range in the southwest of WA – 2022 to 2026 and 2023 to 2027, the intent of the EHCM is to:

(i) outline the baseline hydrological regime, including existing surface water and groundwater quality and quantity

(ii) demonstrate those interactions between water streams, and

(iii) provide a qualitative assessment of the predicted impacts of the Project on surface water and groundwater, inclusive of groundwater mounding and drawdown.

5.1 Summary of mining and water-relevant activities

Alcoa's mining sequence is illustrated in Figure 1.2 (refer Section 1.1), a generalised depiction of the sequence steps is presented in Figure 5.1. For understanding mining process and how Alcoa's activities interact with the hydrological regime, these have been simplified to the following stages:

- pre-mining (including the assessment, clearing, and stripping works in designated DEs),
- mining, and
- rehabilitation.

Possible water affectioning activities during the mining sequence are:

- clearing of native vegetation
- alteration of natural drainage regimes
- alteration of hydrological regimes
- water use for haul road construction and dust suppression
- waste disposal, including the storage and handling of contaminants
- mine closure, decommissioning and rehabilitation
- mining activities within Public Drinking Water Source Areas (PDWSAs), including the application of chemicals such as fertilisers and pesticides
- human and Mining presence within the Reservoir Protection Zones (RPZs), and
- within PDWSAs.

5.2 Baseline hydrological and hydrogeological setting

Under natural conditions, water levels may periodically, as a part of annual climate cycles, rise closer to the surface for short periods following wet climate sequences, where it is quickly removed by evapotranspiration. The structure and species composition of jarrah forest vegetation is influenced by the hydrological regime; with greater waterlogging tolerance traits associated with naturally wetter parts of the forest.

Evapotranspiration (and transpiration) is the dominating process of maintaining groundwater depth balance under natural, undisturbed conditions.



Figure 5.1 Alcoa generalised mining and rehabilitation process overview (after Alcoa 2021–2025 MMP)

5.3 Changes due to Alcoa's activities

5.3.1 Pre-mining

Prior to mining, the existing environment is cleared of the original forest. Timber is harvested (which then is used in the timber industry), other vegetation cleared, and the topsoil and overburden removed and stockpiled separately for re-use.

Forest clearing alters the water balance of the cleared area by typically reducing evapotranspiration, increasing groundwater recharge, and increasing surface water runoff and lateral throughflow. This typically results (in an 'average' rainfall year) in an increase in groundwater elevations (known as 'groundwater mounding'), and in some cases increased streamflow rates (Advisian, 2024).

Timber harvesting (and associated silviculture) of the jarrah forest is expected to result in a temporary decrease in transpiration (Kinal & Stoneman, 2011). This will result in an increase in the quantity of water contributing to the various hydrological processes in these planned mining areas, including groundwater recharge and streamflow, all of which will continue until rehabilitation works are completed and the forest regenerated to former levels (refer to Rehabilitation – Section 5.3.3).

The clearing of vegetation will reduce, and in large partly eliminate evapotranspiration losses, promoting greater infiltration of rainfall in these areas (over an average rainfall period). This will result in higher groundwater elevations at and in the vicinity of the cleared area but is not expected to significantly alter groundwater dynamics and fluxes at the catchment scale, with groundwater recharge primarily occurring in the upland parts of these catchment which is generally not disrupted by the stripping or mining excavation activities (Grigg, 2017).

5.3.2 Mining

During the mining phase, the caprock is broken by methods such as drill and blast or ripping by bulldozers. Ore is then extracted via load and haul and transported to a central crusher.

Localised changes to the terrain morphology (shallow mine pits) may result in:

- temporary ponding of water in pits during and following rainfall events, and
- possible interruption of local quick flow processes which enhances the deep drainage.

Groundwater recharge is generally not disrupted by the stripping or mining excavation activities (Grigg, 2017). Conversely, mining activities are expected to result in increased groundwater recharge, with corresponding increases in groundwater elevations and subsequent discharges (baseflow contributions) to nearby surface water systems. This discharge may have higher salinity concentrations owing the increased mobilisation of salts stored in the vadose zone above previously deeper (pre-mining) watertables but are not expected to overtly impact any nearby GDEs and aquatic ecosystems, with only minor increases in the salinity of streamflows expected with surface water flows remaining fresh.

Although transpiration continues around the vegetated perimeter of the mine pit (i.e., during times of higher groundwater elevations), it is not sufficient to lower the groundwater level for a distance of several tens of metres from the cleared area perimeter (Advisian, 2024). This area forms the zone of impacted vegetation, following which with increased distance from the mine pit, transpiration output eventually results in lowering the groundwater level and maintaining the shallow unsaturated zone required for root system functionality and health.

In the context of catchment-scale hydrological responses, the effect of bauxite mining is indistinguishable from the effect of other forest disturbances such as timber harvesting or clearing for pasture (Grigg, 2017).

5.3.3 Rehabilitation

Following mining, the former mine pits are rehabilitated to Jarrah Forest by first ripping of any compacted pit floors, then re-contouring of this surface, returning of previously stripped soil and overburden to the mined area, and finally the seeding, planting and fertilising of the newly placed surface.

In the context of catchment-scale responses, the primary impacts of Alcoa's operations in the Huntley and Willowvale DEs on-surface water and groundwater dynamics occurs during vegetation removal and regeneration (Grigg & Hughes, 2018). A summary of expected changes to these systems because of rehabilitation activities is presented in the following bullet points.

- Surface hydrology.

  Rehabilitation of mining pits will see the gradual re-establishment of vegetation across the formerly mined areas, and the associated increase in water uptake by this vegetation. Ponding may though occur following rainfall events where local depressions are present in rehabilitated surfaces, which may also promote localised zones of higher infiltration should re-establishing vegetation not fully intercept or transpire available water (GHD, 2021).

  Changes to runoff components are also likely to occur (due to the terrain morphology changes) but are expected to be minor (GHD, 2021) and to occur over the short-term.

- Groundwater hydrology.

  Groundwater elevations beneath the valley floors and hill slopes are expected to rise in response to silvicultural[5] treatments. In studied catchments, groundwater elevations close to valleys typically reached peak elevations about eight years following timber harvest and culling treatments (Kinal & Stoneman, 2011), with groundwater elevation increases are expected to be greatest beneath hillslopes.

[5] Silviculture is the term used to describe the practice of growing and tending to trees whilst controlling their growth, composition, structure, and quality.

- Water quality – salinity.

  Given the Huntly and Willowdale DEs mostly reside within or to the west of the Darling Plateau high rainfall zone (HRZ) region, salt storage within the soils in these areas is typically low. As such, impacts of Alcoa's rehabilitation activities on water quality are expected to result in limited changes to stream salinity, with freshwater conditions expected to be maintained in major tributaries throughout these DEs.

  Similarly, rehabilitation activities are considered unlikely to significant impact aquatic biodiversity because of salinity.

5.4 Qualitative ECHM

Conceptual models have been developed to visualise the understanding of the hydrological processes and the interaction of the mining sequence within the catchment. The EHCM for baseline, pre-mining, mining, and rehabilitation phases are presented in Figure 5.2 to Figure 5.5.

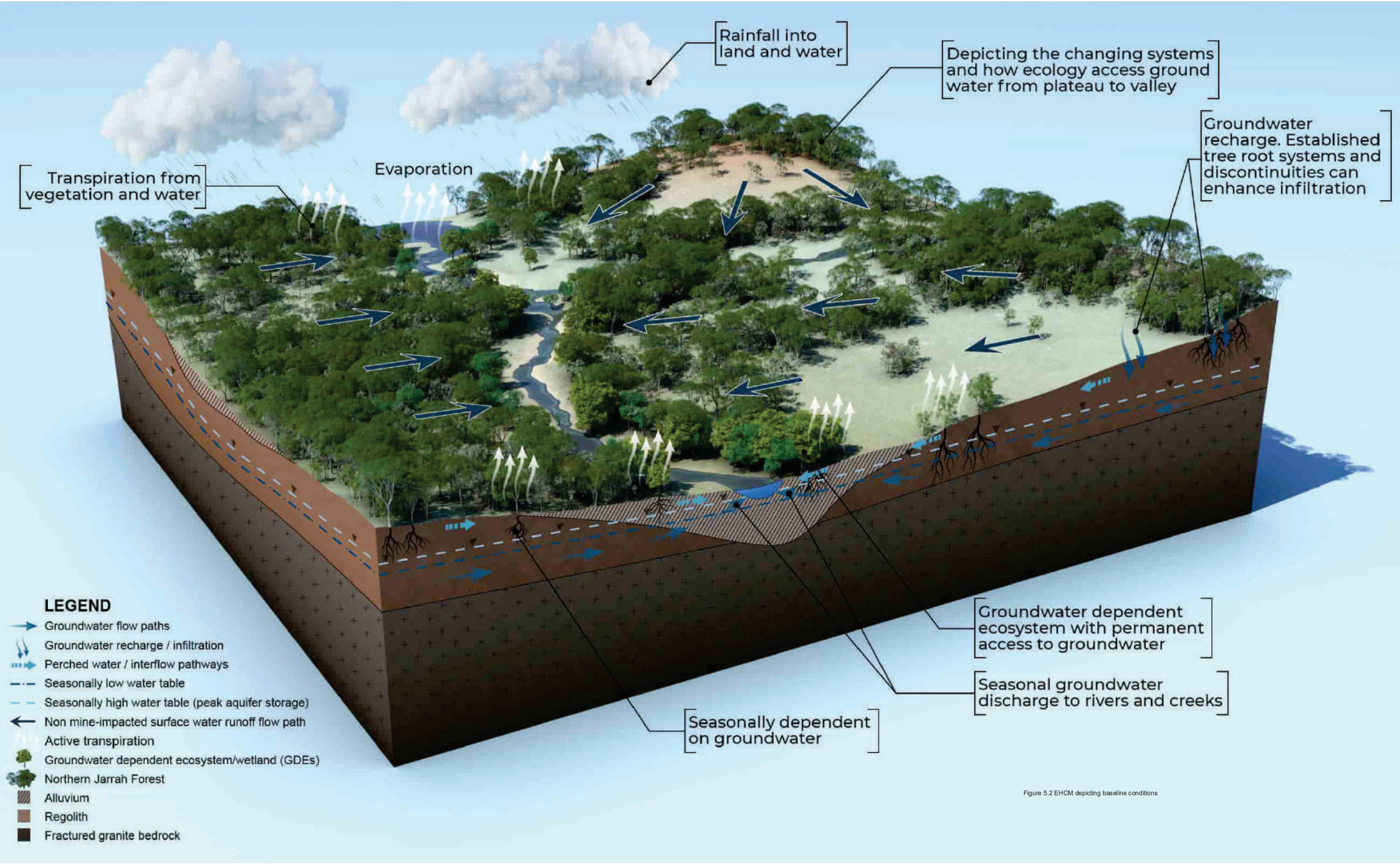


Figure 5.2 EHCM depicting baseline conditions

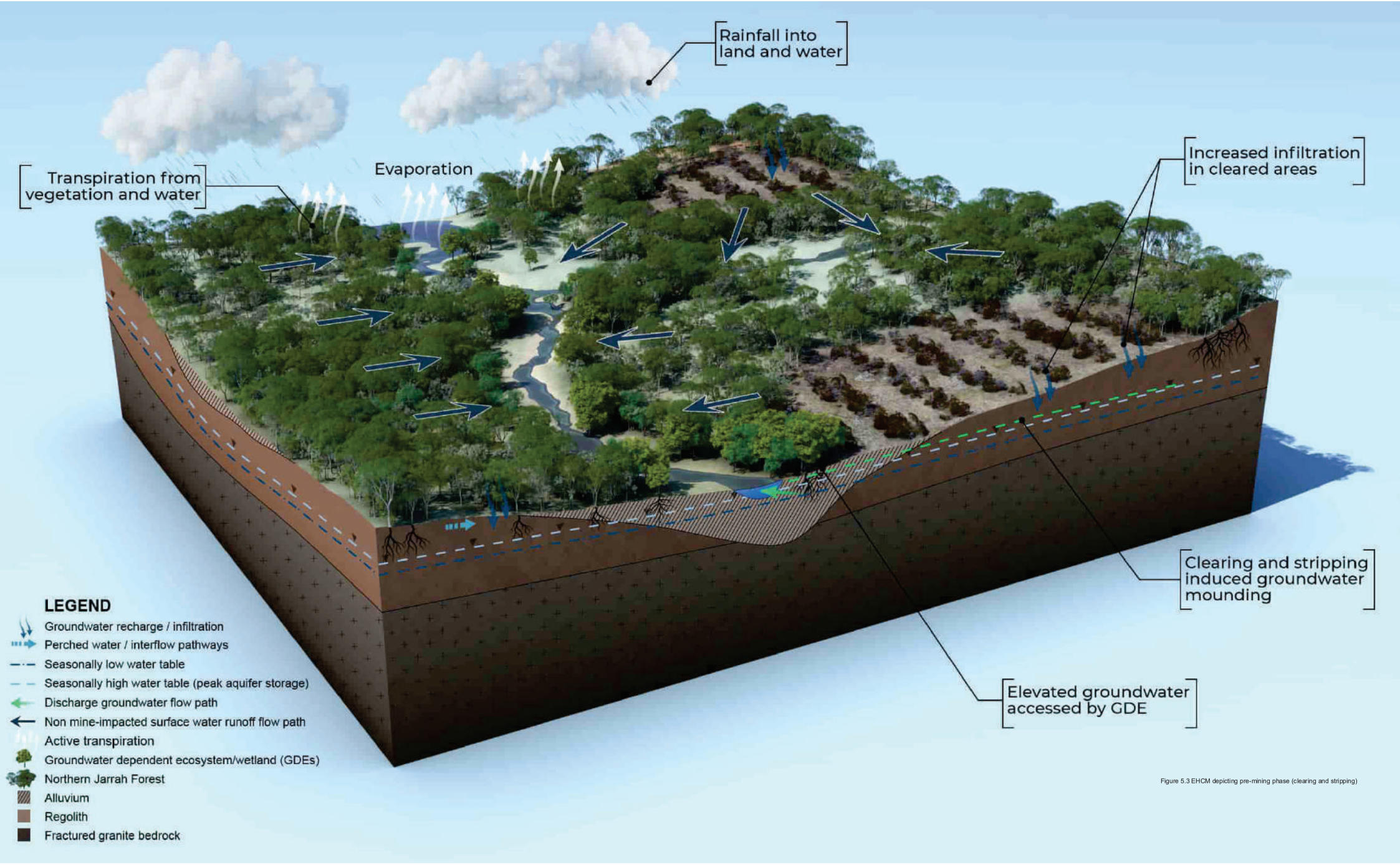


Figure 5.3 EHCM depicting pre-mining phase (clearing and stripping)



Figure 5.4 EHCM depicting mining phase

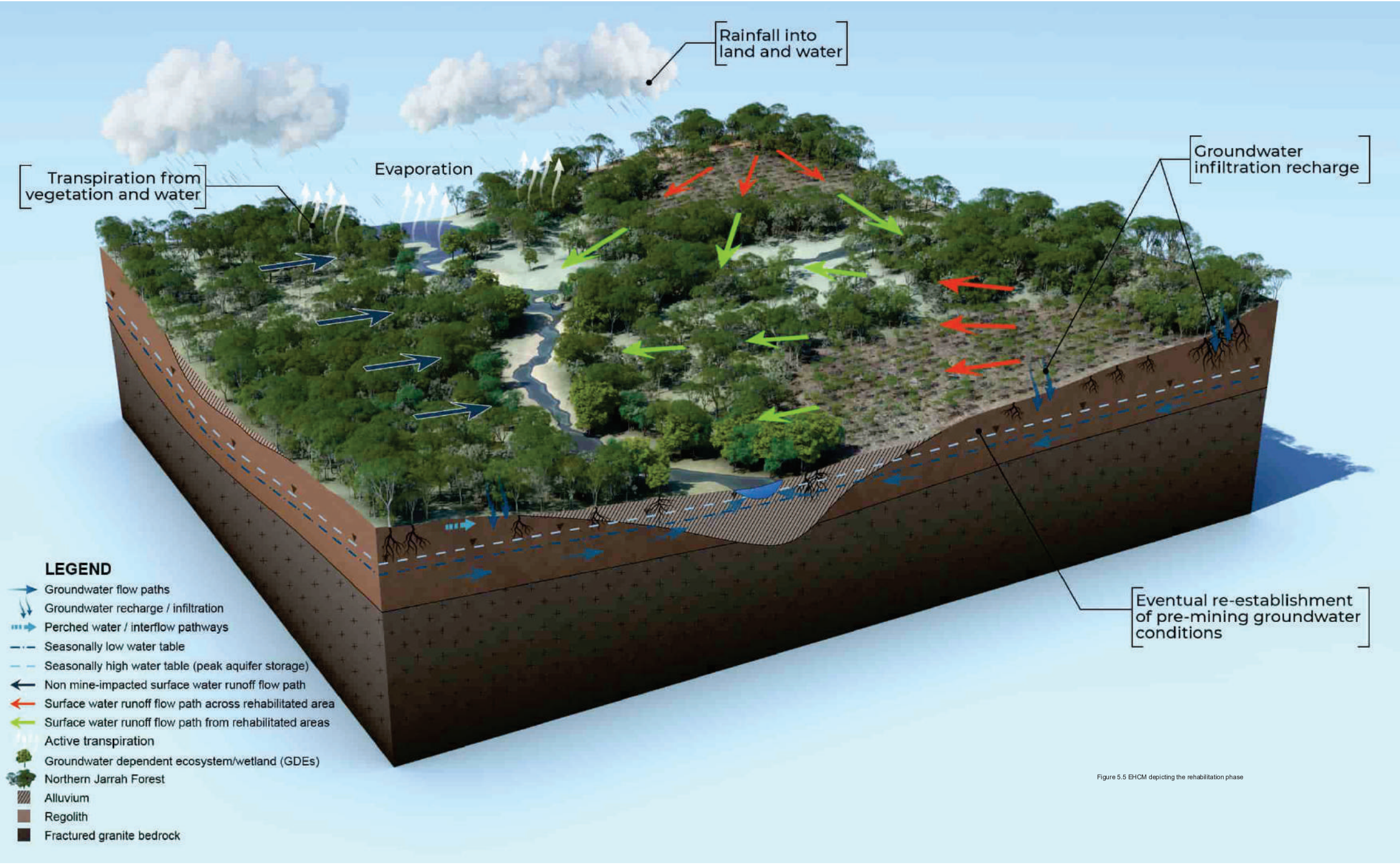


Figure 5.5 EHCM depicting the rehabilitation phase

6 Data gaps and uncertainty

An assessment of the Baseline for Huntly and Willow DE has highlighted the following information gaps, with respect hydrology and hydrogeology.

- There is limited historical surface water quantity and quality data within the Willowdale DE, complicating the formulation and understand of baseline and existing conditions.
- Inadequate coverage of surface water quantity and quality monitoring site across both Huntly and Willowdale DE, leaving some areas under presented.
- There is limited historical groundwater level and quality data within parts of the Huntly DE and across most of the Willowdale DE.
- Furthermore, water level and quality data availability has not been studied in detail for this assessment.
- There is a lack of monitoring data over time at both Huntly and Willowdale DE, resulting in difficulty to track long-term trends.
- Differences in sampling techniques, equipment calibration, and data processing methods, leading to variability in data quality.

The uncertainty associated with unavailable or incomplete data complicates the interpretation of existing water conditions. Variability in data quality and spatial coverage can obscure the true extent of water-related issues, making it challenging to establish baseline conditions or detect long-term changes.

The use of adjacent catchments as a proxy to understand the Project site conditions may be suitable for a high-level understanding of the baseline but it is noted that hydrological conditions are likely to vary spatially across the Darling Range (i.e., due to variable rainfall from east to west and south to north as rainfall changes).

Statements made within this report should be confirmed and validated with site specific data relevant to the DE.

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